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EARTH OBSERVATION SYSTEMS FOR SUSTAINABLE DEVELOPMENT: INDIAN EXPERIENCE

R.R. Navalgund
National Remote Sensing Agency
Hyderabad 500 037 (INDIA)
e-mail: rangnath@nrsa.gov.in

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ABSTRACT:
Adoption of eco-friendly sustainable development strategies has become an imperative necessity to achieve economic and food security while maintaining environmental harmony. The Earth Observation (EO) satellites play a significant role in determining, enhancing and monitoring the overall carrying capacity of the earth. The repetitive satellite remote sensing over various spatial and temporal scales offer the most economic and timely accessibility of environmental parameters and study of impact of development processes. Realizing the vast potential of data from EO satellites, India has established a strong applications programme to take remote sensing technology to grassroot level, in support of the locale-specific development. A number of joint experiment projects have been taken up with different user departments to demonstrate the potential of remote sensing for resource monitoring and management in different fields. An important project namely, the Integrated Mission for Sustainable Development (IMSD) taken up in India for 174 districts covering 84 M ha aimed at generation of locale specific action plans for suggesting alternate land use plans, soil conservation, surface water harvesting and ground water exploitation/ recharge for sustainable development of land and water resources. In many of the watersheds, plans are being implemented by the government as well as by the voluntary agencies. The remote sensing programme is also backed up with adequate and appropriate infrastructure development and capacity building in terms of trained manpower and technology base.

1. INTRODUCTION

Optimal management of natural resources is vital for the world in general and to the developing nations, in particular. The resources of many developing countries have come under severe strain over the past few decades. The rate of degradation and depletion of resources has accelerated tremendously in view of the ever-increasing demographic pressure. Deforestation, desertification, soil erosion and salinisation have degraded the environment, threatening the food security and economic development of many countries. Over exploitation of resources to meet the burgeoning requirements is leading to crowded crop lands, falling water tables, declining biodiversity, overfishing and increased pollution. As against the estimated minimal need of 0.5 ha per capita, over all arable land of 1500 M ha in the world presently available for agricultural activities amounts to only 0.3 ha per capita. This will further dwindle to 0.15 ha by 2100. It is appalling to learn that about 75% of major marine fish stocks are either depleted from overfishing or are being fished at their biological limit. About 50% world's forest cover has shrunk due to logging. About 58 per cent of coral reefs are potentially threatened due to destructive fishing practices, tourist pressures and pollution. About 65% of cropped land experienced significant degrees of soil degradation (World Resources, 2000-2001). These issues cut across geographical barriers and transcend national boundaries. Stretching the finite resources of the world to meet the basic requirements of explosive population growth that is conservatively expected to touch 11 billion by 2075, without impairing ecological and environmental conditions is the biggest challenge facing the world today.

India is endowed with rich natural resources. However, for its size and population, it is one of the most densely populated nations. It suffers from a variety of problems ranging from population explosion to accelerated land degradation. India homes over 16% of world's population in an area, which is 2.42% of global spread. Per Capita arable land in India, which is around 0.15 ha at present is expected to decrease to a meager 0.09 ha by 2075. About 175 M ha of vegetated area is degraded in some form or the other. Agriculture production which stands at 205 M tons today needs to be increased to about 325 M tons by 2050 to meet the needs of the increasing population. About 65 percent of the agriculture is rainfed and is subject to the vagaries of the monsoon. Despite an estimated availability of 3,000 cubic meters of water per person per year, uneven distribution on spatial and temporal dimensions is the root cause of water scarcity in many areas. Almost 50% of the annual rain precipitation is lost due to evaporation and surface run-off. Increasing use of ground water for irrigation, without implementing adequate recharging mechanism, has led to declining water tables and intrusion of sea water into ground water aquifers.

Productivity is showing stagnation and even decrease in some regions. The country has about 17% of world's cattle population, placing a heavy demand on fodder requirements and also resulting in overgrazing of grass lands and forest areas. Forest cover is only about 19 per cent of geographical area of the country against 33 per cent prescribed. Area under closed forest category is half of what it was about fifty years ago. Conservation of bio-diversity is an area of concern. India has a long coastline of about 7500 km. A large fraction of population lives on coastal areas. Increasing population and industrialization along the coastal areas are putting pressure on coastal wetlands, sea grass areas, and coral reefs at an alarming rate. Glaciers in the Indian Himalayas are showing alarming retreat. India is among the most vulnerable group of developing countries suffering from the damage due to natural disasters such as drought, floods, cyclone, landslides, forest fire, earthquakes, locust attacks, etc. India experiences frequent drought, adding to its multiplicity of problems. About half the area of the country is drought prone. About 40 Mha area is prone to floods. Many parts of the Himalayas and Western ghats are prone to land slides. In the context of shrinking per capita land and increasing biotic and abiotic pressures, it is a daunting task to increase food production to meet the needs of the growing population worldwide. In order to reverse this process, it is necessary to adopt methods of development which reduce disparities among people and nations, alleviates poverty and lead to a sustainable development without causing irreversible erosion of natural resource wealth.

2. SUSTAINABLE DEVELOPMENT

Sustainability has many dimensions viz., ecological, economic, social and cultural and it has to be suitably integrated with environment to develop cost effective, energy efficient and environmentally benign systems. The World Commission on Environment & Development (WCED, 1987) defined sustainable development as that which meets the needs of the present without compromising the ability of the future generations to meet their own needs. The Food & Agriculture Organization (FAO) defined sustainable development as the management and conservation of natural resources base and the orientation of technological and institutional changes in such a manner to ensure the attainment and continued satisfaction of human needs for present and future generations. Such sustainable development conserves land, water, plant and animal genetic resources and is less risky, environmentally non-degrading, technically appropriate, economically viable and socially acceptable.

Sustainable development requires a simultaneous progress in three dimensions: the environmental dimension, the economic dimension and the social dimension. That is, it must improve economic efficiency, protect and restore ecological systems, and enhance the well-being of all peoples. There is an often-quoted fourth dimension, the technological dimension. It will also need new technologies that are more efficient and have fewer impacts on the environment. There are close linkages and interactions between these dimensions. For example, if economic growth is to be sustainable it cannot ignore the environmental effects of that growth and it cannot succeed without development of human resources.

Besides planning and management, there is a need to develop indicators of sustainability for land resources. The success of development cannot be measured by economic indicators alone. These need to be measured taking into account the effect of development of environment. The cost of environmental degradation should also be assessed to measure the progress in direction of sustainability. Sustainability indicators take into account social, environmental, economic, political demographic and cultural factors (Table 1). It may not be possible to derive sustainability indicators using only remote sensing data. However, it can be helpful for generating environmental indicators that can be integrated with social and economic indicators using other data. Various studies have shown the potential of remote sensing in this direction.

The Earth Summit at Rio de Janeiro in 1992 (UNCED 1992) defined principles on which the pathway to sustainable development can be based. It states that the only way to have long term economic progress is to link it with environmental protection. Caring for natural resources and making sustainable use of resources is essential for well-being of not only this generation but future generations. Land resources provide the basis for food, fuel, fiber and shelter for human populations worldwide. Expanding human requirements and economic activities are placing ever increasing pressures on land resources, creating competition and conflicts and resulting in suboptimal use of both land and land resources. Anthropogenic

Table 1: Indicators of sustainability

Aspect	Driving Force	Indicators	
		State	Response
Sustainable Agriculture & Rural Development	Use of agricultural pesticides Use of fertilizers Irrigation % of land Energy use in agriculture	Arable land per capita Area affected by salinization and water logging	Agricultural Education
Atmosphere	Emissions of GHGs Emissions of N&S-oxides Consumption of ozone depleting substances.	Ambient concentration	Expenditure on pollution abatement
Conservation of biodiversity	-	Threatened species as a percent of native species	Protected area as a percent of total area
Planning & Management of land	Landuse change	Changes in land condition	Decentralized resource management.
Combating desertification & drought	Population living below poverty line in dry land areas	National monthly rainfall Satellite derived vegetation index Land affected by desertification.	-
Quality & supply of fresh water resources	Annual with drawals of ground and surface water Domestic consumption of water per capita.	Ground water resources concentration of faecal coliform in fresh water BOD in water bodies.	Wastewater treatment coverage. Density of hydrogeological networks
Protect-ion of Oceans, seas & Coastal areas	Population growth in coastal areas. Discharge affluents into coastal water Release of N & P to coastal water.	Maximum sustain-ed yield for fishes Algae index	-
Forests	Wood harvesting intensity	Forest area change	Managed for-est area ratio. Protect forest area as % of total forest area.

(Source: UN Department for Policy Coordination and Sustainable Development, DPCSD, 1995) pressures on agro-ecosystems and marine resources are presented in tables 2(a) and 2 (b). Integrated planning and management of land resources is required for sustainable use and development of natural resources (Agenda 21, Chapter 10). Modern technologies such as biotechnology, remote sensing, GIS, and computing capabilities can be effectively used to improve efficiency of land resource utilization, assess the condition of resources, model their outputs spatially and to monitor them.

Table 2(a) : Anthropogenic Pressure on Agro-ecosystem

Pressures	Causes
• Conversion of farmland to urban and industrial uses • Water pollution from nutrient runoff and siltation • Water scarcity from irrigation • Degradation due to irrational processes • Changing weather patterns	• Population growth • Increasing demand for food and industrial goods • Government policies • Poverty and insecure tenure • Climate change

Table2(b): Anthropogenic Pressure on Marine Resources

Pressures	Causes
• Overexploitation of fisheries • Conversion of Wetland and coastal habitats • Water pollution from agricultural and industrial sources • Destination of natural tidal basics and uses • Invasion of nonnative species • Potential sea level rise	• Population growth • Increasing demand for food and coastal tourism • Government fishing subsidies • Uncoordinated coastal Land use policies

3. ROLE OF SPACE TECHNOLOGY

Satellite Communication, close weather watch and earth observations are three important areas in which space technology plays a significant role towards sustainable development. The data from EO satellites can contribute to sustainable development by providing information, measurements and quantification of natural or artificial phenomena. The synoptic view provided by satellite imagery offers technologically the most appropriate method for quick and reliable mapping and monitoring of various natural resources, both in space and time domains. Change detection through repetitive satellite remote sensing over various temporal and spatial scales, offers the most economical means of assessing environmental impact of the developmental processes, monitoring of bio-species diversity of an ecosystem and evolution of appropriate action plans for initiating sustainable development. Availability of data at different spatial resolutions (as coarse as 1 km, or as fine as 5 m or better in multispectral mode) provides a means for observing the earth simultaneously at macro and micro levels. The advent of 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, to its unimpaired penetration through cloud cover to provide all weather capability to remote sensing.

Decision-making for sustainable development is a complex process and often involves studying trade-offs that need to be made for conflicting goals of different sectors. GIS provides a convenient platform to integrate multisectoral data in different formats for analyzing 'what-if' scenarios of alternative developments. Spatial decision support systems (SDSS) integrating process-based models with scenario analysis greatly aid the process of decision-making. There are possibilities of developing SDSS by tight coupling of GIS tools with those for modeling, simulation, optimization, statistical analysis, image processing and expert reasoning (Densham 1991). Besides allowing spatial analysis, GIS is a powerful tool for empowering communities by enabling people's participation in decision-making.

4. INDIAN REMOTE SENSING SATELLITES (1979-2002)

Launch of two experimental earth observation satellites Bhaskara 1 & 2 (1979, 1981) heralded the beginning of indigenous capability and provided the necessary experience in handling a total remote sensing system at an experimental level. These satellites carried a two band television camera operating in 0.54-0.66 μm and 0.75-0.85 μm and a microwave radiometer acronymed SAMIR (Satellite Microwave Radiometer). With the successful completion of Bhaskara programme, the capability to build operational satellites for remote sensing was well established and this in conjunction with the experience gained through Joint Experiment Prograame with user agencies laid the foundation for the Indian Remote Sensing Satellite Programme.

Indian Remote Sensing Satellite IA (IRS-IA) launched in March 1988 was the first operational remote sensing satellite. This carried two cameras LISS-1 and LISS- 2 (spatial resolution of 72.5 m and 36.25 m respectively) in identical set of four spectral bands providing repetivity of 22 days. IRS-1A was followed by the launch of IRS-1B, an identical satellite, in 1991. IRS-1A and 1B in tandem provided 11-day repetivity. IRS-P2 carrying only LISS-2 camera was added to this constellation by an indigenous launch in 1994. While data available from IRS-1A/ 1B/ P2 provided great impetus to several national level application programmes, need was felt to have higher spatial resolution data for many of the urban applications and detailed inventory of minor crops. There was also a strong requirement of higher repetivity for monitoring. Launch of IRS- IC/ID carrying a set of three unique payloads WiFS, LISS-III and PAN made a quantum difference to such applications. While WiFS provided high repetivity (5 days) enabling study of vegetation dynamics, PAN with 5.8 m spatial resolution facilitated large scale mapping and in particular to urban studies. Inclusion of short wave infrared (SWIR) band in LISS-3 enhanced utility for crop stress investigations. Till recently, 5.8 m resolution data provided by IRS-1C/1D Pan camera was the highest in the civilian domain.

IRS series of satellites represented by IRS-1A/ 1B/ P2/ 1C/ 1D catered to essentially land based applications. Launch of IRS-P3 carrying MOS-A, B, C and WiFS in 1996 revived interest in ocean colour studies. In addition to providing data for ocean colour applications, MOS sensors were also useful for aerosol studies. IRS-P3 WiFs together with IRS-1C/1D WiFS, further enhanced repetivity. IRS-P4 launched in 1999 carried an ocean colour monitor and multifrequency microwave scanning radiometer. Data from IRS-P4 provided greater impetus to both physical and biological oceanographic studies. Table-3 provides major specifications of IRS series of satellites. In addition to these indigenous missions ERS 1&2 (European Remote Sensing Satellites) carrying scatterometer, altimeter and SAR provided microwave data, adding extra dimensions to earth exploring capability. RADARSAT-1 has been another important provider of SAR data for many applications. Data available from many international missions such as SIR A/B/C, SPOT, JERS 1, MOS-A/B, GEOSAT/TOPEX etc were also used in many investigations.

Table 3 : Major Specifications of IRS Series of Earth Observation Satellites

Satellite (Year)	Sensor	Spectral Bands (μm)	Ground Res. (m)	Swath (km) Repeat Cycle (d)/Bits
IRS-1A/1B (1988, 1991)	LISS-1&2	0.45-0.52, 0.52-0.59 0.62-0.68, 0.77-0.86	~72 (LISS-1) ~36 (LISS-2)	148/22/7
IRS-P2 (1994)	LISS-2	0.45-0.52, 0.52-0.59 0.62-0.68, 0.77-0.86	37 x 32	131/24/7
IRS-1C/1D (1995, 1997)	LISS-3 WiFs PAN	0.52-0.59, 0.62-0.68 0.77-0.86, 1.55-1.70 0.62-0.68, 0.77-0.86 0.50-0.75	~23.5 (VNIR) ~69 (MIR) 188 ~ 5.8	140/24/7 810/5/7 70/5/6
IRS-P3 (1996)	MOS-A MOS-B MOS-C WiFS	0.755-0.768; 4 bands 0.408-1.010; 13 bands 1.6 ; 1 band 0.62-0.68, 0.77-0.86 1.55-1.70	1570 x 1400 520x520 520x640 188	195/24/16 200/24/16 192/24/16 810/5/7
IRS-P4 (1999)	OCM MSMR	0.402-0.885, 8 bands 6.6, 10.65, 18, 21 GHz V & H	360 x 236 120, 80, 40, 40 km.	1420/2/12 1360/2--

Simultaneously, India has also established a strong applications programme to take the remote sensing technology to grassroot level, in support of the locale specific development. A number of joint experiment projects were taken up with different user departments to demonstrate the potential of remote sensing for resource monitoring and management in different fields. Closely following these experiments and realizing the need for an institutional framework for remote sensing applications, a National Natural Resources Management system (NNRMS), was set up to coordinate the activities of remote sensing applications of the country. Adequate and appropriate infrastructure development and capacity building in terms of trained manpower, technology base, etc also backed up the remote sensing programme.

Today, remote sensing has been operationalised to cover diverse themes such as agricultural crop acreage and yield estimates, forestry, drought monitoring, flood monitoring and damage assessment, land use/ land cover studies, waste land delineation and reclamation, water resources development and management, ground water prospecting, marine resources survey, urban planning, mineral targeting, environmental impact assessment and so on, thus encompassing almost every facet of the sustainable development and management. A brief description of the utilization of RS data towards sustainable development is provided in the following sections.

5. REMOTE SENSING INPUTS TO SUSTAINABLE DEVELOPMENT – INDIAN EXPERIENCE

Major programmes related to sustainable development, in which Earth observation has played a key role, can be grouped as: (a) those that aim towards sustainable agricultural development and fishery resources; (b) those related to protecting the environment and (c) those that provide support to the disaster management system. EO satellite data have been extensively used in India towards building up the national natural resource database with an objective to improve the resource use efficiency for the overall development of the country. Resourcewise experience gained is presented hereunder.

5.1 Sustainable Agricultural Development:

Improvements in agricultural production through horizontal approach are achieved by identifying and reclaiming hitherto un / under utilized lands and bringing them into cultivation whereas in the vertical approach efforts are put to increase the productivity of the land per unit area of land per unit time per unit input. However, indiscriminate and irrational crop management practices would deteriorate the agro-ecosystem and thus leads to a disastrous situation in the long run. This necessitates the tailoring and selection of the crop husbandry practices through scientific agrotechnology and biotechnology for optimal utilization of land, water and weather resources without any adverse effects on various components of the production system, leading to sustainable agricultural development. A schematic representation connecting these is shown in Figure 1.

5.1.1 Land Resources:

Land is a very important component of sustainable development since it is where our energy, food and raw materials come from, and it is also the habitat for flora and fauna, including the man. It is a finite commodity. Destruction of this natural resource could be irreversible, thereby bringing harm to both natural environment and human lives. Soil degradation also contributes to an increase in atmospheric CO_2 through rapid decomposition of organic matter. Land degradation through erosion, salinization and water logging, compaction, mining and depletion of organic matter further aggravate the problem of diminishing per capita arable land. Unplanned cutting of hill slopes leads to soil erosion and landslides. Globally, 1964.6 M ha of land is affected by human induced degradation. Status of Indian land resources is given in table 4.

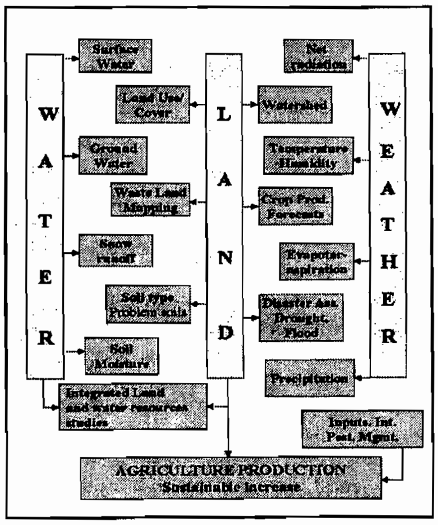

Fig. 1: Scheme for sustainable agricultural production

Table 4 : Status of Indian land resources

Cause of degradation	Areal extent (M ha)	Per cent
Water erosion		
Loss of top soil	132.5	16.4
Terrain deformation	40.3	5.0
Wind erosion		
Loss of top soil	6.2	4.6
Terrain deformation / Overblowing	4.1	1.9
Chemical deterioration		
Loss of nutrients	3.7	10.1
Salinization	1.1	3.1
Physical deterioration		
Water logging	11.6	3.5
Land not for agriculture	18.2	5.5
Soil with little or no degradation	90.5	27.5
Soils under natural conditions	32.2	9.8
TOTAL	328.7	100.0

(Source: http://teriin.org)

Multi temporal space borne multispectral data corresponding to rainy, post rainy and summer seasons have been used to delineate double cropped and rabi fallow areas. These land use/ land cover maps have provided a sound database for agro-climatic regional planning for increasing food production. Similarly, information generated on wastelands on 1:50,000 scale helped prioritization and reclamation of degraded lands. A thirteen-fold classification comprising both culturable and unculturable wastelands is adopted and digital atlas for India has been prepared. The land use information derived from satellite data could be analyzed in GIS incorporating physical and socio economic data to provide land suitability maps and to determine the carrying capacity of the region alongwith the environmental information. About half of the delineated 63 M ha of different categories, of waste lands of India could be reclaimed for productive purposes. The areas where land development conflicts with environment has been found out by overlaying the land suitability and land use maps.

Landsat MSS/TM, IRS-LISS data have enabled generation of soil resource maps ranging from 1:250000 to 1:50000 with the abstraction level of subgroups/ association there of and association of families, respectively. Nationwide mapping of soil resources on 1:250000 scale using Landsat MSS data alongwith the collateral information on lithology, physiography could be carried out. High-resolution stereo data were found to be useful for generating information on soil resources at 1:12500 scale, necessary for microlevel optional land use planning. Derivative information such as land capability, irrigability, erodability / retentivity and suitability for different crops to generate optional land use planning could also be generated.

5.1.2 Water Resources:

Both surface and subsurface water are crucial for sustainable agricultural development. Overexploitation of groundwater and wastage of precipitation water as run off are two major issues to be addressed in the context of sustainable development. In addition, water pollution by mining wastes, solid wastes and farm fields need to be checked for sustainable returns. Water resources development and management largely depends upon proper planning, implementation, operation and maintenance. India is endorsed with a large net work of 12 major river basins covering 256 M ha, 46 medium river basins covering about 25 M ha besides other water bodies like tanks and ponds covering 7 M ha with the ultimate irrigation potential of 140 M ha. The surface water potential has seen developed to an extent of 37% and that of groundwater to 38%. Significantly large gaps exist in the ultimate irrigation potential, creation and the utilization. In addition, the water-use efficiency in the country is reported to be only 25-30 per cent, which could certainly be improved by employing various modern techniques.

The synoptic and repetitive information provided by EO satellite data has been extensively used to map surface water bodies, monitor their spread and estimate the volume of water. Monitoring reservoir spread through seasons has helped irrigation scheduling. Satellite data derived spatial and temporal information on cropping pattern, crop intensity and condition forms basic inputs for developing indicators for agricultural performance of the irrigation systems. Seasonal and spatial violations in the cropping patterns across the command from head end to tail end can be easily maintained using satellite data. Snow-melt runoff forecasts are being made using IRS-WiFS and NOAA/AVHRR data. These forecasts enable better planning of water resources by the respective water management boards. The SWIR band data of IRS-1C/1D are found to be useful in better discrimination of snow and cloud, besides delineating the transition one and patch snow covered areas.

Satellite data derived geological, geomorphological and hydrogeomorphological maps on 1:50000 scale covering parts of the country are prepared and the ground water prospecting maps are generated. These maps show the yield range at different depths besides indicating sites for recharging aquifers and water harvesting structures. This work has facilitated identifying sources of drinking water for deprived villages.

5.1.3 Crop Resources:

Agriculture is the world's major user of land, water and biological resources, so sustainable farming systems are not only critical for ensuring the world's future food supply, but also the quality of the global environment.

5.1.3.1 Crop Inventorying :
EO satellite data enable estimation of pre-harvest acreage and production, besides assessment of condition. Procedures have been developed to make production forecasts at national level to help in planning and formulating policy decisions. Currently multi temporal IRS WiFS data are used to make national and state level wheat production estimates. As most of the rice crop is grown in *kharif* (monsoon) season, coinciding with the over cast cloudy conditions of the sky most of the time, Radarsat data is being used to generate national level estimates. High resolution data are used for estimating minor crops. Realizing that remote sensing data cannot provide a stand-alone system for making multiple and reliable forecasts, recognizing the importance of agro meteorology in determining crop growth and its yield and taking advantage of a conventional system existing in the country, a new programme viz., Forecasting Agricultural Output using Space. Agrometeorology and Land-based observations (FASAL) has been conceptualized and being institutionalized (Navalgund, 2002).

5.1.3.2 Precision agriculture and Cropping systems approach:
Development of geomatics is facilitating integration of GIS, GPS and RS spatially, temporally and economically to assist farm producers in effectively managing their valuable resources. Precision agriculture with the main objective of economic optimization of crop production maintaining eco balance is an ideal option to meet the objectives of the sustainable development. Towards this objective, specific studies to explore the role of remote sensing technology in different agro ecological situations of India have been taken up. As a pilot project, a study has been taken up in collaboration with the Dr. MS Swaminathan Research Foundation (MSSRF), Chennai to implement precision farming. In one selected village, four soil types could be delineated using RS data. This input was used for reducing the number of soil samples to be analysed for fertility evaluation and recommending a variable fertilizer application for the village. Similarly, in another study, soil spectral variability and yield maps were generated over potato fields using RS data and correlated with ground observations for generating crop management options based on inherent variability.

In places like Punjab and Haryana states, where intense farm management practices are followed, information generated from the remotely sensed satellite data on the spatial and temporal variability of the soil and crop growth patterns can be used for efficient input application. This reduces the excessive use of agrochemicals, which would otherwise cause soil-chemical pollution.

Diversified cropping using rotations involves several potential advantages compared to monocultures. These include synergetic yield interactions, reduced operating inputs, and reduced machinery ownership and labor costs. Unfortunately, crop budgets and crop programming studies are almost always developed from a single-crop framework without allowing for joint-products. Multi temporal EO satellite data provides information on cropping patterns in spatial and temporal domains at both micro and macro levels. Interface with the crop growth models would provide information on the utilization patterns of the resources in achieving the sustainable agricultural production from a cropping system perspective. Using multi-temporal remote sensing data, along with soil, physiographic rainfall and temperature information, a potato-growing environment index was derived through modelling. Agricultural areas suitable for growing potato crops and the present land utilization pattern of the study area were generated. The results indicated the probability of success of potato crop intensification in the study area.

5.2 Fishery Resources:

India has 7500 km. of coastline and extensive exclusive economic zone of about 2 million sq.km. The Indian EEZ supports vast resources, both living and non living. However, the marine fish production has remained stagnant at about 2.83 million tonnes (MT) as against the estimated potential of 4.5 MT from EEZ of India. Anthropogenic activities along the coast are further deteriorating the delicate ecosystem. The population on coast is increasing and increased dependence on the ocean for various industrial, commercial and recreational activities has been causing concern and a major threat to sustaining the biological richness of the oceans and the coastal areas. Agenda 21 of UN Conference on Environment and Development has provided a broad framework for this purpose. Therefore, there is a need for a long-term management and sustainable development coastal and oceanic resources. This would require sound understanding of the coastal and oceanic dynamics and a proper evaluation of marine resources. The gap can be bridged and sustainability of a marine production can be achieved by 3 pronged approach: (a) Identification of potential fishing areas for deep sea fisheries: The oceanic resources and the resources within 50 – 200 m zone of the Indian EEZ are either under exploited or unexploited due to the lack of knowledge of the distribution and abundance of these resources. Important resources being Tuna and allied fishes, sharks, Cephalopods, bigeye, deep sea shrimps etc. The estimated potential for these resources is about 1.7 MT. Environmental parameters amenable to the remote sensing, suitable for fish aggregation can be used to indicate potential of fishing areas, (b) Site selection for sea ranching/ coastal farming: Remote sensing data and GIS can help in identifying suitable sites for sea ranching. These areas can be used to grow the fry and fingerlings of depleted stocks so that the population can be sustained, and (c) Monitoring of industrial affluents/ dispersal, harmful algal blooms: Satellite data have helped in monitoring the discharge of industrial affluents and their pattern of dispersal over space and time scales. This helps in mitigating the effects caused to the exploited vulnerable stocks from further depletion, reducing mortalities in the nursery grounds (Nayak et al., 1999).

Aggregation of fish is influenced by many variables pertaining to environmental and biological stimuli. These in turn depend upon a number of physical, biological and environmental parameters such as Sea Surface Temperature (SST), ocean biology as manifested by chlorophyll concentration, currents, mixed layer depth, internal waves, winds, oxygen, salinity, predator-pry relation ship etc. Upwelling results in bringing nutrient rich cooler water to the surface leading to enhanced biological activity. This phenomenon manifests in the form anomalies/ gradients in SST pattern. Using this approach, fishery prospect charts are generated and disseminated. These maps are improved when SST integrated with Ocean colour. Data available from IRS P4 OCM and NOAA AVHRR are being used for these investigations.

5.3 Environmental Monitoring

5.3.1 *Forests:*

Forests have acquired increasing importance in the recent past for their role not only in meeting material requirements but also for their ecological and environmental functions. Forests have a profound effect on global carbon cycle. Therefore, accurate and updated information on forest resources has attracted higher importance. Deforestation increases the amount of CO_2 and other trace gases in the atmosphere. When a forest is cut and burnt to establish crop land and pastures, the carbon stored in the trunks (Wood is 50% carbon) joins with oxygen and released into the atmosphere as CO_2. Satellite remote sensing has enabled generation of forest cover maps and monitoring changes therein at operational level. Biennially forest cover mapping is carried out using satellite data by the Forest Survey of India (FSD) on 1:250,000 scale; and the relevant inputs required for forest management are generated at 1:50,000 scale. The advent of high resolution IRS-1C/1D LISS-III and PAN data has enhanced the capability to prepare forest type and large scale stock maps. EO data from space platforms also hold promise for providing information on potential, extent and composition of various ecosystems. The rates of afforestation and deforestation could also be assessed using multi-temporal satellite data. Conservation of forest ecosystem requires on understanding of the biospherical processes, understanding their spatial interlinkages and continuous monitoring of the human interventions.

5.3.2 Biodiversity :

India is identified as one of the important biodiversity pools for their genetic, economic and ecological prudence. Conservation of biodiversity can only be achieved through conservation of biological habitats, which require a detailed survey and inventory of existing bio-resources, conservation of ecosystems and protection of marine resources, parks, sanctuaries, forest, wetlands and coral reefs. RS techniques are useful in locating different types of bioresources, to identify appropriate corridors surrounding natural habitats and protect them from human intervention. Spatial and temporal composition patterns and their inter relationships can be derived from identification and analysis of landscale units using RS techniques. Biological richness, disturbance index and habitat suitability index maps are being prepared for four ecologically important sites viz., the north-eastern region, Western ghats, north western Himalayas and Andaman & Nicobar Islands of India (Roy, 1999).

5.3.3 Coastal Environment :

Coastal zone, covering about 18% of earth's surface, comprises of ecologically diverse ecosystems and it is a zone of intense biological activity, where around a quarter of global primary productivity occurs. The coastal zone is used extensively and increasingly for a large number of activities such as human settlement, agriculture, trade, industry, fishery resources, dumping, mining, etc. In most parts of the world, renewable coastal resources tend to be limited. Overexploitation and environmental degradation coupled with poor planning and resource management and rapidly destroying the ecosystems and threatening the resources for present and future generations. Development and management of coastal zones, thus, assumes greater importance. Mangrove forests, coral reefs and wetlands are the critical habitats of the coast. Coral reefs cover 0.17% of the ocean floor, home for $1/4^{th}$ of all marine species and are among the most endangered ecosystems on the earth. 20% of Indian reefs are lost or seriously damaged. Rise in global temperature and CO_2 concentartions and run off of terrestrial sediments and eutrophication (Navalgund and Bahuguna, 1999). The information required for the purpose of coral reefs include the spatial distribution of the reefs, vegetation cover, reef zones and reef morphology, biodiversity of fauna and condition assessment, etc. EO satellite data from IRS, SPOT and Landsat corresponding to low tide periods of October to March, were used to prepare 1:50000 coral reef maps for assessing their extent and condition for all the four major coral reef regions of India .

Mangroves are the important economic resource of the coastal population. Destruction of mangroves also leads to decline in fisheries. Based on the remote sensing data, mangroves could be assessed in terms of their extent, density, condition and diversity. Information about the aerial extent and its condition were generated at 1:250000 as well as 1:50000 scale. The Marine National Park was monitored and the causes for the destruction of mangroves are analysed. Wet lands, kidneys of the terrestrial ecosystem, harbour varied and unique biodiversity and are ecologically important habitats under tremendous pressure during the recent years. EO satellite data was found to be useful to map and monitor both the inland and coastal wetlands of India on 1:250000 scale and some selected wetlands on 1:50000 scale. These maps are the first reliable database on wetlands of India. Seasonal characteristics could also be analysed using pre and post monsoon satellite images.

5.4 Support to Disaster Management System:

Natural disasters like drought, flood, cyclone, landslides, forest fire, earthquakes, hailstorms, locusts, etc., cause devastating impact on human life, economy and environment. India is among the most vulnerable group of developing countries suffering from the damage due to these natural disasters. Though natural disasters could not be fully avoided, it is possible to minimize the potential risks by employing management strategies of developing early warming capability, preparation and implementation of developmental plans to provide resilience, mobilization of resources including communications and tele medicine services and rehabilitation and post disaster reconstruction (Roy et al., 2000).

5.4.1 Agricultural drought:

Vegetation index (VI) derived from space borne data is sensitive to moisture stress in crops and vegetation as a surrogate measure to assess agricultural drought. A nationwide project titled, "National Agricultural Drought Assessment & Monitoring System" is being implemented to monitor the drought during kharif (monsoon period) season by generating VI from NOAA/AVHRR and IRS/WiFs data. Temporal profile of NDVI of the current season is compared with that of a normal season to assess the stress conditions. This is complemented by in-situ observations on rainfall and other agricultural practices.

5.4.2 Floods:

Information on near-real time flood inundation, and damage assessment for monitoring flood events, post flood river configuration to assess vulnerability of flood control structures, preliminary flood hazard risk zone mapping and flood forecasting are generated using currently available cloud free optical data or microwave data under overcast sky conditions: Flood inundation maps are being prepared and electronically transmitted to affected areas within hours of data acquisition operationally.

5.4.3 Cyclones

Tropical Cyclones, one of the most destructive natural disasters, are the low pressure systems around which air circulates with speeds exceeding 200 kms. per hour. These atmospheric disturbances which form over the tropical oceans move towards land, resulting in storm surges inundating vast coastal areas, strong winds and low pressures damaging major structures and wide spread heavy rain fall causing extensive flooding. The most significant contribution of the meteorological satellite has been the systematic monitoring and tracking of the cyclones at very frequent intervals. Critical parameters of cyclone monitoring like cloud structure, cloud top temperature, cloud height, eye of the cyclone, sea surface temperature, low and medium level winds and rain fall estimates are being derived using spaceborne data. Taking the advantage of direct broadcast capability of the INSAT system, locale specific Disaster Warning System with about 150 disaster warning receivers is installed.

5.4.4 Landslide Hazards

Hilly terrains in the unstable mountain systems are the potential areas for frequent occurrence of landslides involving large mass movements of surface material, rocks and soil from sloppy areas, the degree of the vulnerability closely depending on the lithology of the terrain, extent of decision power etc. Using IRS 1C/1D Multispectral and Panchrometic data, alongwith the collateral and ground information, landslide hazard zonation maps on 1:25,000 for major pilgrim/ tourist routes and relatively more vulnerable areas of the Himalayas of the Uttaranchal and Himachal Pradesh states of India, covering a total length of 2000 km are prepared.

5.4.5 Forest fires:

Forest fires are recurrent problems in Indian forests. Prioritization of forest zones is a practical concept and an aid to fire management and planning. Fire alters the spectral response of the vegetation canopy and manifests in the EO satellite data in black to grey tones. RS data have been used in preparing forest fire prone area maps, in monitoring forest fires and in damage assessment.

5.4.6 Desertification:

It is a systematic phenomenon involving climate, soils, flora, fauna and human intervention which if neglected, continues to creep into adjoining areas and expand. Beginning gradually with the deterioration of the vegetal cover due to overgrazing, deforestation and improper cultivation, the desertification process quickly accelerates through both the natural processes of drought, wind and water arosen as well as human intervention involving uncontrolled grazing, over exploitation leading to loss of soil humus and fertility. Since overgrazing and drought are the primary causes leading to desertifications, EO satellite observations address these issues and become relevant for desert monitoring. Mapping of spatial and temporal changes of soil moisture, the most important factor affecting the wind erosion can also be studied using EO satellite data. Using NDVI data in the central Luni Basin of Rajasthan, specific areas effected by severe wind and water erosion within the desert region were delineated. Continuous monitoring over a period of time has also enabled detection of changes in the desert area due to initiated recovery process through vegetation cover and irrigation techniques.

Through the International Charter on Space and Major disasters, for which India is a signatory, the space based resources are being deployed to monitor natural disasters and help relief, damage assessment and mitigation.

6. INTEGRATED RESOURCE MANAGEMENT

As most of the natural resources are interdependent and co-exist in nature, they need to be considered collectively for their utilization. This fact has led to the development of the concept of integrated assessment of the natural resources. Attempts have been made in India to integrate the information on various natural resources viz., soils, water both underground and surface, land use / land cover including forest cover as derived from remote sensing data alongwith the socio-economic factors such as social and demographic profiles, economic status and other data such as slope aspect, drainage etc., in a GIS environment to generate specific action plans on a watershed basis for sustainable development (NRSA, 2002).

6.1 Watershed Development:

Watershed is a natural hydrologic unit, considered as the most appropriate basis for sustainable management of the land and water resources. Watershed development requires delineation, characterization, prioritization, generation of development plans, monitoring their implementation and impact assessment. An essential component for preparation of watershed development plans is the database of the natural resources. Generation of such a database by conventional means is tedious, expensive and time consuming. Information on all the natural resources of the watershed namely soils, geology, geomorphology, ground water, land use/ land cover, slope, generated from satellite data are highly efficient. Thus, space borne remote sensing data is playing a crucial role in this effort. Availability of stereo data helps in delineation of a microwatershed and higher spatial resolution data facilities better characterization of microwatershed in terms of its resource potential.

Realizing the great potential of remote sensing in achieving the development objectives of the watersheds on a sustainable basis, a large programme called Integrated Mission for Sustainable Development (IMSD) for 174 districts covering 84 M ha was carried out in India. As a part of this, various thematic maps were generated on 1:50,000 scale. Specific action plans were drawn up indicating alternate land use systems, soil conservation, surface water harvesting and ground water exploitation/ recharge for sustainable development of land and water resources. In many of the watersheds, plans are being implemented by the government as well as by the voluntary agencies. Besides evolving locale-specific prescriptions for development, this project succeeded in harmonizing the local wisdom of small and marginal farmers with scientific knowledge and administrative acumen.

6.2 Voluntary Organizations in Watershed Development and Joint Forestry Management:

The non-governmental and voluntary agencies play a substantive role in initiating the process of sustainable development. Their strength lies in reaching the needy, organise active available resources and technologies. Their small size, freedom from interference from political and needless bureaucratic constraints and administrative flexibility, makes their participation fully effective. Several voluntary organisations are using inputs available from remotely sensed data in planning, execution and monitoring watershed development. Space inputs are also bringing in transparency at different layers of administration and decision making. The NGOs are also playing a key role in promoting gender sensitive planning and decision making. Some NGOs make it a precondition for taking up watershed works that women be equally represented in the village watershed committees. The Joint Forestry Management (JFM) programme, started in 1990 involved village communities and NGOs in the regeneration, management, and protection of degraded forests. Various state governments have provided in their resolutions, the modalities of forest protection, benefit-sharing arrangements and membership norms. Water conservation has been accorded the status of core activity under JFM programmes. Hence, besides protecting the forests, water harvesting structures are also being built and watershed development activities are being undertaken. This programme adopts a three-point strategy: villagers are paid wages for forestry activities in the degraded forest to stop migration and to involve people more closely with the regeneration activities. While wage earning becomes the immediate benefit and ensures that the people stay in the villages, the regenerating forest provides the mid-term benefits like constant supply of fodder and fuel. The third benefit is the rise in the water table, thanks to the watershed activities. The degree of success of these activities has been varied in different provinces depending upon the proactive administrative machinery, forward looking voluntary agencies, presence of RS centers in those regions and above all enterprising farmers and people.

6.3 Jhabua Experiment:

Jhabua Development Communications Project (JDCP) aimed at study of the efficacy of satellite based development communications support to the developmental activities in the district. Jhabua was chosen since it is one of the most backward districts of India and the level of literacy is as low as 14%. In this project, 150 receive terminals at the village level and one talk back terminal in each of the twelve block headquarters were installed. This network of talk back and receive terminals has been utilised to conduct training programmes for the field staff and for communicating specific development oriented messages to the audience at the receive terminals. Watershed management, health, education and *Panchayati Raj* (decentalized governance at the village level) have been identified as the priority areas for communication. Watershed development included agriculture, animal husbandry, forestry and fisheries, etc. The mid term evaluation of 1998 indicated that 50.3 and 37.2 per cent of men and women had viewed the JDCP programmes. More number of younger people viewed the programmes. About 75% viewers felt the programmes are useful and 45% reported as gaining new information (Bhatia, 1999). Effectiveness of the technology has been proved. Major challenge lies in creating managerial systems that can operate the systems efficiently over a long period of time.

6.4 Experience gained :

In the process of the generation of resource information from RS data, preparation of locale specific action plans, and their implementation, valuable feed back was received on some of the lacunae. Some of these are summarized here. The natural resources information generated at 1:50,000 scale was found to be adequate for data base creation. However, implementation of the suggested action plans demanded larger scale maps, preferably at cadastral level, with which the implementing agencies are familiar. It was also felt that involvement of participating officials and voluntary organisations during the stages of resources information generation and preparation of action plans would be most beneficial for better acceptance of the recommendations. A multi disciplinary team can handle the situations more effectively for realising the best potential of the available natural resources. It was strongly felt that the recommended action plans should ensure the best compatibility between natural resources development vis-à-vis the requirements of the society. Though the perceived cost of the developmental plans was apprehended to be high, it was noted that the returns on long term basis were more beneficial economically as well as ecologically. Integration of socio-economic data was observed as a major bottle neck since well demonstrable technology are not readily available to convince the participants of the development programmes regarding the usefulness of the recommendations. As the task of the sustainable programme is cost and time involving, it was observed that only those areas, which were assured for implementation, should be covered. Though the Government of India issued the Watershed Guidelines to encourage the participation of women in the developmental programmes, their participation was observed to be inadequate. NGOs and voluntary organisations certainly had a preferential role in enhancing the people's participation.

7. ORGANISATION OF THE INFORMATION

Information infrastructure has become an essential element of the development of any country. In the global sense the concept of Global Information Infrastructure (GII) is being talked of based upon the vision of open connectivity and information access. Currently, the establishment of a National Spatial Information Infrastructure (NSII) is a prime activity in many countries. The core of NSII consists of hierarchical GIS based database- containing both spatial and aspatial data, linked through keys and indices. In India, a major effort is on-going towards establishing a National (Natural) Resources Information System (NRIS). It is a three tiered hierarchy of GIS databases pertaining to districts on 1:50,000 scale, states on 1:250,000 and nation on 1:1 million scale. The NRIS is networked across the levels so that the aggregated information can be obtained at high levels. NRIS has a standard GIS design and contains 21 layers of primary spatial data sets and 8 types of non spatial attributes which were adopted from IMSD project. NRIS has application shells that allow information modeling and access for decision making on water and land management, facilitie siting, service centre location, etc.

8. FUTURE PERSPECTIVE

Brief scenario of space technology development and applications discussed so far gives an idea of the tremendous role played by EO satellite data for the development in the country. Of course, there are several improvements required in the quality of details/ information provided by space technology. Some of the data needs felt acutely by the user community are: i) improved spatial resolution (2-3m) of RS data to provide terrain details on cadastral level (1:10,000), ii) stereo capability (2-3m height resolution) to help planning/execution of development plans, iii) high resolution (5-10m) multi-spectral data to facilitate identification of crops grown in small fields (~0.1ha), iv) high repetivity data (-3days) to monitor dynamic phenomena such as flood, changes in snow line, crop growth etc. and v) data pertaining to physical and biological parameters of the ocean. Considering these, in the next 6-7 years, a host of spacecraft systems carrying different sensors have been planned in India. Cartographic satellites viz., Cartosat 1and 2 carrying panchromatic cameras providing data at 2.5 and 1m resolution and stereo capability are planned for launch in a couple of years. This should help large-scale mapping and terrain evaluation.

Resourcesat carrying a LISS-IV camera providing 5.8 m multi-spectral data, LISS-III camera and a 4-band Wide Field Sensor providing data at 60m spatial resolution at 5-day repetivity is also planned. Oceansat carrying a scatterometer, an altimeter and a radiometer and an independent SAR mission are also be in the offing. All these missions providing data at higher spatial and temporal resolutions, and in different parts of electromagnetic spectrum, alongwith the technical advances made in processing and modelling techniques including GIS should be revolutionizing the field of remote sensing applications in the country. Several new application experiments and demonstrations using interactive satellite based communication system for development training and continuing education using INSAT satellites are also playing a crucial role in national development. More importantly, efforts to ensure absorption of technology at implementation levels and people's participation are a must for reaching sustainable development.

9. CONCLUDING REMARKS

Humankind in pursuit of its needs has put natural resources to a severe strain, which is degrading the environment thereby causing at times, irreversible damage to the very existence of life on this planet earth. Rational utilization of the resources in meeting the requirements, following the concepts of carrying capacity and resilience would maintain the balance of the ecosystem. In this regard, the EO Satellites meet the observational requirements and enable extraction of information on resource dynamics. Indian earth observations programme conceptualised and developed to meet these needs, is playing a key role in the sustainable development of the country.

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