OPTIMIZING BENEFITS FROM WATERSHED THROUGH USE OF REMOTE SENSING

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Commission VII, WG VII/3.5

KEYWORDS: Remote sensing, watershed, soil conservation, *kharif* fallow

ABSTRACT :

For a successful watershed development programme, baseline information on land and water resources, and socio-economic conditions is a pre-requisite. Besides, a well-defined and built-in mechanism for monitoring the success and progress of the programme, and effecting necessary mid-course corrections, if required, is equally important. Spaceborne multispectral measurements by virtue of providing synoptic view of a fairly large area at regular intervals, hold very good promise in providing reliable information on nature, extent, spatial distribution, potentials and limitations of land and water resources of a watershed which forms a sound database for generation of developmental plan by suitably integrating with socio-economic and other relevant information in a Geographic Information System (GIS) domain. Furthermore, the multi-temporal nature of satellite data enables objective monitoring of the progress and success of the watershed development programme. The article illustrates the potentials of space technology in various facets of watershed development through two case studies; one on assessment of the impact of soil and water conservation measures in a watershed, and another on identification of *kharif* fallows aiming at their optimal utilization.

1.0 INTRODUCTION

Watershed development programme aims at conserving soil and water thereby improving the productivity of land with the consequent improvement in the crop yield and stakeholders' income. The process of watershed development entails the delineation of watersheds, and sub-dividing into smaller and manageable hydrological units, and prioritization for treatment. Baseline information on land and water resources is required for planning interventions and for monitoring the progress and success of the programme and effecting necessary mid-course corrections. By virtue of providing synoptic view of a fairly large area at regular intervals, spaceborne multispectral measurements offer immense potential in providing reliable information on land and water resources of a watershed. Such information forms a sound database for generation of action plan / developmental plan for land and water resources by suitably integrating it with socio-economic and other ancillary information in a Geographic Information System (GIS) domain. Additionally, spaceborne multispectral measurements along with GIS also enable prioritizing the watershed / (s) requiring immediate attention since the treatment of entire watershed simultaneously is not a feasible proposition. Once soil and water conservation programmes have been implemented, multi-temporal characteristics of spaceborne multispectral measurements enable monitoring its progress and success.

As pointed out earlier, for optimal utilization of available land and water resources of a watershed, information on the nature, extent and spatial distribution is a pre-requisite. Until the

1920s, such information had been collected through conventional surveys, which are labour-intensive, cost-prohibitive and impractical in the inhospitable terrain. During the 1920s and early 1970s, aerial photographs were used for deriving information on various natural resources (Bushnell, 1929; US Department of Agriculture, 1951; Howard, 1965). The launch of the Earth Resources Technology Satellite (ERTS-1), later renamed as Landsat-1, in 1972, followed by Landsat-2,-3,-4 and –5, SPOT-1,-2, -3 and –4; and the Indian Remote Sensing Satellites (IRS-1A/-1B/1C/ and-1D) with Linear Imaging Self-scanning Sensors (LISS-I,-II and-III) and Panchromatic sensor (PAN) have opened up a new vista in deriving information on land and water resources of a watershed. Several researchers have utilized aforesaid spaceborne measurements in deriving information on geological and geomorphologic and hydrogeomorphological features (Bhattacharya and Reddy, 1991; Reddy et al., 1996;Rao et al., 1996a); soil resources (Singh and Dwivedi, 1986; Karale, 1992); land use/ land cover (Landgrebe, 1979; Raghavaswamy et al., 1992, Rao et al.,1996b); forest resources (Dodge and Bryant, 1976; Unni, 1992; Roy et al.,1996); surface water resources (Thiruvengadachari et al,1996) and degraded lands (Food and Agriculture Organization, 1978; Karale et al., 1988 Dwivedi et al., 1997a and b; 2001). Furthermore, apart from generation of information on individual natural resources, spaceborne multi- spectral data have also been operationally used for integrated assessment of natural resources on a watershed basis and subsequent generation of action plans for land and water resources development and for assessment of the impact of implementation (Rao and Chandrashekhar, 1996).

The article illustrates the potentials of space technology in various facets of watershed development through two case studies: one on assessment of the impact of soil and water conservation measures in a watershed, and another on identification of *kharif* fallows aiming at their optimal utilization.

2.0 IMPACT ASSESSMENT OF SOIL AND WATER CONSERVATION MEASURES

Soil and water conservation measures employed in an area result in the prevention of soil loss, improvement in soil moisture status and subsequent development of vegetation cover. An objective assessment of such an impact enables implementing authorities to effect midcourse correction, if required. Reported hereunder are two such case studies wherein spaceborne multi-spectral and multi-temporal measurements have been used for assessment of the impact of interventions aimed at preventing/reducing soil loss.

2.1 Test Sites

Two test sites – (i) Adarsha micro-watershed in Kothapally village, Shankarpally *mandal* (an administrative unit) of Ranga Reddy district, Andhra Pradesh lying between geo-coordinates 17^0 21' to $17^0$24'N and 78^0 5' to 78^0 8'E, and (ii) Lalatora micro watershed, Lalatora village, Vidisha district of Madhya Pradesh, central India (Fig.1) representing predominantly black soil region were selected to realize the objective of the study.

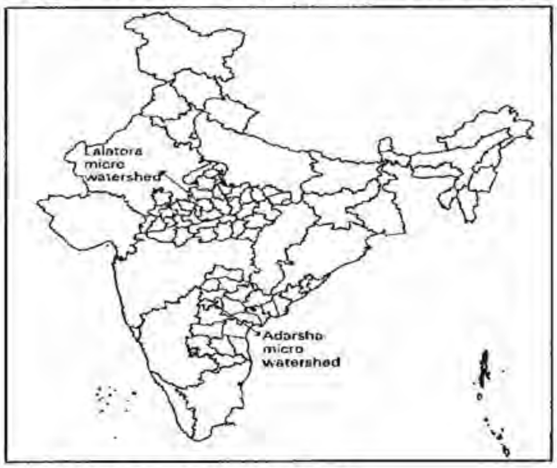

Fig 1. Location map of the test sites

2.2 Database

The Indian Remote Sensing Satellite (IRS-1B, 1C and–1D) Linear Imaging Self-scanning Sensor (LISS-II/III) and Panchromatic sensor (PAN) data were used for deriving information on various natural resources and for generation of intervention plans for sustainable development of land and water resources (Table-1). In addition, Survey of India topographic maps at 1:50,000 scale, and published soil and other resources maps, and reports were also utilised as collateral information.

Table - 1 The details of remote sensing data used

S. No	Satellite/sensor	Path/row Nos.	Date of pass
1	IRS-1B LISS-II	26-56	25-11-1996
2	IRS-1D LISS-III	99-60	29-11-1999
3	IRS-1D PAN	99-60	01-12-1999
4	IRS 1C LISS-III	97-55	16-02-1997
5	IRS-1D LISS-III	97-55	02-02-2001
6	IRS 1C WiFS	97-56	01-02-2000
7	IRS 1C WiFS	103-58	02-03-2000
8	IRS 1D WiFS	98-55	28-09-2001
9	IRS 1D WiFS	104-57	19-09-2001
10	IRS P3 WiFS	98-55	06-10-2001
11	IRS P3 WiFS	104-57	12-10-2000

2.3 Approach

Information on agricultural land use/land cover and soil erosion status was generated through computer-assisted digital analysis of multi-temporal IRS-1C LISS-II/LISS-III data of 1996/1997 and 2000/2001 using Gaussian maximum likelihood per-pixel classifier. Since vegetation condition is the reflection of soils and hydrological conditions that are altered in the event of implementation of suggested interventions, the Normalized Difference Vegetation Index (NDVI), which is an indicator of vegetation condition and vigor was also generated from the spectral measurements in red and near IR region of the spectrum.

2.4 Results and Discussion

The NDVI has been used as a surrogate measure of terrain transformation in terms of changes in ground water table and soil moisture status, and its effect on vegetation cover as a consequence of the adoption of soil and water conservation measures. A close look at Figure-2 depicting the NDVI images of Adarsha micro-watershed for the years 1996 and 2000 reveals a considerable increase in vegetation cover during this period. The changes in the vegetation cover could be seen in the NDVI images as light and dark grey colours representing moderately dense and dense vegetation cover, respectively. The spatial extent of moderately dense vegetation cover that was 129ha in 1996 had risen to 152 ha by 2000. There is, however, no perceptible change in the dense vegetation cover.

Being rich in water dispersible clays, soils of Lalatora micro-watershed are more susceptible to soil erosion by water as compared to soils of Adarsha micro watershed. The results of Lalatora micro watershed indicate an increase in the crop land to the tune of 269 ha i. e. 3,402, ha in 1997 versus 3672 ha in 2001, during four years period. Contrastingly, there has been an attendant shrinkage in fallow lands. The fact is supported by an increase in area under vegetation cover during this period as indicated by NDVI. There has been an increase in the area

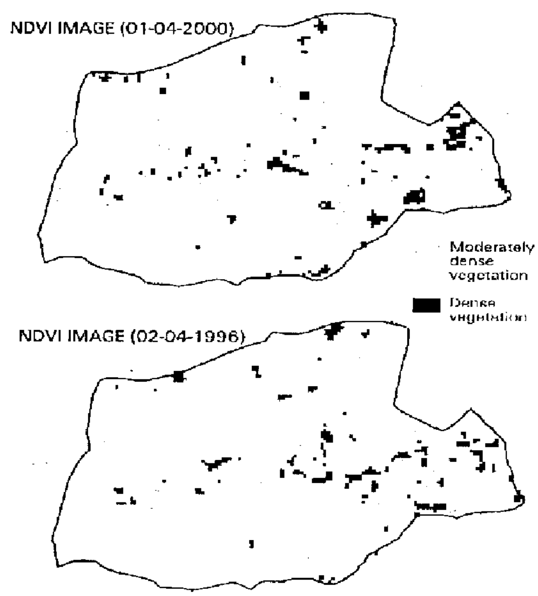

Fig 2. NDVI image of Adarsha micro-watershed

under NDVI values range of 0.10 to 0.55 during the period 1997-2001.

Apart from improvement in vegetation cover, soil and water conservation measures employed in the watershed have also resulted among other changes, in arresting soil loss. Consequently, there has been an improvement in the soil health. The fact is supported by a shrinkage in the eroded lands during four years period (2,962ha in 1997 versus 2,797ha in 2001).

Another interesting feature that was noticed in the watershed is the fallowing of agricultural lands during *kharif* (rainy) season. The major portion of these fallow lands are observed during rainy season especially in rain-fed agricultural situations, not withstanding adequate rainfall. This phenomenon is based on farmer's perception that in the event of early withdrawal of monsoon and late harvesting of rainy season crops, adequate reserves of moisture may not be available in the soil for sowing operations of subsequent season (*rabi*) crop which will ultimately affect the crop yield. If optimally utilized, these land can contribute significantly to improving crop production.

3.0 IDENTIFICATION OF *KHARIF* FALLOWS

Identification of *kharif* fallows aiming at their optimal utilization was a sequel to the study carried out in Lalatora micro-watershed, which was extended to entire state of Madhya Pradesh. Madhya Pradesh, in Central India, is endowed with Vertisols and associated soils. With assured rainfall (700 to 1200 mm/ yr) the area is considered as heartland of dryland agriculture. In the Semi arid tropics where rainfall is often extremely erratic and execution of tillage operations can be difficult, yield from rainy season crops can be precarious. The threats of mid-season drought and other weather-induced losses at critical stages of plant growth contribute to the risks involved in growing a rainy season crop. Rainy season (*kharif*) fallowing results in underutilization of land, water and human resource and when monsoons arrive in the form of sporadic, high intensity showers, a significant portion of the annual rainfall endowment can be lost through surface runoff causing soil erosion owing to absence of protective cover, and economy of the farmers.

3.1 Database

The mapping of *kharif* fallow land was accomplished using the IRS-1C/1D Wide Field Sensor (WiFS) data for the period Februay-March2000, and September 2001, and October 2001 (Table- 1).

3.2 Approach

The approach essentially involves preparation of the mosaic of WiFS digital data covering entire state, preliminary digital analysis, ground truth collection, map finalization and generation of area statistics. Gaussian maximum likelihood per-pixel classifier was used to generate information on fallow lands from multi-temporal IRS-1C/1D WiFS data. For identification of *kharif* fallows a deductive approach involving delineation of agricultural land and forests from temporal satellite data was adopted. Three sets of satellite data corresponding to three periods, namely mid- *kharif*, late *kharif* and *rabi* season were used. While mid-*kharif* season satellite data provide the information on agricultural lands, which were lying unutilized along with those agricultural lands that have been supporting *kharif* crops, the satellite data of *rabi* season, on the other hand, exhibits the spatial distribution pattern of lands supporting rabi crops. These lands include the areas, which were lying fallow during *kharif* season, and are now supporting crops. Contrastingly, the satellite data acquired during late *kharif* season exhibit the agricultural lands that were lying fallow during *kharif* season and the areas where *kharif* crops were taken.

3.3 Results and Discussion

An estimated 18.29 lakh ha of land have been observed to be lying fallow during rainy season. Such lands could be utilised for raising short-duration crops like soybean during *kharif* (rainy) season followed by wheat or chickpea during *rabi* (winter) season. The spatial distribution of fallow lands (*kharif*-fallow) in Vidisha and Guna districts is given in Figure-3 and their spatial extent in Table- 2. As could be seen from Table- 2, fallow lands are confined mostly to Vidisha district (2,80,649 ha) followed by Sagar and Guna districts with an estimated area of 2,40,739 ha and 1,84,100 ha, respectively. Balaghat districts accounts for the minimum area under fallow lands (Table-2).

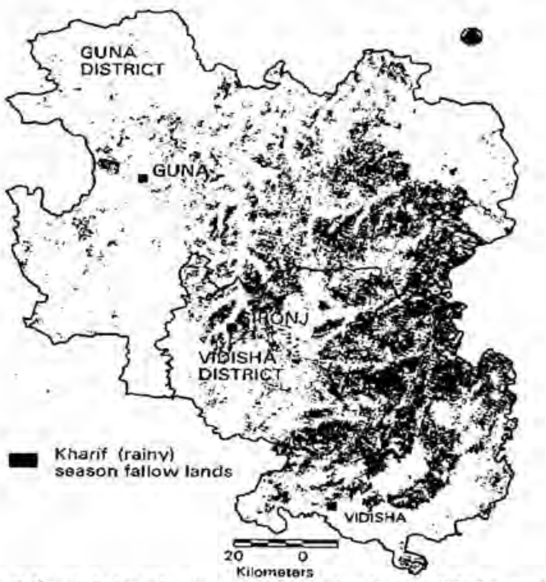

Fig 3.Spatial distribution of fallow lands in Vidisha and Guna districts, Madhya Pradesh.

Sl. No	Districts	Area (ha)	Sl. No	Districts	Area (ha)
1	Balaghat	272	20	Morena	2085
2	Betul	46424	21	Narsimhapur	56971
3	Bhind	8705	22	Panna	67786
4	Bhopal	25589	23	Raisen	182845
5	Chhatarpur	79736	24	Rajgarh	11960
6	Chhindwara	32548	25	Ratlam	2898
7	Damoh	99886	26	Rewa	78269
8	Datia	11024	27	Sagar	240739
9	Dewas	28855	28	Satna	118385
10	Dhar	64768	29	Sehore	42148
11	East Nimar	31583	30	seoni	46131
12	Guna	184100	31	Shahdol	18110
13	Gwalior	18976	32	Shajapur	2902
14	Hoshangabad	13615	33	Shivpuri	20871
15	Indore	30399	34	Sidhi	18930
16	Jabalpur	80556	35	Tikamgarh	11653
17	Jhabua	11395	36	Ujjain	1679
18	Mandla	5061	37	Vidisha	280649
19	Mandsaur	10373	38	West Nimar	32813

Table 2. Spatial extent of fallow lands in Madhya Pradesh

Farmers' decision to sow a rainy season crop or keep his land fallow is based on several assumptions he/she makes, ability to take risk, availability of technologies and existing biophysical and socioeconomic conditions. Probing into the reasons for *kharif* fallowing, Krantz and Quackenbush (1970) cited three fundamental barriers to rainy season cropping in black soil regions: (i) difficulty of soil preparation prior to the monsoon for timely sowing of a rainy season crop; (ii) threat of flooding of the rainy season crop under heavy rains; and (iii) the threat that the rainy season crop will transpire sufficient water to reduce available soil moisture for the post-rainy season crop to the point that post-rainy season yields are significantly reduced. Jodha (1979) states that "given the uncertainty of rainy season cropping in these deep black soils and the extreme difficulty of raising two rain-fed crops on these lands with the traditional technology, the farmer perhaps makes a rational choice in leaving the deep black soils fallow in the monsoon". Kampen and associates (1974) opine that high rainfall areas exhibit large tracts of rainy season fallow due to drainage problems, difficulties in cultivation and weed control and the absence of viable rainy season crop technologies.

In order to utilize these fallow lands and prevent them from further degradation, recommendations based on extesive field experiments conducted by ICRISAT, several ICAR institutions and State Agriculture Universities may be adopted. The ICRISAT demonstrated the technical and economic feasibility of double cropping on dryland with Vertisols where rainfall exceeds 750 mm per year (ICRISAT, 1987; Wani 2000, and Wani et al. 2000). In Madhya Pradesh early sowing of soybean could increase the yields by many folds as observed from the crop simulation studies using SOYGRO model using historical weather datasets (Singh et al. 2001). Estimates on the size of the production environment where double cropping is technically feasible range from 5 to 12 million hectares (Ryan, et al. 1982). Using state-of-the-art techniques, cultivating these fallow lands would generate additional income to the farmers, create employment, reduce the edible oil imports if crops like soybean are taken up besides reducing the soil erosion by water.

4.0 CONCLUSIONS

It is evident from the foregoing that the space technology offers immense potential in generation of baseline information on land and water resources, and in monitoring the progress and success of soil and water conservation programmes. The capability would be further enhanced with the availability of 6m spatial resolution multispectral data from Linear Imaging Self-scanning Sensor (LISS-IV) onboard Resourcesat-1 and very high spatial resolution panchromatic data with stereo capability from Cartosat- 1 and -2 missions.

Identification of fallow lands at a state (an administrative unit) level from coarse spatial resolution IRS-1C/-1D WiFS data is yet another dimension which space technology could add to optimal utilization of available land and water resources. Further refinement in the level of information on rainy season fallows at state levels seems feasible with the availability of Advanced WiFS sensor data with around 60m spatial resolution, < 370 km swath and 3-4 days repetitivety, aboard planned Resourcesat-1 mission .

ACKNOWLEDGEMENTS

We are thankful to Shri S.Senthil Kumar, Junior Research Fellow, National Remote Sensing Agency for providing necessary technical support. Logistics support provided by Dr.Pande, BAIF, Bhopal, Madhya Pradesh is also duly acknowledged.

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