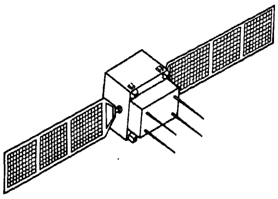


Special Issue on:
Remote Sensing for National Development

Remote Sensing for National Development

U. R. Rao

Introduction

The phenomenal developments in science and technology, which have taken place in India since independence, is the direct outcome of the major Science Policy Resolution adopted in 1958, the credit for which rightly belongs to Pandit Jawaharlal Nehru, who expressed his basic faith that: "Science alone could solve the problem of hunger and poverty, insanitation and illiteracy, of superstition and deadening custom and tradition, of vast resources running to waste, of a rich country inherited by starving people". One of the most significant outcomes of this scientific approach has been the initiation of the green revolution in the sixties which enabled India to become self-sufficient in food, raising India's annual food production from a mere 55 m tonnes in 1950 to 172 m tonnes, and thus meeting the minimal requirements of its citizens. While a part of the increase in food production is due to large scale irrigation of over 45 m ha of land, the post-green revolution productivity growth rate of 3 per cent a year, double that during the pre-green revolution, has been responsible for this dramatic change. High yielding wheat varieties in Punjab and Haryana, for example, today produce 55 m tonnes of wheat from just 23 m ha of land; almost a three fold increase compared to the pre-green revolution era.

The phenomenal population growth from 350 m to 850 m since Independence in the country and non-optimal management of our land and water resources have completely eroded whatever gains that have been achieved from the green revolution and operation flood. At the present growth rate, the population in India is expected to reach a billion by the turn of this century, demanding over 225 m tonnes of food grain production, which calls for a 6 per cent annual growth rate, double that achieved during the green revolution period. The limited land of about 0.17 ha per capita available for agricultural production is already getting degraded because of non-optimal agricultural practices being followed. Of the 154 m ha of agricultural land, 100 m ha of rainfed area contribute just about 40 per cent of the total food production, which is further subject to vagaries of the monsoon. The extreme pressure on land has already led to large scale depletion of forests with the result that the closed forests in the country have reduced from 14 per cent to 11 per cent of India's total area in less than a decade. Space imagery have clearly shown the extent of salinity in large parts of the country, particularly along the irrigated areas of the Indo-Gangetic plain resulting from soil mismanagement, indiscriminate use of fertilizers and inadequate drainage mechanism. As a result, U.P. and Bihar, for example, which account for about 50 per cent of the total sugarcane cultivation area with a yield of just about 40 tonnes/ha, contribute practically the same as the sugar output from half that area in Karnataka, Tamil Nadu and Maharashtra with a sugarcane productivity of about 90 tonnes/ha. In the estimate of Mr. Lester Brown, the world is losing 14 m tonnes of food grain every year because of land degradation; the bulk of which is in the developing countries like India.

Mismanagement of water resources in India, a country which receives a bountiful amount of annual rain of about 130 cm/year, has assumed such alarming proportions that underground water table in many areas of the country is depleting at a rate faster than 10 metres/year, because of lack of any viable recharging mechanism. In spite of the green revolution, the crop yield in India is one of the lowest in the world; the national average being about 1.7 tonnes/ha as against a world average of 3.2 tonnes/ha for rice and 2.2 tonnes/ha as against a world average of 3.7 tonnes/ha for wheat. The average total food grain production in India is just about 1.6 tonnes/ha as against a world average of 2.5 tonnes/ha and 4.3 tonnes/ha, achieved in Europe.

While one out of every two persons has access to a telephone in the developed society, even in metropolitan cities of India, the available communication facility is less than one for every 100. The picture in the rural areas is even more dismal with over 2,000 persons having to compete for access to a single telephone. In spite of the large increase in the number of universities and colleges, over 30 per cent of our population will remain illiterate even by the year 2000, unless we tackle the problem of illiteracy on a war footing. It is shocking to note that almost 6 million children, over 40 per cent of global infantile mortality rate, die every year in just three countries – India, Pakistan and Bangladesh – and almost seven times this number continue to suffer from malnutrition. The available per capita food consumption in India, even today, is just about 450 grams per day; the energy consumption is less than a thirtieth of that in the USA and the per capita annual income is just about $ 550 as against over $ 12,000 in the USA. The promise of benefits from the spectacular advances in science and technology still eludes the majority of our people, whose aspirations for a better and richer life remain unfulfilled. It is clear that with the exponentially growing population and shrinking resources, unless drastic steps are taken to harness the bounty of science and technology to leap frog, millions of citizens in India will continue to be plagued with the problems of malnutrition, hunger, illiteracy, lack of resources, inadequate health care and an abysmally low standard of living.

Need for sustainable integrated development

Continued achievement of self-sufficiency in food and water resources in the wake of the large population growth demands application of the most optimal technologies for achieving sustainable development. While dry land farming has to be improved substantially, the fate of the irrigated areas in the country is no better, because of the poor soil management resulting in waterlogging and salinity. Large scale deforestation, poor watershed management, unhealthy industrial practices and indiscriminate building of large dams are already causing not only great hardships to millions of our population, but also irreversibly changing our ecology and climate in a perceptible way. Large scale emission of green house gases such as carbondioxide, CFCs and methane into the atmosphere, largely due to anthropogenic activities in the developed countries and intensive deforestation of tropical forests have led the entire world to the brink of disaster. The solution lies in utilising the best technological tools available to achieve sustainable and integrated development, to meet the immediate needs of the present and the growing demands of the future generations, ensuring the conservation of ecological and natural environment.

The first step in the formulation of any environmentally sustainable development programme is to address existing development strategy, examine lacuna in the present system of implementation and identify viable alternatives. It calls for preparing an exhaustive data base on the natural resources and identifying priorities of development for the region in order to work out a developmental plan. It also calls for understanding the mutual inter-dependencies of various resources (both renewable and non-renewable) and providing necessary inputs for developing a cost-effective, energy-efficient and environmentally benign management system. The existing conventional system of data collection and analysis has limitations, because the inter-dependencies of the natural resources are not taken into consideration. The optimal exploitation of the resources with proper enriching mechanism calls for cutting across the narrow confines of sectoral approaches and taking a holistic view of the region as a whole.

Space technology

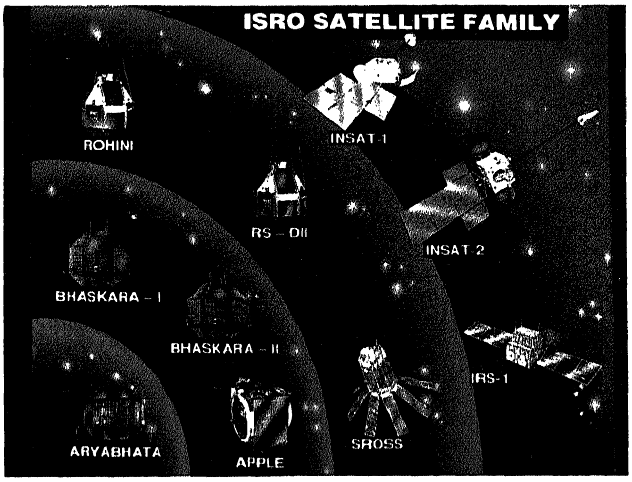
The remarkable developments in space technology and its applications during the last three decades have firmly established its immense potential for transforming the life style of the human society as a whole. The direct benefits from this technology to the vital sectors of human life cycle, particularly in providing unique solutions for achieving global communication even into remote areas and mobile platforms, for keeping a close weather watch, and in the conservation, monitoring and management of natural resources, have already significantly contributed to the development of human society. The ability of space technology for obtaining systematic, synoptic, rapid and repetitive coverage in different windows of the electromagnetic spectrum, and over large areas from its vantage point in space is the fundamental character which makes this technology unique and powerful for solving basic problems related to communications, weather prediction and management of natural resources.

Availability of high resolution (20–30 m) multispectral imagery from satellite remote sensing with a repetitive cycle of about 18–22 days over the same areas of interest has virtually revolutionised the resource monitoring and management system. Backed up by adequate ground truths and aerial photography, space remote sensing has fully established its potential to provide vital inputs to the monitoring of our basic natural resources, such as agriculture, forestry, water resources and also in soil classification, mineral exploration, wasteland delineation, ocean resource monitoring and drought management. The advent of active microwave remote sensing has provided another quantum jump in remote sensing capability due to its ability to critically look at ocean resources and, more importantly, due to its unimpaired penetration through cloud cover to provide all weather capability to remote sensing. Rapid advances in computer technology and data handling capability combined with advances in sensor technology have resulted in the realisation of progressively increasing onboard resolution and reducing the turn around time for data handling, crucial for dealing with disaster forecast and disaster management situations.

BEGINNING OF SPACE REMOTE SENSING IN INDIA

Firmly convinced of the potential of space remote sensing for achieving rapid development, in the agrarian sector in particular, ISRO initiated its remote sensing effort in the late 60s with aerial survey using multi-data instruments and aircraft carrying a variety of sensors, such as infrared scanners, multispectral scanners and radiometers for monitoring the health and yields of crops, such as coconut plantation in Kerala and sugarcane in Mandya. Extensive aerial surveys were carried out, backed up by ground truth measurements, to carry out soil studies and land use studies in Anantapur, Patiala and other selected areas. Water pollution of the Godavari river and of a number of lakes caused by anthropogenic industrial activities and deforestation leading to silting of reservoirs are some of the other major studies conducted using multispectral aerial photography. The establishment of the Landsat receiving station at NRSA, Hyderabad in 1979 was an important step taken by ISRO in the use of satellite-based remote sensing, which provided scientists from ISRO and other user agencies an opportunity to gain valuable experience in the interpretation and analysis of space-based data.

Envisaging the need for parallel development of our own space segment and following the successful launch of Aryabhata in 1975, Bhaskara 1 and 2 satellites incorporating a two band TV camera system, one in the visible and the other in the near infrared, along with a three frequency passive microwave radiometer system, were launched in 1979 and 1981, respectively using Soviet rocket carriers to carry out remote sensing on an experimental basis. Whereas microwave data was primarily used for studying ocean and atmosphere related aspects, the TV imagery, in spite of their limited resolution of about 1 km, were usefully employed for studying resources related to forestry, hydrology, large water and land masses. These satellite images have been utilised to study the snow melt run-off from Himalaya, forest resources including moist deciduous and dry temperate forest covers, silting in Cambay and Sundarbans and geological features in the Deccan trap region.



A number of joint experiment projects in remote sensing undertaken by the Department of Space along with user Departments/Agencies covering different fields, such as water, soil, agriculture, forest, ocean, minerals, etc., successfully demonstrated the potential of satellite-based remote sensing for the development of the country. Closely following these successes, a National Natural Resources Management System (NNRMS), with Department of Space as its nodal agency, was set up to derive the benefits from space remote sensing on a nationwide basis.

ERA OF OPERATIONAL REMOTE SENSING IN INDIA

Based on the clear appreciation that large scale benefits can accrue to a large country like India, only when we have our own Space segment specially tailored to meet our requirements, ISRO conceived of dedicated remote sensing satellite series which can provide uninterrupted, and assured operational services. The successful launch and commissioning in March 1988, of the indigenous, state-of-the-art, Indian

Remote Sensing Satellite, IRS-1A, the first in the series of such satellites, was a major milestone for the operationalisation of remote sensing services in the country. In over three years of its operation in Space, IRS-1A has demonstrated its unquestionable importance in the national development, having become the mainstay of NNRMS. IRS-1A imaging sensors – Linear Imaging Self Scanners (LISS-I and LISS-IIA and LISS-IIB) – were selected based on specific application needs of the users, adopting state-of-the-art technology and with scope for future growth. The 975 kg satellite, placed in a 904 km polar sun-synchronous orbit with an orbital period of 103 minutes, crosses the equator at 10:25 hours local time and returns to its original orbital trace every 22 days enabling repetitive collection of data over the same area at the same local time.

Since its launch into orbit, IRS-1A has covered India more than 55 times and beamed about 3.5 lakh high quality imagery which have been effectively put to different applications. The imageries are comparable in quality to those obtained from the French SPOT and the American LANDSAT satellites, demonstrating the Indian capability for building and operating state-of-the-art remote sensing system, both space and ground segments.

REMOTE SENSING FOR NATIONAL DEVELOPMENT

The Indian space programme has made great strides in using the sophisticated remote sensing technology to maximally benefit the grass-roots of the nation in a timely and cost-effective manner. Even with the relatively modest investment made so far, the nation has established a self-reliant base in this technology, which is now playing a crucial role in the management of natural resources. India is one of the very few countries to have its own indigenous operational space and ground segment as well as necessary expertise and infrastructure for implementing various remote sensing application projects.

Remote sensing applications in India, under the umbrella of the National Natural Resources Management System (NNRMS) for which the Department of Space is the nodal agency, now cover diverse fields such as agricultural crop acreage and yield estimation, drought warning and assessment, flood control and damage assessment, land use/land cover mapping for agro-climatic planning, wasteland management, water resources management, ocean/marine resource survey and management, urban development, mineral prospecting, forest resources survey and management, etc., thus touching almost all facets of national development. Active involvement of the user Ministries/Departments, both Central and State, has ensured effective harnessing of this powerful technology in solving problems of relevance to the country.

Agriculture

Agriculture, on which over 75 per cent of the country's population depend upon, has been given utmost importance in the Indian remote sensing effort.

Remote sensing is being operationally used to predict crop acreage and yield estimate of wheat, rice and sorghum at the national level. It is being expanded to cover other major crops in the country. Crop acreage and condition assessment for important commercial crops like oil seeds, cotton and mulberry are being provided. Timely information on the production of major crops will greatly assist in taking policy decisions like level of buffer stock, imports, fixing of support prices, etc.

Methodologies are being developed for using remote sensing data for timely detection of pests and diseases as well as for assessing crop stress conditions. Department of Agriculture and Cooperation has sponsored a joint project for developing a number of remote sensing applications in various areas of agriculture.

Drought Management

Satellite data is providing advance information at tehsil/ district level on the extent and severity of agricultural drought conditions. Fortnightly drought assessment bulletins for 12 states are now being issued on a regular basis. This information is made available to all the district authorities and agricultural resources planners on near realtime basis. Such bulletins which have proved to be extremely useful in drought management are being extended to cover all states. Department of Agriculture and Cooperation has sponsored a national level drought monitoring and assessment project.

Integrated land and water resources management to combat drought on long and short term basis in the drought-prone districts of the country has been initiated. In the first phase, 16 districts from 12 states have been taken up. After successfully operationalising the pilot experiment, the approach would be extended to benefit about 250 districts in the country which are drought-prone. This programme will provide long term solutions for conservation of soil and water resources towards mitigating drought.

Forest Management

Satellite remote sensing is playing an important role in the survey and monitoring of forests. Large areas marked as forests in 1970s vintage maps hardly have any trees left due to the immense pressure on land. This naturally causes degradation of the total environment. It was observed, from forest maps prepared using remote sensing data, that in just eight years since 1974, India's closed forest cover had fallen from 14 per cent to only 11 per cent of the total land area. This is against 30 per cent regarded as a minimum desirable by ecologists. The amount of area deforested during this period alone is about twice that of the entire state of Kerala. Even in the comparatively greener state of Maharashtra, almost 10 per cent of the forest cover, totalling 2 lakh hectares, has been lost in just last two decades.

Forest Survey of India is now carrying out on an operational basis, biennial forest mapping for the entire country using satellite remote sensing data. New techniques for forest density and volume estimation are also being developed.

Wasteland Mapping

About 20 per cent of India's land area is considered as wasteland due to salinity of soil caused by excessive use of fertilisers, improper irrigation procedures, degradation due to the prolonged agricultural usage, use of slash and burn clearance techniques and due the to the spread of desert. Recent satellite data have shown that about 45,000 sq. km, covering 13 of the 17 districts in the Aravalli hills region, have already become wasteland.

Under the aegis of National Wasteland Development Board, a project was taken up for wasteland mapping of 146 critically affected districts in India. Twenty State/Central agencies were involved to carry out this nationwide wasteland mapping. Detailed satellite mapping of wasteland has helped in identifying thirteen recognisable wasteland categories; almost half of which, with some efforts, can be reclaimed for agricultural production. Using geographical information system, land use/wasteland information derived from satellite data is being used to generate comprehensive solutions towards reclamation of wastelands. Work on wasteland mapping for an additional 80 districts has also been taken up. Considering that almost half of the wasteland in India which amounts to about 25 m hectares can be reclaimed for productive use with appropriate agricultural practices, the delineation of the extent and type of recoverable and non-recoverable wasteland at micro level, from space imageries assures a great importance.

Ground Water Potential Mapping

The national drinking water mission, initiated in 1987, aims to bring adequate potable water to every one of India's 6,00,000 villages. Under this mission, the hydrogeomorphological maps, generated using satellite remote sensing data, are being extensively used for locating borewells. Mapping on 1:50,000 scale has been completed for about 1,60,000 villages which have acute shortage of drinking water. It is for the first time that the entire country, covering 447 districts, has been mapped on a 1:250,000 scale for an important resource like ground water. They serve as the starting point for identifying underground aquifer for providing basic drinking water to rural population.

Success rates of 88 to 95 per cent has been achieved for striking ground water using satellite data compared to about 45 per cent success rate achieved using only conventional water location procedures.

Snow-melt Runoff Estimates

Specific models have been developed for the Sutlej and Beas river basins to map seasonal snow cover areas and to estimate the snow-melt runoff during the summer seasons. These estimates are provided three to four months in advance of the actual runoff period and are accurate to within ±4 per cent of the actual runoffs. The estimates have been utilised for optimising the use of water for power and irrigation.

Surface Water Mapping and Monitoring of Major Reservoirs

Remote sensing data are being used for identification and prioritisation of erosion prone areas in various watersheds as well as to provide inputs for undertaking desiltation plans. Monitoring of seasonal changes in the volume of major reservoirs and agricultural crops in their command areas is being carried out to draw suitable plans for optimum utilisation of water for irrigation and other uses.

Flood Management

Satellite remote sensing data are being successfully used for obtaining real-time information on areas affected by major floods and to take up rehabilitation measures. Quantitative estimation of the flood damage to infrastructure and crop losses are also provided. Various departments in the Ministry of Water Resources and Central Water Commission are using these data. IRS-1A imagery provided objective assessment of the severity of the damage during the cyclone that hit the Andhra coast in May 1990 and the imagery was successfully used for assessing crop damages. Methodologies are also being developed for flood prediction and control including identification of flood risk zones, river migration and training courses, embankments, water-shed prioritisation, etc.

Mineral Survey

Geological Survey of India has taken up a joint project with the Department of Space, namely, Vasundhara, which envisages an integral appraisal of data from satellite remote sensing, air-borne geophysics and ground geological, geophysical and geochemical data for mineral prospecting on a regional scale. An area of 4,00,000 sq. km of south India, which envelops a wide geological column from Archaean to Recent, consisting mainly of granulites, granite-greenstones and Proterozoic basins has been covered under the project. A Geographical Information System is being developed for creation of digital cartographic data-base and geostatistical models.

Mapping of underground coal fires is being carried out for major coal fires in the Jharia-Raniganj area to provide inputs for capping of mines and prevention of further fire spread. Also, mapping of major mines and their environs is helping in arriving at suitable protection plans needed to overcome the effects of mining on environment.

Urban Sprawl Mapping

Simultaneously with the shrinking of India's forest cover, concrete structures are mushrooming everywhere. While land-starved Bombay has become an ecological disaster, some of the other cities are only marginally better off. Through digital analysis of satellite data, land use and urban sprawl maps for Bombay, Calcutta, Madras and Ahmedabad have been prepared. Land use maps for Hyderabad, Delhi, Lucknow and Jaipur have also been drawn. The need for a vigorous follow up action for many of the major Indian cities has been emphasised through these maps. A specific example of how satellite-based remote sensing data can be used for city planning was demonstrated recently by conducting a survey for aligning the proposed ring road for Bangalore Development Authority using satellite and ground based data.

Coastal and Ocean Resources Survey

Remote sensing technology has considerable potential in monitoring of coastal resources such as mangroves, estuaries and other land forms. The technology can also enable understanding of erosion and accretion processes in the coastal areas. Under a coastal management project, a coastal map of the country's entire coastline on a 1:250,000 scale has been prepared. Identification of brackish water and water bodies suitable for inland fisheries has also been carried out.

The farming of ocean resources is a field where India, like most of the other developing countries, is lagging. For a country with a coastline of over 7,000 km, the annual fish catch is less than 2 million tonnes. With about 15 per cent of the world's population, India has only about 2 per cent of the catch. Using satellite data, methodologies for identification of areas rich in fish through the estimation of phytoplankton density and ocean temperature distribution have been developed. Forecasts on fish school location are now broadcast on All India Radio to enable fishermen in coastal regions to go for fishing in these areas.

Specific experiments towards obtaining various parameters related to surface waters, wind swells, internal waves, etc., have been carried out using data from microwave satellites.

Department of Ocean Development has instituted a major National level project for use of remote sensing for ocean development.

Land use Mapping for Agro-climatic Zonal Planning

Information on land use/land cover in terms of maps and statistical data is very vital for spatial planning, management and utilisation of land for agriculture, forestry, urban/industrial environmental studies, etc. Realising the need for an up-to-date nationwide land use/land cover maps by several departments in the country, Planning Commission has approved the nationwide land use/land cover mapping for agro-climatic zonal planning. Under this National Project, mapping of the whole country identifying 24 land use categories on 1:250,000 scale, using both visual and digital interpretation techniques, is nearing completion.

Integrated Development

A unique area where satellite remote sensing can be effectively utilised for resource management is in surveys for integrated development planning at manageable administrative units like village, tehsil and district, involving a number of resource disciplines. It is ideally suited to bring out the inter-relationships of various disciplines. These surveys involve preparation of a set of resource maps using remotely sensed data, such as surface water bodies, ground water potential zones, zones requiring ground water recharge, types of soil, salinity/ alkalinity and erosion status, existing land use and distribution of wastelands, etc. Based on these maps, an integrated land and water resource map, highlighting priority areas for agriculture development, fuel and fodder development, soil conservation and afforestation, etc., is prepared for arriving at a package of practices and strategies to address the local problems at the village/tehsil/district level.

Making use of such surveys, strategies can thus be worked out for ensuring allround development of vast rural areas of the country without upsetting the ecological balance.

Natural Resources Information System (NRIS)

Under NRIS, it is planned to develop digital data base on all natural resources at various levels of decision making, namely, tehsil, district, state and central levels, specifically highlighting information essential for the strategic, tactical and operational level planning. The system will contain information on all the natural resources, such as forests, crops, wastelands, land use, minerals, water resources, geology, soils, etc., besides the topography and other terrain conditions. While remote sensing derived information on these resources may form the major inputs, the socio-economic indicators will be added to the information in the form of Geographical Information System (GIS).

REMOTE SENSING SERVICES

Towards providing appropriate facilities for the users in the country for digital analysis and interpretation, five Regional Remote Sensing Service Centres (RRSSCs) have been set up by the Department of Space in collaboration with major user departments. These RRSSCs are located at Bangalore, Dehra Dun, Jodhpur, Nagpur and Kharagpur. They have data processing computer facilities with image processing functions. Multiuser terminals have been provided to facilitate several users to utilise the facilities at a time. The RRSSCs are also provided with Interactive Intelligent Image Graphics Display Terminals (IIGDT). The RRSSCs also provide training in digital analysis for users in the country.

Towards taking up specific application projects at state and district levels, several state governments have set up state level remote sensing application centres as part of NNRMS activities. In all, 21 states have operational application centres. These centres have essentially visual interpretation equipment. A few states such as Tamil Nadu, Uttar Pradesh, Orissa, Punjab and Haryana are also having digital image processing facilities. The state centres carry out projects of direct relevance to their states and also participate in national endeavours such as mapping of wasteland, ground water potential zone, land use mapping, etc.

Over the years, considerable infrastructure has been built up at different institutions in India to impart training in remote sensing. The Indian Institute of Remote Sensing formerly known as Indian Photo-Interpretation Institute, Dehra Dun, is a pioneering training institute set up in 1965. Since early 70s major institutions in India have set up training centres in their organisations. Specialised training programmes have also been established at reputed academic institutions.

Digital image processing and analysis systems have been developed indigenously which are capable of image data handling, preprocessing, enhancement and formatting functions. These low cost, stand-alone systems have already been licenced to Indian industries.

REMOTE SENSING – FUTURE PERSPECTIVE

IRS-1A has become the mainstay of the National Natural Resources Management System providing vital inputs to the management of nation's resources. In order to provide remote sensing services on a continuous and assured basis, a series of remote sensing satellites has been planned. IRS-1B, identical to IRS-1A, is scheduled for launch in August 1991 to provide the continuity of services.

The second generation IRS satellites, namely, IRS-1C and 1D take into account the technology development scenario and user requirements during the nineties. These satellites will have better spectral and spatial resolutions, more frequent revisits, stereo viewing and onboard recording capabilities. They incorporate an improved camera, operating in three spectral bands; in visible and near infrared regions with a ground resolution of about 20 m, and in the middle infrared region with a ground resolution of 70 m. It will also incorporate a camera with better than 10 metres resolution in the panchromatic band besides a wide field sensor operating in visible and near infrared region with a resolution of 188 m and swath of 774 km. IRS-1C is expected to be launched during 1993-94 and IRS-1D during 1995-96.

The availability of data from IRS-1C and 1D satellites, due to their inherently better resolution data as well as availability of data in the infrared band, should throw open many new applications. For example, it should be possible to provide information on water stress and pest infestation which will help in arriving at better agricultural management practices. The higher resolution data will help in arriving at locale-specific solutions for micro level development. Detailed digital cartographic database with digital terrain models will help in arriving at engineering solutions to complex problems involved in micro level development.

In the area of microwave remote sensing, based on the experience gained from development and operationalisation of Side-Looking Air-borne Radar (SLAR), an air-borne Synthetic Aperture Radar (SAR) is under development and will be available for operational use in the beginning of 1992. Plans are also afoot to receive microwave remote sensing data from the European satellite, ERS-1.

As a follow-on to the second generation IRS-1C and 1D satellites, it is planned to embark upon complex remote sensing platforms which would carry payloads with high spatial resolution in narrow optical spectral bands along with active and passive microwave sensors to ensure availability of integrated database, vital for an allround development of the country at micro level.

Conclusions

The continued and sustained efforts over the last two decades have significantly contributed in developing a viable, self-reliant remote sensing programme for the national development. The establishment of the National Natural Resources Management System with emphasis on the sensor development, hardware and software for data products generation, visual and computer-aided interpretation methodologies, development of low cost indigenous interpretation equipment and application methodologies has paid rich dividends. The take-off of such a full-fledged operational remote sensing programme is now well poised to reach even greater heights, through the series of satellites planned to be launched following IRS-1A, to ensure data services to the users on a continued and assured basis. The great deal of indigenous development, both in space and ground segments as well as in application areas, has provided wide ranging opportunities for various work centres/application scientists in the country for furthering the scope of their activities.

With the emphasis, globe over, shifting to the emerging need for optimal exploitation of the various natural resources, keeping the environmental impacts in view, there is a need to take a holistic approach to resources management. Remote sensing is a unique field which has brought scientists of various disciplines together. It is also a demonstration of how science can directly contribute in the national development through judicious planning as exemplified by the fructification of several national level study projects into regular operational practices. The various integrated surveys like integrated study to combat drought or micro level planning at district level are worth noting. With the advent of advanced techniques like digital terrain modelling and geographical information system and the availability of advanced sensors/satellites as well as new methodologies, optimum utilisation of remote sensing technology for national development is well in the offing for the nineties. The application of satellite remote sensing in India is an example for many developing countries to show how relevant advanced technology can be, for the development of a country.

REMOTE SENSING IN LOCUST SURVEILLANCE

Flush of vegetation creates conditions for the desert locust to multiply fast and become a menace. The latter half of the year 1989 witnessed an unusually large local build-up as well as influx of locust swarms from breeding sites in Pakistan to Rajasthan. The Locust Warning Organisation (LWO) of the Directorate of Plant Protection of the Govt. of India had to mount large scale control measures to contain the menace. The LWO made use of the RRSSC facility to monitor the desert vegetation and to identify potential sites of locust multiplication which is otherwise a tedious task taking into account the inaccessibility and poor trafficability of the area. Density slicing of NDVI output of NOAA data and ratio 4/3 output of IRS data, was carried out to generate five green biomass levels within the sparse desert vegetation. Analysis of various satellite passes during the season permitted an appreciation of changing scenario. The digitally enhanced products were found useful in launching of selective control measures in an area spread over 2,00,000 km^2.

Source: NNRMS Bulletin, **13**, 1990, ISRO HQ, Bangalore.