Remote Sensing and GIS for Assessment, Monitoring and Management of Degraded Lands

L.VENKATARATNAM, T.RAVI SANKAR

National Remote Sensing Agency, Dept. of Space, Govt. of India, Balanagar, Hyderabad-500037, India.

Abstract

The extent and geographical distribution of degraded lands like salt-affected lands, areas under soil erosion and shifting cultivation, waterlogged areas, and ravines, form an essential input for planning reclamation/conservation programmes. Remote sensing satellites provide timely, accurate and reliable data on degraded lands at definite time intervals in a cost effective manner. Experiments have been carried out to map and monitor the areas with erosion and shifting cultivation and salt-affected soils, using remotely sensed data from Landsat MSS, TM and Indian Remote Sensing satellite (IRS) sensors. The details of the methodology employed to derive information from remotely sensed data on above mentioned degraded lands and the results of the experiment are discussed in this paper. The salt-affected soils of India have been mapped for the whole country at 1:250,000 scale by the National Remote Sensing Agency (Hyderabad) in association with National organisations like National Bureau of Soil Survey and Land Use planning, All India Soil and Landuse Survey and provincial soil survey organisations and Agricultural Universities. The changes in the spatial extent of eroded and shifting cultivation areas and salt-affected soils are also studied using multi-temporal satellite data. The development of satellite image processing, artificial intelligence, global positioning system and mathematical morphology has promoted the use of GIS technology for storage, retrieval, management and analysis of spatial data as well as solving decision making problems. The information generated on degraded lands through remote sensing data and other ancillary information available are stored in GIS to perform integrated analysis.

Introduction

Throughout the world the concern for the environment is increasing day by day due to physical, chemical and biological degradation of the natural resources that have led to the ecological imbalances. The over-exploitation and mismanagement of land resources have resulted in the degradation of land, a major environmental issue in the contemporary times. Nearly 175 million hectares of land in India is subject to one or other kind of degradational process (DAS, 1985). The main degradational processes operating on land are erosion (water and wind), accumulation of excess salt (salinization / alkalisation), chemical degradation (toxicities / deficiencies), physical degradation, biological degradation (decrease in flora and fauna) and waterlogging. About 150 million hectares of land are suffering from different types of erosion, out of which 69 million hectares are in severe deterioration phase (ANON, 1976). The salt-affected soils and waterlogged areas are reported in 7 million hectares and 6 million hectares, respectively (BALI, 1985). About 4.36 million hectares of forest land is under shifting cultivation that leads to accelerated soil erosion.

Hence, the timely information on the extent and geographical distribution of degraded lands viz., areas under soil erosion and shifting cultivation, salt affected soils, waterlogged areas, ravines, etc. forms an essential input for planning reclamation / conservation programmes of these lands. Moreover, these lands are to be monitored at regular intervals of time to know the impact of the implemented reclamation / conservation measures.

Remote sensing technology and GIS in India

Among the new technologies developed for the study of natural resources the space borne remote sensing technology in association with computer technology proved to be the most valuable one to study the various aspects of environmental degradation. The systematic efforts in the application of remote sensing technology in the study of natural resources has resulted in the development of well established methodologies for mapping and monitoring of various degraded lands in a cost effective manner.

In India, initially aerial photographs were used in deriving information on degraded lands (KAMPHORST and IYER, 1972; IYER *et al.* 1975). The application of remotely sensed data in mapping degraded lands from space borne sensors started with the launch of the first Earth Resources Technology Satellite ERTS-1/Landsat-I. However, the satellites Landsat-TM, SPOT and Indian Remote Sensing Satellites (IRS) with better spatial and spectral resolution, enabled to map and monitor degraded lands more efficiently. Many studies are reported in literature on the use of Landsat-MSS, TM, IRS and SPOT data for inventory of degraded lands. Studies are carried out on mapping eroded lands (VENKATARATNAM and RAO, 1977; RAO *et al.* 1980), ravines (NRSA, 1981; KARALE *et al.*, 1988), watershed prioritisation (DOHARE *et al.*, 1985, SHARADA *et al.*, 1993), salt-affected soils (VENKATARATNAM, 1983, 1984; BAJWA *et al.*, 1990) and shifting cultivation (KUSHWAHA and UNNI, 1987).

Geographical information system (GIS)

The advancements in the field of computer technology, image processing, global position system and mathematical morphology have resulted in the development of Geographical Information System (GIS) technology for storage, retrieval, management of spatial data (e.g. maps derived from remotely sensed data etc.), attribute data (e.g. soil properties, climatic parameters etc.) and other related ancillary information more efficiently. GIS proved to be an effective tool in handling spatial data available at different scales, voluminous point data such as soil information, rainfall, temperature etc. and socio-economic data and to perform integrated analysis of data on various resources of any region and to arrive at optimum solutions for various problems. In India, GIS is being used in various fields such as for optimum land use planning, planning for sustainable development of land resources, assessment of crop water requirements, development of wastelands etc. The efforts are going on to use GIS in crop yield modelling, developing measures for reclamation / management of salt-affected soils, quantification of soil loss to suggest suitable conservation processes, evaluation of soils for various purposes like horticulture, agroforestry, silvipasture, and aquaculture development.

Methodology

The two methods used in the interpretation and analysis of remotely sensed data to derive information on degraded lands are visual interpretation and digital analysis. Visual interpretation involves identification and delineation of degraded lands that are manifested on False Colour Composite (FCC) or black & white prints in different size, shape, tone, texture, pattern etc. The remotely sensed data in Computer Compatible Tapes (CCTs) or floppies or diskettes are analysed with the help of computers having image analysis software packages. The spectral reflectance of degraded lands forms the basis in the digital analysis. Both visual and digital techniques are used in extracting valuable information on degraded lands from remotely sensed data.

The False Color Composites or Computer Compatible Tapes are analysed initially with the help of topographical maps, published reports and other available ancillary data; broad categories of degraded lands will be delineated. Again each unit will be divided into sub-units on the basis of erosion status or drainage density or vegetation cover or land use. These delineated units will be transferred on to base maps prepared from Survey of India topographical maps. Representative sample areas will be selected for various degraded lands for ground truth collection. During field visits, features of topography and soil profiles will be studied, site characteristics and soil samples will be collected for laboratory analysis. The preliminary interpreted maps will be modified in the light of field data and soil chemical analytical data; final maps are prepared with appropriate legend.

Assessment, monitoring and management of degraded lands

Soil erosion and shifting cultivation

Satellite data from spaceborne sensors, namely Landsat MSS, TM and IRS-LISS-I & II, were used for qualitative assessment of areas, being subject to soil erosion and to shifting cultivation practices (NRSA, 1990) in parts of north eastern India. Based on length and degree of slope from topographical maps, land use / land cover and soil characteristics as revealed by Landsat TM data and other related ancillary data, four soil erosion classes namely nil to slight, moderate, severe to very severe and very severe could be mapped in parts of Manipur state. Figure 1 shows the soil erosion map of the test site at 1:250,000 scale. The eroded areas and shifting cultivation patches were manifested distinctly on the FCC. The shifting cultivation areas appeared in small and irregular patches with bright yellowish white tone (freshly cut areas) or black tones (burnt areas) in the background of forest vegetation, which appeared in red / magenta tone on the FCC. The severe to very severe erosion class occupied 44.18 km^2. followed by nil to slight class 20.81 km^2. The moderate and very severe erosion classes are encountered in 1.94 and 8.63 km^2 area, respectively. The shifting cultivation area was found to be 0.40 km^2. FCCs obtained from Landsat MSS sensor (with 80 m spatial resolution) and TM sensor (with 30 m spatial resolution) were evaluated for delineation of eroded areas and shifting cultivation areas. It was observed that Landsat TM data with 30 m spatial resolution enabled better delineation of small units of eroded and shifting cultivation areas as compared to Landsat MSS data with 80 meter spatial resolution at 1:250,000 scale.

A small part of the test site was taken up to map eroded and shifting cultivation areas using 1:50,000 scale Landsat TM FCC (Fig. 2). At the 1:50,000 scale above mentioned four soil erosion classes could be mapped as pure units and small areas that could not be resolved at 1:250,000 scale (due to scale limitation) could also be picked up. In the case of shifting cultivation, current and abandoned areas could be identified and mapped.

The digital analytical technique was attempted for the test site in Manipur with Landsat TM data. Nil to slight, moderate and severe to very severe erosion classes could be classified as against four erosion classes in visual interpretation because digital analysis depends solely on spectral response of classes. The third and fourth erosion classes (in visually interpreted map) exhibited almost similar spectral response and could not be classified separately.

In North Eastern states the soil erosion depends mostly on intensity of shifting cultivation. Hence, the areas under shifting cultivation should be monitored at regular intervals. Multidate satellite data with a time gap of 8 years were taken to demonstrate their utility for monitoring purpose in south Tripura state. The eroded and shifting cultivation areas around Gumti reservoir in South Tripura district, Tripura were mapped at 1:250,000 scale, using Landsat MSS data of 15th April, 1978 and Landsat TM data of 26th March, 1986 (NRSA, 1990). The area statistics of erosion classes and shifting cultivation are given in table 1.

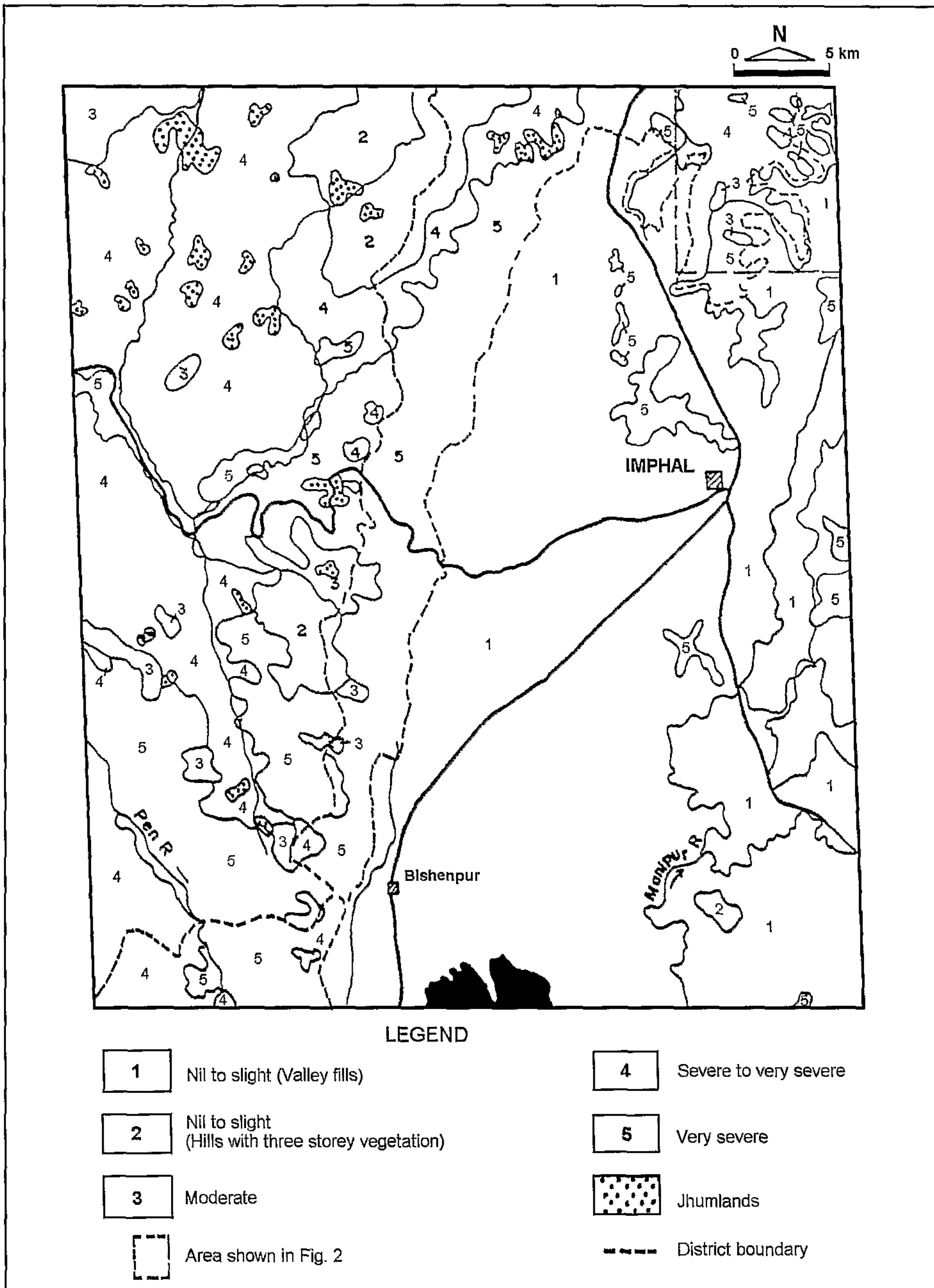

Figure 1. Soil erosion map of part of Imphal Valley Manipur (based on visual interpretation of Landsat TM data, dated January 30, 1986).

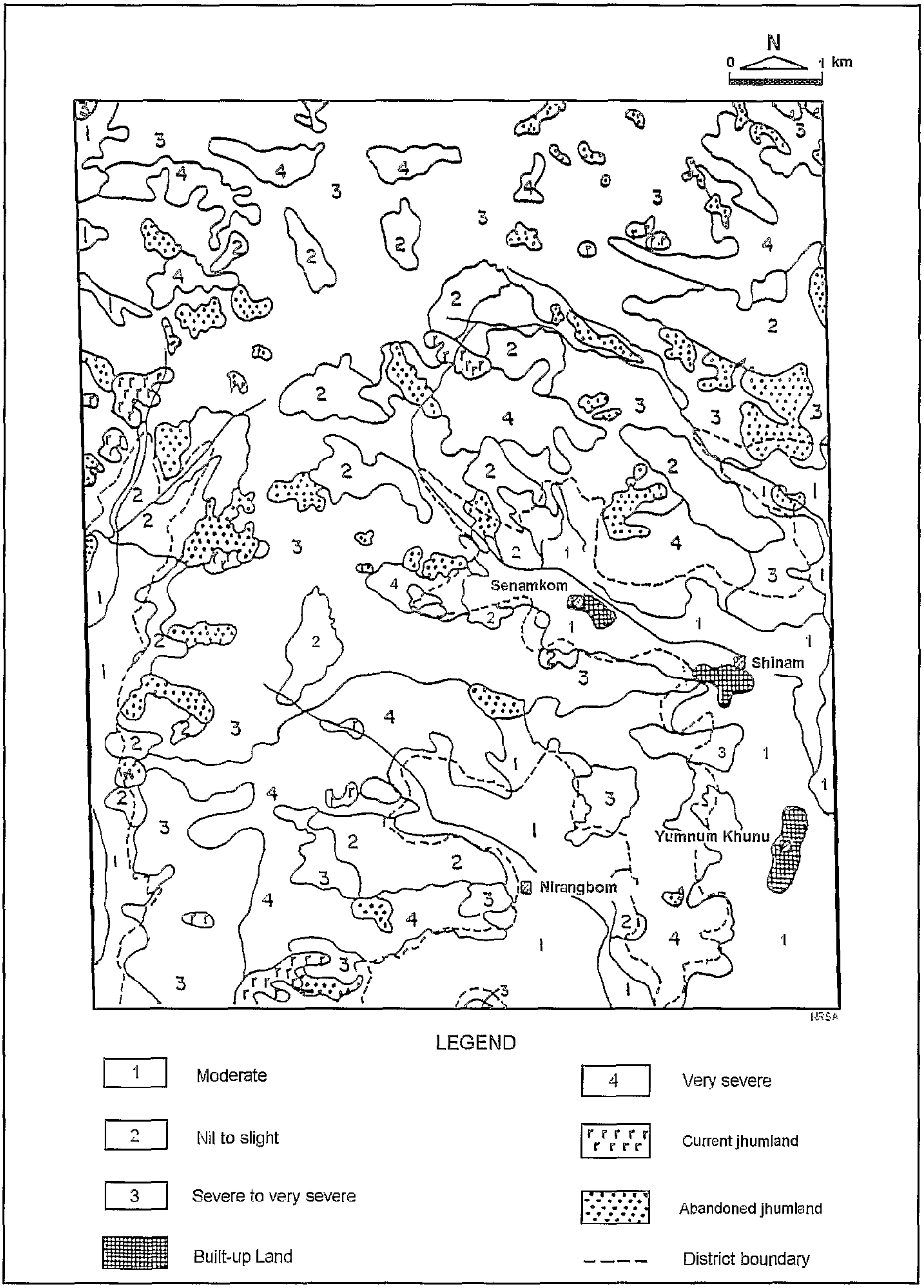

Figure 2. Soil erosion map of the area around Senamkom North Manipur (based on visual interpretation of Landsat TM data, dated January 30, 1986).

In the test site the area under nil to slight erosion class decreased from 19.46% in 1978 to 5.62% in 1986. The area under moderate erosion has increased from 30.94 to 36.97% during the same period. Similar trend of increase was found in the severe to very severe class during 8 years of time. The shifting cultivation area increased from 5.13% in 1978 (Fig. 3) to 6.54% in 1986 (Fig. 4).

Table 1. Area of erosion classes and shifting cultivation.

Erosion class	April 1978 No. of polygons	% of total area	March 1986 No. of polygons	% of total area	% of variation
Nil to slight (Valley fill)	28	06.73	28	06.73	=
Nil to slight (Three storey)	23	19.46	15	05.62	- 13.84
Moderate	27	30.94	22	36.67	+ 05.73
Severe to very severe	13	34.10	11	42.77	+ 08.67
Jhumlands	405	05.13	412	06.54	+ 01.41

Salt-affected soils

Salt-affected soils have distinct expression on the FCCs in bright to dull white tone patches within the background of normal soils supporting good vegetation (that appears as bright red / magenta tone). The salt-affected soils with poor crop growth appear in dull red tone / mottled tone and enable to identify and map them. In general, the FCCs of February-March period were found suitable to map salt-affected soils in the Indo-Gangetic alluvial plain and other areas. In certain cases, especially in black soil areas, data of two different seasons help in better delineation of these soils in addition to more intensive ground truth.

The salt-affected soils of India have been mapped at 1:250,000 scale through visual interpretation of Landsat TM/IRS imagery at the National Remote Sensing Agency (NRSA, Hyderabad) in association with the National Bureau of Soil Survey and Land Use Planning (Nagpur), All India Soil and Land Use Survey (New Delhi) and state government organisations. The legend of the salt-affected soil map shows physiographic units, nature of the problem (saline / saline-sodic / sodic), magnitude of the problem (slight / moderate / strong) and extent of problem in each mapping unit (<1/3, 1/3-2/3, >2/3). Figure 3 shows salt-affected soils in parts of Pali district, Rajasthan along with the legend.

NRSA has also mapped salt-affected soils at 1:50,000 scale on a limited extent, using Landsat TM and IRS FCC imagery at the same scale. The salt-affected soil maps have been prepared for Mainpuri and Unnao districts of Uttar Pradesh and for South Coastal districts of Andhra Pradesh. The map shows the physiographic unit, type of salt-affected soil and magnitude of the problem. At 1:50,000 scale, pure units could be mapped and even small units, not to be mapped at 1:250,000 scale, could also be delineated.

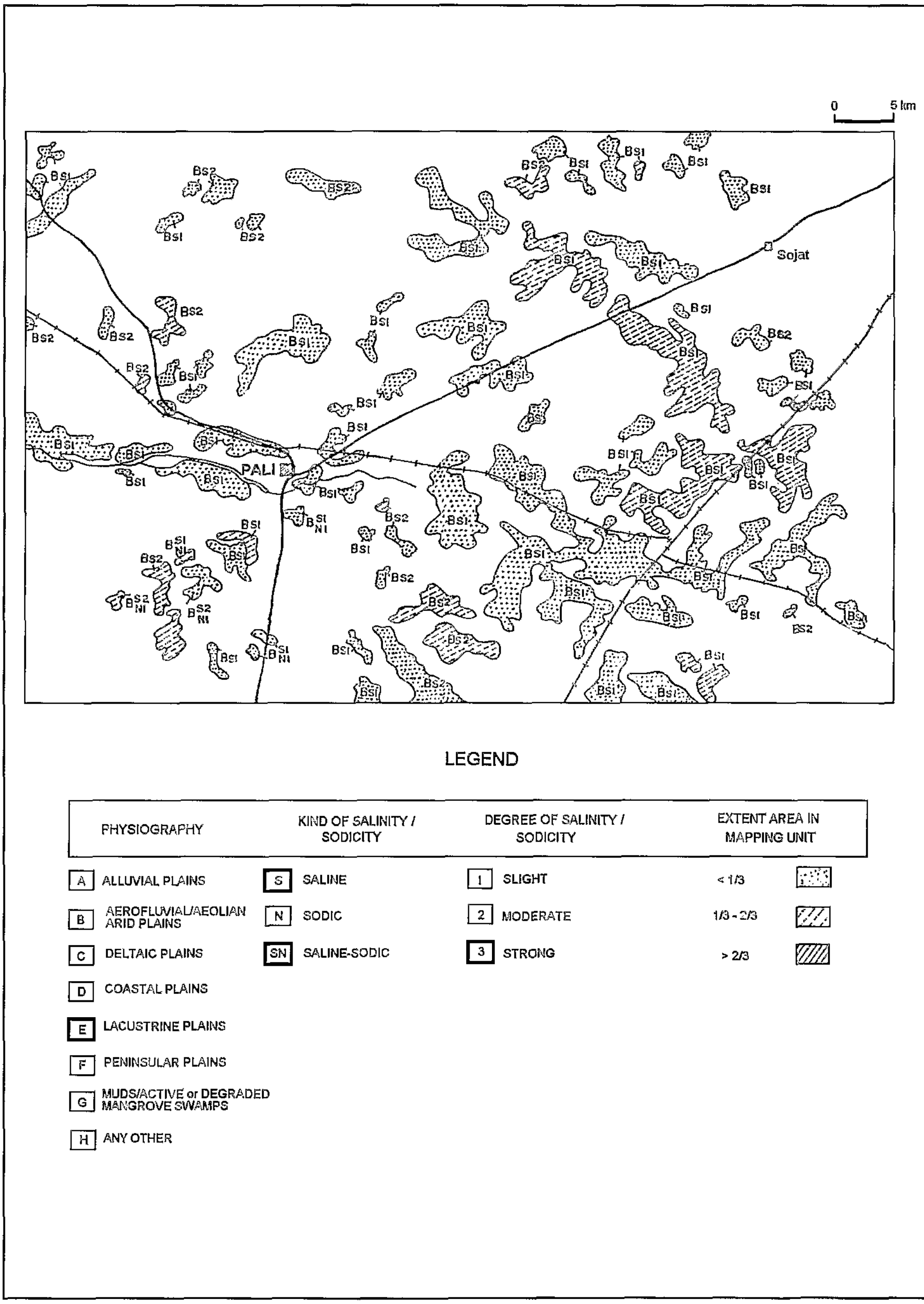

Figure 3. Salt-affected areas in parts of Pali District, Rajasthan (based on visual interpretation of Landsat TM imagery with adequate field checks).

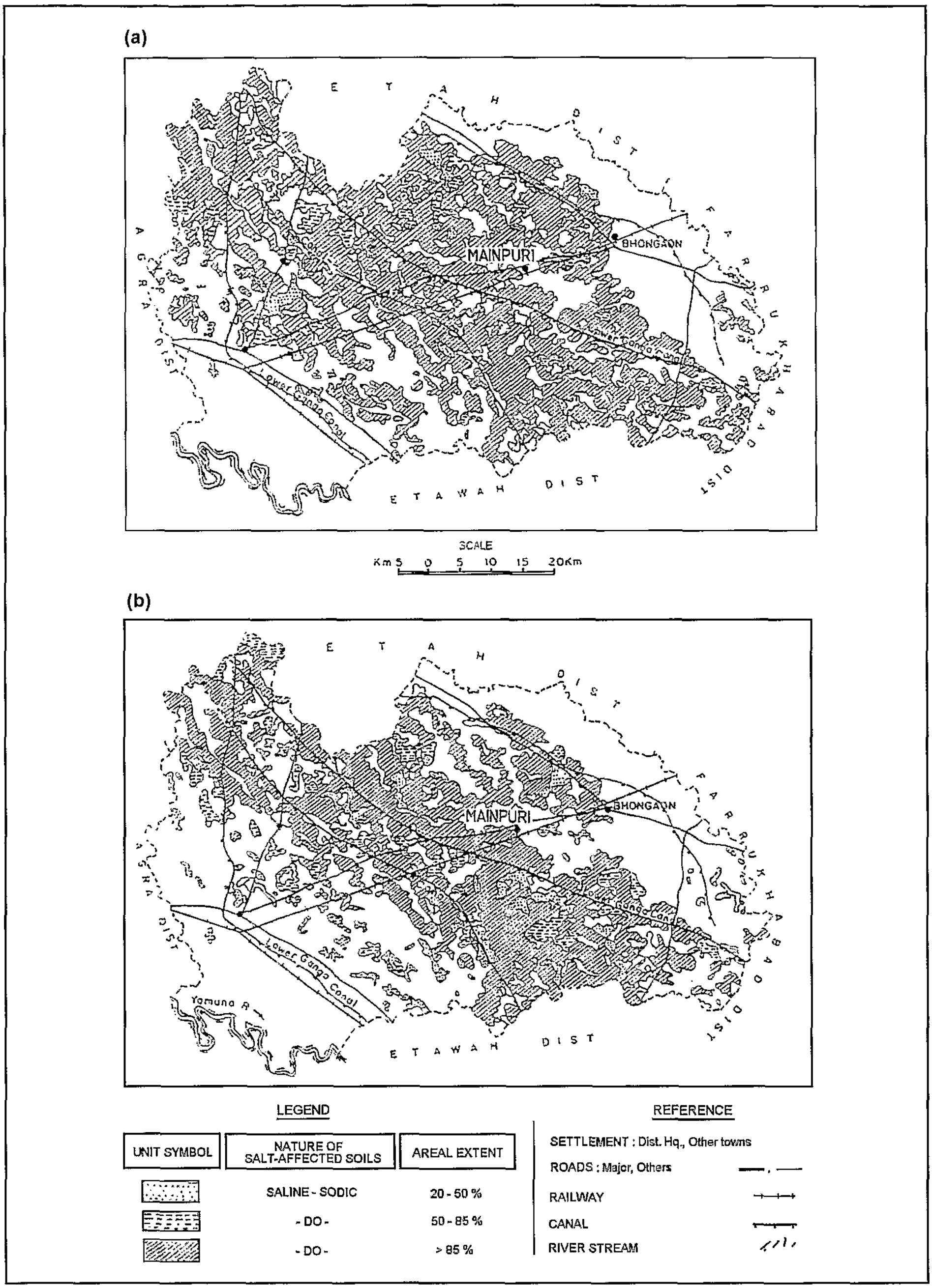

Figure 4. Salt-affected soils of Mainpuri District (U.P.) based on visual interpretation of : **(a)** Landsat MSS data of February 28, 1975; **(b)** Landsat TM data of March 9, 1986.

Digital techniques were also used to study especially the salt-affected soils of Indo-Gangetic plains. For the first time in the country, VENKATARATNAM and RAO (1977) have used the multispectral data analysis system for the categorization of salt-affected soils of the Punjab state, using the digital data of Landsat-2. VENKATARATNAM and RAVI SANKAR (1992) used Landsat-TM digital data to classify salt-affected soils in Mainpuri district of Uttar Pradesh along with other degraded lands. The salt-affected soils could be classified into strongly sodic and moderately sodic soils and the area under these classes were found to be 55,092 ha and 63,672 ha, respectively.

Multidate satellite data covering extensive areas are the only means for monitoring the salt-affected soils over a period of time. Many studies are reported in literature dealing with monitoring of salinity / alkalinity in the soils. VENKATARATNAM (1983, 1984) has used the multitemporal data of Landsat to monitor the salt-affected soils vis-à-vis reclamatory efforts taken by the state government authorities for parts of Punjab and Haryana states. According to him, monitoring of salt-affected areas of Indo-Gangetic plains can be effectively done by using multitemporal data on any multispectral data analysis system. The salt-affected soils are monitored in Mainpuri district of Uttar Pradesh, using Landsat MSS data of 1975 and Landsat TM data of 1986 (RAO *et al.*, 1994), following a visual interpretation approach. Figure 4a shows a salt-affected soil map for the year 1975 and figure 4b for the year 1986. The area statistics of different categories of salt-affected soils in both years are given in Table 2.

Table 2 shows that over a period of 11 years, the spatial extent of salt-affected soils has decreased. The salt-affected soils under the unit > 85% affected, decreased from 1,074,450 ha in 1975 to 1,028,806 ha in 1986. In the case of units 50-85% affected and 20-50% affected units the salt-affected areas decreased marginally by 1.84% and 0.9% respectively.

Table 2. Area statistics of different categories of salt-affected soils.

Sl. No.	Category of salt-affected soils	Areal extent (ha) 1975	1986	% total area 1975	1986	Remarks
1.	> 85%	1,074,450	1,028,806	40.17	29.66	Significant decrease (10.51%)
2.	50-85%	14,800	22,800	3.41	5.25	Marginal increase (1.84%)
3.	< 20-50%	9,131	13,031	2.10	3.00	Marginal increase (0.9%)

In one of the recent projects, the degraded lands in Sharda Sahayak Command area are being studied using satellite data from 1975 to 1992 (Landsat MSS-TM and IRS sensors). For a part of the study area, digital techniques were used to monitor the salt-affected and waterlogged areas. It was observed that the area with salt-affected soils and waterlogging decreased from 1975 to 1992. In the test site the salt-affected soils during 1975 was estimated to be 29,122 ha; which reduced to 21,205 ha by 1985 and further reduced to 12,872 ha by 1992.

Other degraded lands

Besides above mentioned major categories of degraded lands, the other degraded lands are ravines, waterlogged areas, wetlands and marshy areas. These categories of degraded lands are also manifested distinctly on remotely sensed imagery. The ravines are seen on FCC with light greyish brown to dark greyish brown tone with coarse to medium texture along the major river systems. VENKATARATNAM and RAVI SANKAR (1992) classified the ravines along the Yamuna river in Uttar Pradesh state into deep and shallow ravines through digital analysis of Landsat TM data. The area estimated under the ravines was 18,470 ha in Mainpuri district of Uttar Pradesh state.

Spaceborne multispectral data have been successfully used in mapping and monitoring of waterlogged / wetlands / marshy areas. The waterlogged areas appear in different shades of bluish green or greenish blue patches on FCC with smooth texture. Delineation of waterlogged areas in black soil region poses problems, where multidate imagery was found to be useful. Efforts are being made to use microwave remote sensing using Synthetic Aperture Radar (SAR) data. DWIVEDI *et al.* (1994) studied the wetlands of Sunderban and its adjoining areas in West Bengal, using microwave SAR data from ERS-1 satellite. They could map the coastal and inland wetlands through visual interpretation of ERS-SAR data in conjunction with IRS-1B LISS-II data. In the case of coastal wetlands, they could identify and map the estuaries, creeks and mangrove forests. Similarly, in the inland wetlands they could demarcate lakes / ponds, oxbow lakes, seasonal waterlogged areas and swamps / marshy areas.

The land degradation problem (soil erosion) in the catchment areas can be tackled scientifically by managing the soil and water resources on watershed basis. The basic step in this direction is prioritizing the watersheds in the catchment, to take up conservation practices that control soil erosion and sediment inflow into the streams and subsequently into the reservoirs / waterbodies. Remotely sensed data help to derive at information on soils, crops, land use / land cover etc., of watersheds in association with topographical maps and other ancillary data. The spatial data (maps) derived from remotely sensed data and other attribute data can be efficiently integrated in Geographical Information System (GIS) to calculate the sediment yield indices for watersheds, which can be used for prioritization of watersheds.

Mining is an important economic activity for the development of any country. Mining for mineral resources has severe ecological implications if proper planning and management strategies are not adopted. In India, remotely sensed data were used to study the impact of mining on the natural environment with the help of temporal satellite data. Satellite data were used to study the impact of iron ore mining on surrounding forest cover and in the coal field areas to prepare environmental management plans.

GIS for management of salt-affected soils

A study has been carried out with the objective of extracting the spatial information on salt-affected soils of Unnao district, Uttar Pradesh state using IRS-1B L1 digital data and to calculate the gypsum requirement for the reclamation of salt-affected soils for the whole district, using GIS techniques with the help of attribute data on salt-affected soils. Image analysis was carried out using EASI/PACE image analysis software package on IBM 6000 workstation. PAMAP GIS (a raster based package) was used for storing, retrieving and analysis of spatial and attribute data on a Sun work station. As the digital data of the Unnao district were covered in two adjacent paths (25 & 26) and row 49, the data were mosaiced digitally. The satellite data were registered with the topographical maps of the district and resampled to the map through identification of sufficient number of ground control points and the district boundary was extracted. Subsequently, a mask was built for the area falling outside the district. Based on available information, training areas were defined for various land use / cover classes including salt-affected soils. After studying the spectral response of salt-affected soils and relating them with soil properties they could be grouped into strong and moderate degree classes. Then image classification was done to obtain the spatial extent of salt-affected soils in the district. The base map of the district was prepared along with road, railway and canal network and scanned using Contex scanner.

The scanned base map was imported into a PAMAP GIS environment. The soil sample points in 17 locations were identified and an attribute database was created for these points, including: soil pH, ESP, electrical conductivity, gypsum requirement, etc. The classified file from remotely sensed data was also imported into the GIS environment. In PAMAP GIS the overlaying of base map, classified data and attribute data was done using the "Mapper" module. Attempts are going on to extrapolate the information available for 17 points to other unknown points for the calculation of gypsum requirement for the entire district.

Conclusion

Spaceborne satellite data have become valuable tools in studying the spatial extent of degraded lands and for monitoring the changes that have taken place over a period of time due to reclamation / conservation measures. The methodologies are well established to extract precise and timely information on different aspects of degraded lands in a cost effective manner on operational basis. The present status is that the remote sensing techniques are being regularly used in the study of degraded lands. The usage of GIS in storing, retrieving, integrated analysis and presentation of results on degraded lands started on a limited scale. In the near future it will become a very important tool for handling voluminous data generated on degraded lands through conventional and remote sensing techniques and for integrated analysis of data to derive plans for reclamation / conservation of natural resources. The future generation of satellites with higher spatial and spectral resolutions (e.g. IRS-1C) and advanced GIS techniques not only enable to derive information on degraded lands but also to store and manipulate data for arriving at environment friendly plans.

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