Role of remote sensing in resource management for arid regions with special reference to western Rajasthan

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The arid region of western Rajasthan is about 20.87 Mha covering 85 blocks of 12 districts of Rajasthan which constitutes 61% of the state. About 38% of the total population of the state with a density of 84 persons per sq km area lives in the arid region of Rajasthan. The constantly increasing human and livestock population is putting tremendous pressure on the available natural resources. The major problems of the region are: scarcity of water, frequent droughts, land degradation, deteriorating pasture lands and advancement of desert. Therefore, it is essential to explore newer sources of resources as well conserve the existing natural resources. Optimal management of natural resources is of utmost importance in today's context to increase the production of food grains, fodder and develop water resources for meeting the demand. Remote sensing provides timely, reliable and spatially comprehensive data on various natural resources for effective planning, implementation and monitoring. Some of the natural resources problems of the western Rajasthan, use of remote sensing techniques and role of current and future Indian remote sensing programme are highlighted in this paper.

ARID zone in India covers about 39 million hectare (Mha) area constituting about 12% area of the country. It covers 32 Mha as hot and 7 Mha as cold arid zone. Twelve districts in western Rajasthan covering 20.87 Mha fall in the hot arid zone, constituting around 61% of the total area of the state. These districts are Barmer, Bikaner, Churu, Ganganagar, Hanumangarh, Jaisalmer, Jalore, Jhunjhunun, Jodhpur, Nagaur, Pali, and Sikar and together constitute 85 blocks. According to the 1991 census about 38% of the total population of the state with a density of 84 persons per sq km area lives in the arid region. The livestock population is around 25 million (1987–88) with a density of 120 per sq km. This makes it one of the most densely populated deserts of the world. The constantly increasing human and livestock population is putting tremendous pressure on the available natural resources.

The western Rajasthan has typical characteristics. They are (i) mean annual rainfall of about 310 mm, (ii) about 50% of the region has plain lands without stream network, (iii) about 30% of the region has slopy lands with stream network mainly in the Luni basin, (iv) about 20% of the region is covered under Indira Gandhi canal command area.

The main problems of the region are: (i) low and erratic rainfall, frequent droughts, (ii) scarcity of water, (iii) available groundwater resources is also not sufficient since it is brackish/saline at many places and found at greater depths with low discharge, (iv) soil is less productive, (v) water logging problem in Indira Gandhi Nahar Project areas, (vi) wind erosion causing high erodibility of sandy soil, (vii) deteriorating pasture lands and (viii) advancement of desert.

Remote sensing is the science of making inferences about material objects from measurements, made at distance, without coming into physical contact with the objects under study. In this context, any force field – gravity, magnetic or electromagnetic, could be used for remote sensing, covering various disciplines from astronomy to laboratory testing of materials. However, currently the term remote sensing is used more commonly to denote identification of earth features by detecting the characteristic electromagnetic radiation that is reflected/emitted by the earth surface.

Satellite remote sensing provides synoptic view, enabling one to understand the inter-relationship between various features observed. In addition, remote sensing satellites cover the same area repetitively, making it possible to understand and monitor changing physical processes. Availability of data at different spatial resolution provides information at macro level and micro level. Microwave remote sensing provides all weather capability. Thus satellite remote sensing provides timely, reliable and spatially comprehensive data on various resources for their exploration, monitoring and effective management.

The data received from the satellites can be analysed using computer or by visual interpretation. For visual interpretation the data is converted into photographic images. The photographic images are usually generated using green, red and near infrared (NIR) assigning blue, green and red respectively. This is called False Colour Composite (FCC) since it does not depict true colour, as the information of the blue band is missing. Since for the vegetation the reflectance in NIR is higher, the vegetation appears red in the FCC. Figure 1 shows the imagery of western Rajasthan produced by the IRS-1C WiFS camera, with the district boundaries overlaid. It depicts vegetation biomass in red colour wherein good vegetation is seen in Ganganagar, part of Hanumangarh, east Nagaur, Jhunjhunun, Sikar, Pali and Jalore districts. Medium vegetation is seen in central part of Jaisalmer and west part of Jodhpur districts. Low vegetation is seen in part of Bikaner, east Barmer and Churu districts. No vegetation/dry area are in parts of Jaisalmer, Barmer, Bikaner, Churu and Hanumangarh districts.

Table 1 gives some of the major problems in the region of Rajasthan and possible applications of remote sensing to help in evolving suitable strategy for their management. The details of application of remote sensing in tackling some of the natural resource problem areas are discussed here.

Water resources

The western Rajasthan faces acute shortage of potable water and village women have to fetch water from many kilometers away to meet domestic requirements. Sixty to sixtyfive per cent of western Rajasthan has saline to highly saline groundwater with the TDS (total dissolved salts) content ranging from 2000 ppm to 20000 ppm. In addition to problem of obtaining potable water, deterioration of land due to the use of poor quality groundwater for irrigation is causing serious concern.

Remote sensing aids quick identification of groundwater prospective zones. Some of the indicators of groundwater prospective zones are lineaments, lineament intersection, palaeochannels and valley fills. During the drought of 1986, hydrogeomorphological maps on 1 : 250,000 scale for the entire state using Landsat TM imagery were prepared. These maps show hydrogeomorphological units and the related groundwater prospects. A typical hydrogeomorphological map of Shahbad Tehsil of Baron district in Rajasthan is given in Figure 2.

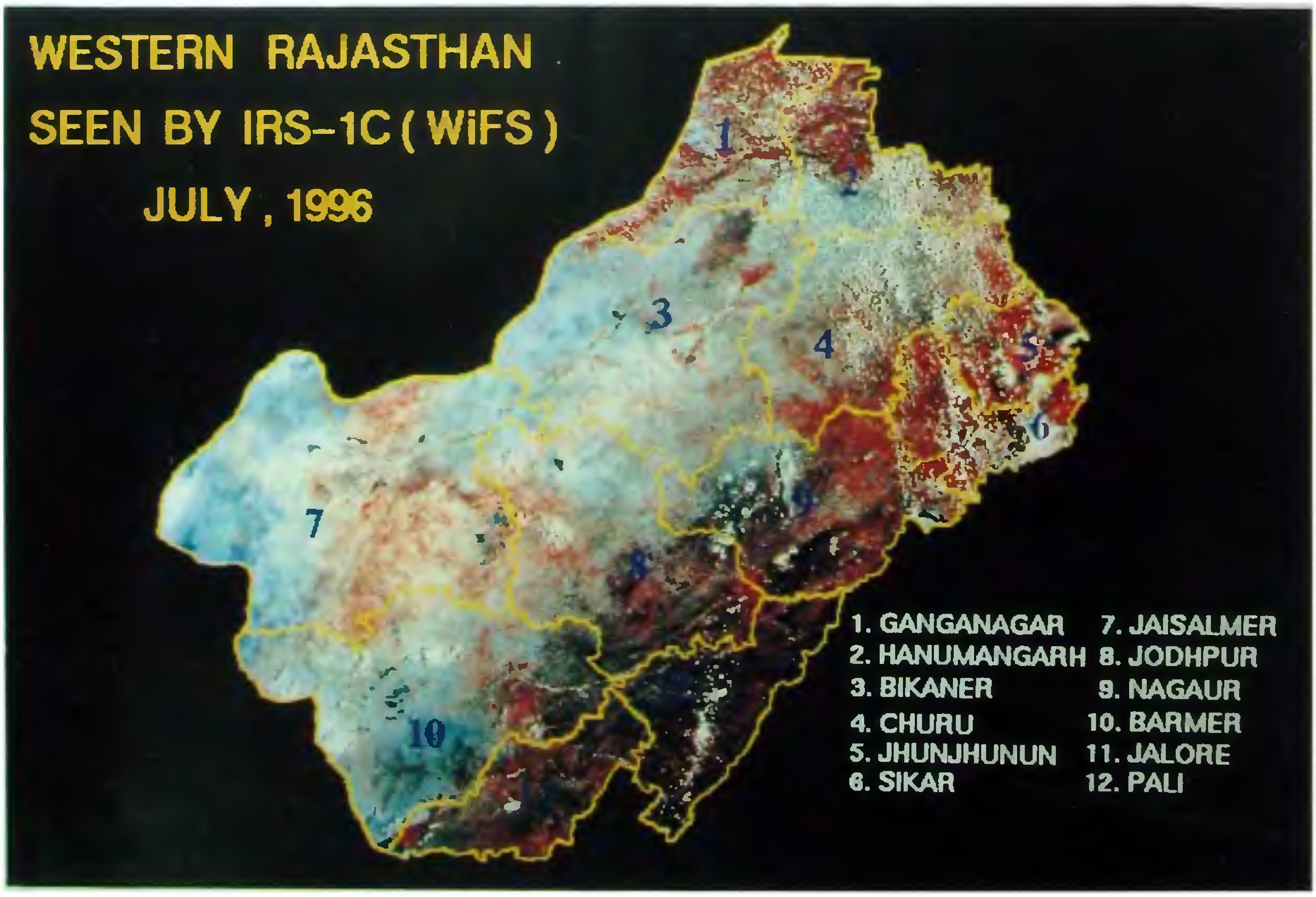


Figure 1. IRS-1C WiFS view of western Rajasthan with district boundaries overlaid.

Table 1. Major resource management problems in arid region of Rajasthan

Problems	Remote sensing potential
Scarcity of water	Identification of groundwater prospective zones, Sites for recharge structures
Frequent droughts	Assessment of drought conditions through NDVI
Advancement of deserts	Monitoring of sand drift/movement
Land degradation	Monitoring wastelands, Water logged area, Land use/cover, Impact of mining
	Prioritize erosion prone area for soil conservation measures
Deterioration of pasture lands	Grassland inventory, condition assessment and monitoring

The map shows spatial extent of various hydrogeomorphological features. Good to very good groundwater prospects are represented by valley fills, lineaments and buried pediment in sandstone. These maps provided the 'first cut' information for carrying out follow-up hydrogeological and/or geophysical measurements for pinpointing sites for exploratory drilling. Detailed mapping for Jaisalmer and Bikaner districts on 1 : 50,000 scale has been carried out using IRS LISS-II and partially SPOT images. Currently under the Integrated Mission for Sustainable Development, detailed action plans for water resources development like sites for water conservation and harvesting have been generated for many districts in the western Rajasthan, where the satellite data and field data have been integrated. Efforts have also been

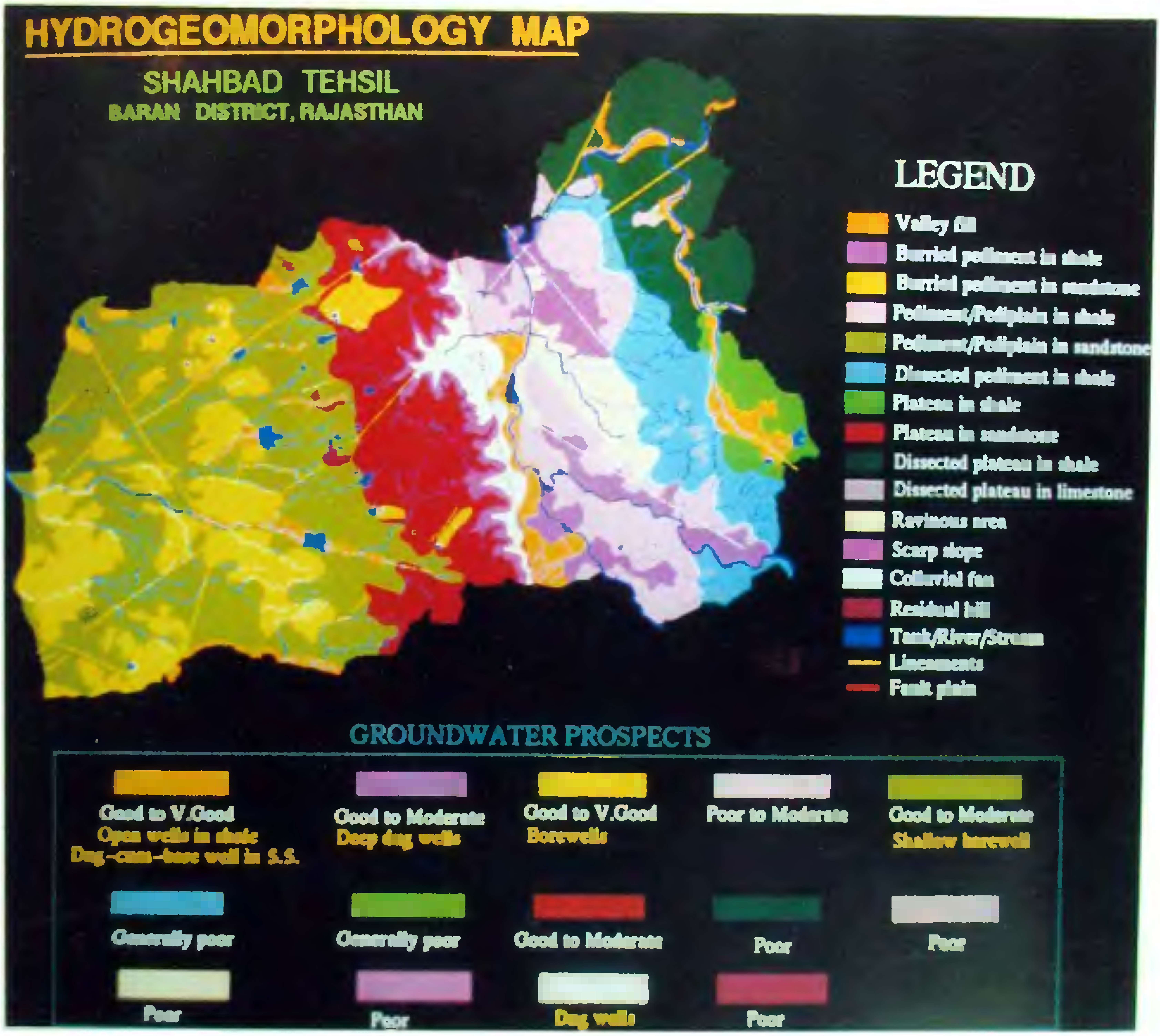
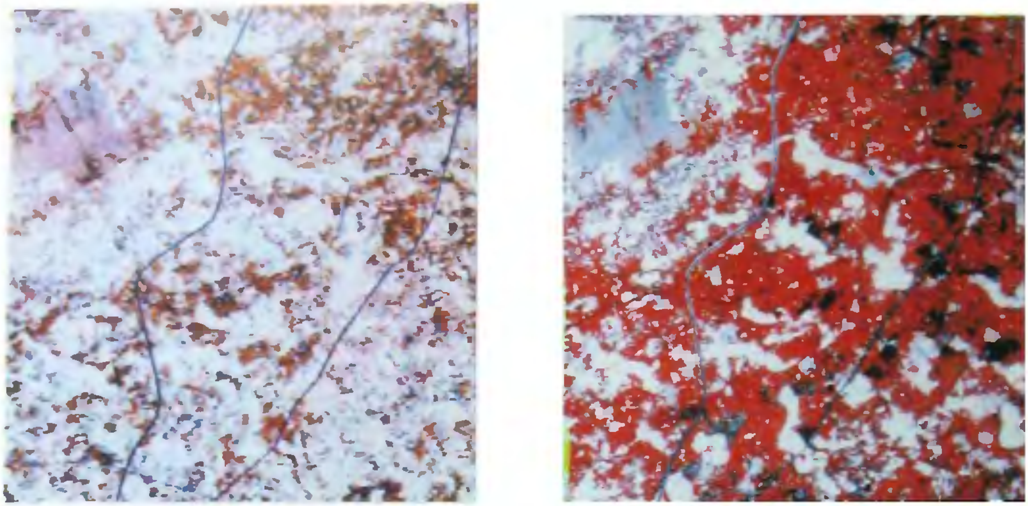


Figure 2. A typical hydrogeomorphological map showing groundwater prospects in Shahbad tehsil, Baran district, Rajasthan.



MSS October 1975
Cropped area: 36073 ha
Waterlogged area: Nil

IRS LISS II October 1995
Cropped area: 57208 ha
Waterlogged area: 6885 ha

Figure 3. Impact of IGNP: increase in cropped area (red tone) and increase in water logged area (black and bluish tone) in October, 1995 image as compared to October, 1975 image.

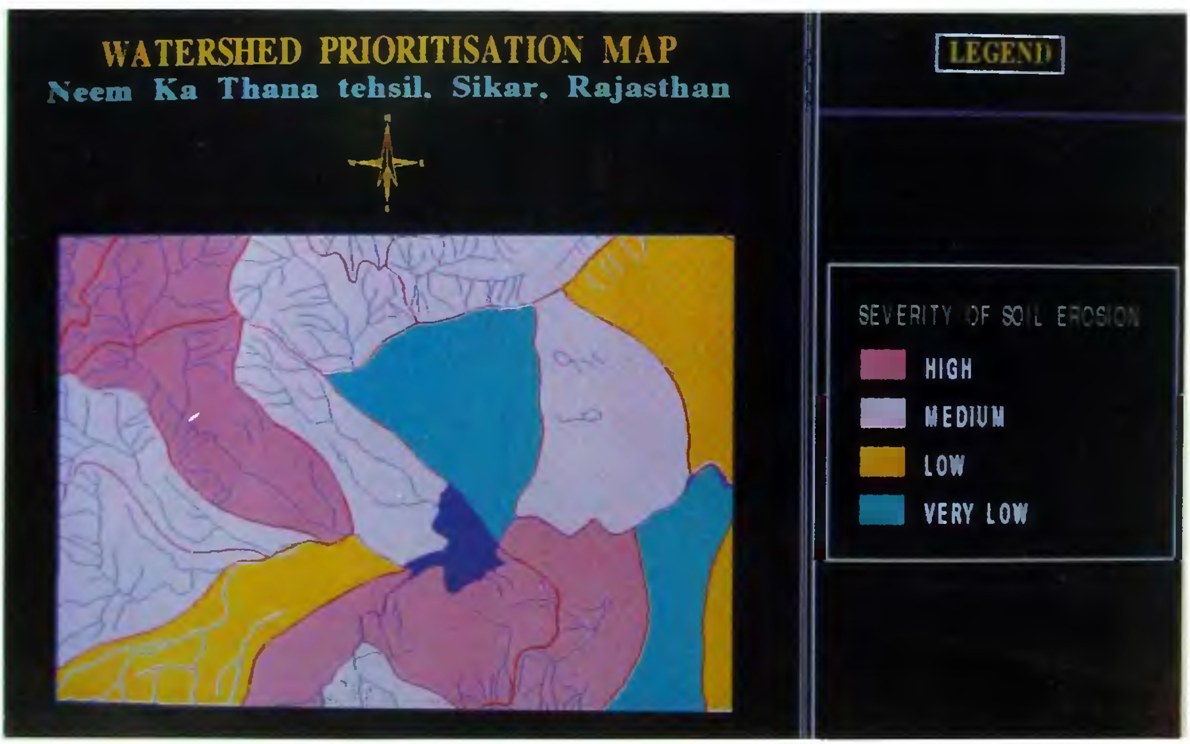


Figure 4. Watershed prioritization map showing severity of soil erosion in Neem ka Thana tehsil, Sikar district, Rajasthan.

made to explore potentials of radar (ERS-1 SAR) data in identification and mapping of buried channel and relict valleys near Jaisalmer for groundwater prospecting. Also a synergistic methodology of integrating optical with microwave data to reconstruct the palaeo drainage network of western Rajasthan is being attempted.

To sustain the groundwater potential it is essential to recharge the groundwater. The recharge is achieved primarily by three methods, viz. i) spreading, ii) induced recharge, iii) injection. Remote sensing provides useful inputs for siting various recharge structures, through thematic maps on hydrogeomorphology, land use/cover, surface water bodies, slope, etc. The main guiding factor is location of a permeable zone. Some of the indicators, which can be deciphered from the remote sensing images, are crossing zones of dykes over streams, low drainage density, higher lineaments intensity, confluence of channels, valley fills, palaeochannels, etc.

Drought assessment and monitoring

Drought in western Rajasthan is a regular phenomenon. Generally, mild and moderate agricultural drought occurs in the entire region, while the Jaisalmer region experiences severe drought conditions. The climatologists have estimated that the drought occurrence probability in western Rajasthan is less than 20%, implying that, on an average, one in every five years is expected to have large rainfall deficit. The sand and dust movements generally assume serious proportions in the years following the drought year, when the vegetation cover is minimum. Sand flux rates of up to 150 kg per square meter are common during the peak of dust storm activity. Generally May and June are the periods of strong wind when sand movement causes problems for human settlements and transportation networks. The average wind speed during June is more than 25 kmph in the western part, while in the eastern part it is between 10 and 15 kmph. These natural climatological conditions have impact on acute water shortage and land degradation.

Satellite data has proved to be extremely useful in monitoring drought. Starting from mid 1989, the National Remote Sensing Agency (NRSA) has been issuing fortnightly drought bulletins based on the analysis of the NOAA–AVHRR data for the entire country including Rajasthan. The bulletin contains maps on vegetation index, comparative greenness and district-wise assessment of the drought like normal, mild, moderate or severe. In the present day context IRS-1C data with high spectral/spatial resolution can even provide village level severity assessment and thereby determine the quantum of relief assistance and crop insurance.

Advancement of desert

The western Rajasthan suffers from destabilization of dune systems due to high wind erosion, excessive grazing by livestock and cattle coupled with other activities like road building, canal excavation, quarrying, ploughing besides deforestation. It is estimated that nearly one third of the cultivated lands is severely affected by the problem of sand drift, while another one-fourth is moderately affected. The mean soil loss in the deeply ploughed fields for example in an unusually windy year of 1985 was estimated to be 2837 tonnes/ha (ref. 1). The spread of desert towards east and north east has endangered the productivity and fertility of soil cover. A regular monitoring is therefore required for the above activities so that suitable remedial measures can be suggested.

Change detection on the fringe of the desert region in Rajasthan has been carried out using multi temporal satellite data and digital analysis techniques. This has brought out that the desert is spreading through something like twelve large size gaps in the central and northern Aravalli hill ranges. This study thus speculates that an area of about 160 km^2 every year is engulfed by the advancing desert. Measures to check the spread of desert have been suggested[2].

Under a joint study by CAZRI and RRSSC, Jodhpur a number of sites have been studied to identify the stability of sand dunes using multi-temporal satellite data which causes shifting of sand.

Grassland inventory and monitoring

The region receiving mean annual rainfall of 200 mm and less is incapable of supporting agriculture on its own. It can sustain animals on its natural vegetation comprising of shrubs and grasses. Animal husbandry replaces agriculture in this region, which is crucial to the economy of the region. Therefore, the natural grasslands are one of the most precious natural resources. Amongst the other grasses, Sewan (*Lasiurus sindicus*) is the dominant perennial grass. There are nearly six million ha of Sewan-dominated open pasture lands. These grasslands are being degraded either due to impoverishment of the useful species or indiscriminate grazing. Nearly 24 and 44% of the pasturelands are in desertified and highly degraded states respectively.

Satellite data have been used to carry out inventory and monitoring of the areas under Sewan grass. Using multi temporal IRS LISS-II data of 1988 and 1989 and image differencing techniques, areas under four categories of Sewan grasslands in Jaisalmer, Bikaner and parts of Jodhpur district could be estimated and a reliable inventory of this crucial resource could be made.

Locust warning and surveillance

Locust breeding is one of the major problems in western

Rajasthan as it poses threat to the standing agricultural crops and plantations. Moist sandy soil of the desert and flush of desert vegetation during monsoon creates optimal conditions for fast locust breeding and development.

In the later part of 1989 there was a sudden build up of locust swarms from Pakistan to India. The Locust Warning Organization of the Directorate of Plant Protection, Govt of India used IRS and NOAA data to generate five green biomass levels within the sparse desert vegetation. Multidate imagery helped to monitor and launch selective control measures in an area of 200,000 km^2 (ref. 3).

Land degradation *vis-à-vis* IGNP

In the canal command area under Indira Gandhi Nahar Pariyojana (IGNP), Stage I a mean rise in water table of more than one metre per year has been recorded. This is leading to the problem of land degradation as the productive land is getting converted into water-logged and salt-affected areas.

Environmental impact of the Indira Gandhi Canal in the command area has been monitored using multidate IRS LISS II and NOAA–AVHRR data. The analysis of satellite data helped in monitoring land use changes, mapping and assessing the progress of afforestation programme along the canal network, monitoring the extent of waterlogged areas, inventory of irrigated crop, assessing crop water demand and monitoring crop growth patterns. Figure 3 shows the Rawatsar area satellite imagery of October 1975 and October 1995. The distinct red colour in October 1995 image clearly depicts increased cropped area as compared to October 1975 image. The waterlogged areas are seen in 1995 image as black and bluish patches. The cropped area has increased by more than 50% from 1975 to 1995. However, waterlogged area has also increased due to excess irrigation and poor drainage. Thus remote sensing can be used to monitor the change during every cropping season and the information is vital for proper land use planning and corrective measures to be taken.

Wasteland inventory

Large areas in the arid region are under wasteland category. The development of wastelands not only helps in improving the land productivity and socio-economic conditions of the region but also helps in re-establishing the ecological balance.

Under the National Wasteland Mapping Project, wasteland mapping at 1 : 50,000 scale using Landsat TM data has been carried out for three districts namely Churu, Jodhpur and Pali. Various categories of wasteland like gullied/ravinous land, upland with or without scrub, land affected by salinity/alkalinity, sandy areas, mining-industrial wasteland, under-utilized/degraded notified forest land, degraded pastures/grazing land, barren rocky/stony wastes/sheet-rock areas, and steep sloping areas have been mapped. It has been estimated that about 60.9, 30.6 and 26.6% of the total area of Churu, Jodhpur and Pali districts respectively is under wasteland. Depending upon the nature of the wasteland categories at village level, reclamation measures have been suggested.

Soil erosion studies

Soil erosion seriously affects the productivity of land. Life of a reservoir is dependent on the soil erosion in the catchment areas. It is essential to characterize the watershed according to intensity of erosion-prone areas, so that soil conservation measures can be taken on priority in those areas which are highly prone to erosion. For this purpose thematic maps such as land use/cover, geomorphology, slope and soil are prepared using remote sensing and conventional data. Integrating these maps and suitable models, it is possible to categorize watersheds into various severities of erosion. A classified image showing severity of soil erosion for Neem Ka Thanna tehsil of Sikar district is shown in Figure 4. High priority watersheds, shown in pink colour, represent hilly areas having steep slopes and degraded forest lands. Similar work has also been carried out for Kishanganj, Shahbad, Devli and Nadoti blocks of Baran, Tonk and Sawai Madhapur districts respectively.

Agroclimatic-zone based land use planning

A systematic district-wise land use mapping on 1 : 250,000 scale has been carried out using IRS LISS-I data. These maps show Level I and II categories. Using two-date imagery, acreages under kharif and rabi crops have been estimated. The information thus generated is being extensively used for agroclimatic-zone based land use planning. Presently 49.4% of the total area is under cultivation, 35.5% area is under cultivable wastes and fallow lands, 4.1% area is under permanent pasture, 1.8% area is under forest and 9.2% area is either barren or settlement[1].

Mineral prospecting

The occurrence of minerals is not random, i.e. mineralization is always confined to specific geological environments and various guides for mineral prospecting are utilized. Satellite data indicates, for e.g., i) zones of crustal weakness, e.g. faults, fractures, joints, folds, shear zones, etc. which serve as passage ways for mineralizing solutions, ii) tonal anomalies – alteration zones, vegetation anomalies, etc. and, iii) major rocks types and landforms.

Important industrial minerals and rocks occurring in the western Rajasthan are the building stones (like marble, limestone, sandstone and granite), limestones of cement, flux and chemical grades, various types of clays for ceramics, common salt, bentonite and Fuller's earth, gypsum/gypsite and phosphorite, lignite and wolframite.

Although there has been limited use of satellite data for mineral exploration it has been observed that gypsite (earthy porous gypsum aggregate with sand, clay and calcareous matrix) occurs in low-lying playa deposits and in palaeochannels, which can be mapped using satellite data. Rajasthan accounts for about 90% of the total production of gypsum in the country. In the western parts of the Jaisalmer district the Khuiala and Bandah limestone deposits occur. It has been estimated that about 2500 million tonnes of chemical and flux grade limestone occurs in the region. In this region recently ERS-1 SAR data could detect shallow sand buried limestone deposits. The structural and geomorphological information in the Jaisalmer district has provided useful clues to the oil and natural gas exploration.

Integrated mission for sustainable development

Realizing the importance of adopting an integrated approach, and recognizing the mutual inter-dependencies of natural resources, the Department of Space, at the behest of the Planning Commission, Govt of India has taken up a major programme 'Integrated Mission for Sustainable Development (IMSD)', along with various state and central government agencies. Participation of voluntary agencies and the local people is an important component of this programme. Under this mission, it is proposed to undertake remote sensing-based integrated land and water resources studies for 174 problem districts of the country. The major goal of this mission is to generate locale-specific plans by integrating natural resources information generated from satellite data in conjunction with socio-economic data to meet the needs of the local people for sustainable development of the region. The goal when translated into executable tasks results in the following:

i) Analysis of socio-economic, demographic data of the region to find the felt/perceived development needs of the region.
ii) To generate various thematic maps on natural resources and integrate them to identify homogeneous units of land parcels for suggesting measures for soil conservation, water resources development, agriculture/horticulture, and fodder development.
iii) To critically assess the existing infrastructure of the region and to arrive at development schemes (suitable sites for location, alternate strategies, etc.).

The Regional Remote Sensing Service Centre (RRSSC), Jodhpur along with State Remote Sensing Applications Centre (SRSAC), Central Arid Zone Research Institute (CAZRI), and other Non-Government Organizations (NGOs), is carrying out IMSD studies in ten districts, viz. Barmer, Bikaner, Churu, Nagaur, Jalore, Jaisalmer, Jhunjhunun, Jodhpur, Sriganganagar, Sikar and Pali of western Rajasthan and Jaipur, Dausa, Ajmer, Bharatpur, Sawai Madhopur, Banswara, Dungarpur in east and south Rajasthan. Besides this, eleven blocks under special IMSD study have been completed. These are Kishanganj, Shahbad, Ramganj, Mandi, Sangod, Kherwara, Garhi, Nadoti, Devli, Dag, Dungarpur and Masuda.

Indian Remote Sensing Programme

Indian Space Research Organization (ISRO) successfully developed and launched the operational first generation remote sensing satellite IRS-1A in March 1988 and the follow-on IRS 1B in August 1991. These satellites carried two imaging payloads operating in four bands in the 0.45–0.86 μm region. One of the payloads (LISS-I) has the geometric resolution of 72.5 m and a swath of 148.48 km and the other camera LISS-II has a geometric resolution of 36.25 m. Two LISS-II cameras were displaced laterally so as to provide a combined swath of 145.48 km with an overlap of 3 km (ref. 4). A third operational remote sensing satellite IRS-P2 was launched in October 1994 using the Polar Satellite Launch Vehicle (PSLV) developed by ISRO. IRS-P2 carried a modified LISS-II camera.

Data from these remote sensing satellites have been extensively used for various applications towards national development. Starting from field experiments to district level studies, currently a number of projects are being carried out covering the entire/most part of the country on an operational mode. Groundwater targetting, Regional Geological Mapping, Flood Mapping, Forest Mapping, Land Cover Mapping, Wasteland Mapping, Snow Area Mapping, Crop Production Estimation, Watershed Characterization, Coastal Zone Mapping, etc. are some of the national level projects taken up. These have been taken up in 'mission-mode' under the umbrella of a programme called Remote Sensing Applications Mission (RSAM). The Integrated Mission for Sustainable Development (IMSD), wherein various themes using remote sensing and socio-economic and other data are integrated to find out optimum developmental plan opens new vistas to apply remote sensing technology for practical application.

The IRS-1C launched in December 1995 carries three distinct and mutually complementing imaging payloads which enhance the capabilities of IRS-1C as compared to IRS-1A/1B in terms of spatial, spectral and temporal resolutions. Another remote sensing satellite IRS-P3 was launched on March 1996 with PSLV carrying a Wide Field Sensor similar to IRS-1C, with an additional band in SWIR and an ocean colour monitor, developed by DLR (Germany) for earth observation.

The IRS-1C has a PAN camera with 5.8 m resolution, a multispectral camera (LISS-III) with 23.5 m resolution in visible and near infrared region and 70.5 m in the shortwave infrared region. The PAN camera covers a ground swath of 70 km which is steerable up to ±26° from nadir in the across track direction. This off-nadir viewing provides the capability to acquire stereoscopic pairs from two different orbits and an ability to revisit any given site with a maximum delay of five days. Currently the IRS-1C, PAN camera is the highest spatial resolution civilian earth observation system.

A Wide Field camera (WiFS) has a spatial resolution of 188 m and covers a swath of 804 km. This wide swath coverage results in a repeatable observation of the same ground location after every 5 days. The WiFS operates in the B3 and B4 spectral bands of LISS-III.

Application potential of IRS-1C

The payloads of IRS-1C complementing each other for earth viewing have immense application potential which was hitherto not possible. Some of the unique advantages from the applications point of view are:

- Monitoring vegetation, snow and water body more frequently (5 days) and mapping them at regional scale
- Improved identification/discrimination of vegetation types/crops in view of higher spatial resolution (VNIR 23 m) and SWIR band
- Moisture stress detection especially by the use of SWIR band
- Large scale mapping using merged LISS-III and PAN data
- Stereo capability and frequent viewing using PAN
- Availability of data at different spatial resolutions from a single platform (acquired simultaneously) suitable for multistage/sampling approach.

Using the data available so far from IRS-1C, a host of applications have been demonstrated.

Future Indian Remote Sensing Satellites

IRS-1B, IRS-P2, IRS-P3 and IRS-1C are presently in use providing information on earth resources to various user agencies on an operational basis. IRS-1D, which is similar to IRS-1C, is planned to be launched in 1997. Other approved space systems for future include Oceansat-1 carrying an ocean colour monitor and a multifrequency radiometer, a cartographic satellite with fore and aft viewing with about 2.5 m resolution and a satellite system tuned to meet many of the needs for agricultural applications.

Future systems being conceived include Oceansat-2 carrying various sensors for ocean applications such as scatterometer, altimeter and radiometer, satellites for climate studies and high resolution imaging systems for updation of large scale maps.

All these missions providing data at higher spatial and temporal resolutions along with the technological advances made in processing and modelling techniques including GIS should be revolutionizing the field of remote sensing applications in the country. It is for us, the user community of scientists, policy and decision makers, planners and implementation level officers of various government and non-government agencies to make full use of this opportunity for national development.

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