Remote sensing applications: An overview

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Remote Sensing (RS) refers to the science of identification of earth surface features and estimation of their geo-bio-physical properties using electromagnetic radiation as a medium of interaction. Spectral, spatial, temporal and polarization signatures are major characteristics of the sensor/target, which facilitate target discrimination. Earth surface data as seen by the sensors in different wavelengths (reflected, scattered and/or emitted) is radiometrically and geometrically corrected before extraction of spectral information. RS data, with its ability for a synoptic view, repetitive coverage with calibrated sensors to detect changes, observations at different resolutions, provides a better alternative for natural resources management as compared to traditional methods. Indian Earth Observation (EO) programme has been applications-driven and national development has been its prime motivation. From Bhaskara to Cartosat, India's EO capability has increased manifold. Improvements are not only in spatial, spectral, temporal and radiometric resolutions, but also in their coverage and value-added products. Some of the major operational application themes, in which India has extensively used remote sensing data are agriculture, forestry, water resources, land use, urban sprawl, geology, environment, coastal zone, marine resources, snow and glacier, disaster monitoring and mitigation, infrastructure development, etc. The paper reviews RS techniques and applications carried out using both optical and microwave sensors. It also analyses the gap areas and discusses the future perspectives.

Keywords: Applications, image analysis, remote sensing, signature, microwave, sustainable development.

HUMANKIND, in pursuit of its needs, has put natural resources of the earth to a severe strain. The rate of degradation and depletion of resources has accelerated tremendously in view of the ever-increasing demographic pressure. Deforestation, desertification, soil erosion and salinization have degraded the environment, threatening the food security and economic development of many countries. Although India is endowed with rich natural resources and considered as one of the important biodiversity pools for genetic, economic and ecological prudence, it suffers from a variety of problems, ranging from demographic pressure to accelerated land degradation.

Agricultural food grain production, which stands at around 210 million tonnes today needs to be increased to 325 m tonnes in the next decade or so to meet the needs of increasing population. Improving productivity in the rain-fed agricultural areas is one of the major concerns. Inappropriate cropping systems, reduction in crop diversity, inadequate post-harvest infrastructure are other major areas of concern. Area under closed forest category is presently half of what it was about fifty years ago. Added to this, the increasing requirements of timber, estimated at 68,857 m tonnes in 1980, would rise to 181,270 m tonnes by 2025, is yet another area of concern. Surface water resources support wide ranging natural and man-made biological systems and hence, play a key role in better management of natural resources. However, the per capita availability of fresh water in the country has decreased from a healthy 5177 m^3 in 1951 to 1869 m^3 in 2001, which might further decrease to 1341 m^3 in 2025. Increasing population and industrialization along the coastal areas are adding pressure on coastal wetlands, seagrass area, and coral reefs at an alarming rate. Global warming is showing its impact, with the glaciers in the Indian Himalayas showing an alarming retreat. India, owing to its geographical location with coast on either side of its boundary, complex mountainous terrain, bioclimate, vegetation type and geological features, is vulnerable to several natural disasters. About 40 m ha of land mass is prone to floods; 5700 km out of 7500 km of coastline is prone to cyclones; 54% of land mass is vulnerable to earthquakes and 68% of the total geographical area is drought-prone. Fifty-five per cent of Indian forests are prone to fires.

Considering India's resource richness and the mounting problems, the country needs a sustainable resources development plan. Towards this, mapping and monitoring of existing natural resources and forecasting the future scenarios are highly important. Remote Sensing (RS) plays a significant role in providing geo-information in a spatial format and also in determining, enhancing and monitoring the overall capacity of the earth. Satellite observations of land, oceans, atmosphere, and specifically, during natural and human-induced hazards have become crucial for protecting the global environment, reducing disaster losses, and achieving sustainable development. Remote sensing using space-borne sensors is a tool, par excellence, for obtaining repetitive (with a range from minutes to days) and synoptic (with global coverage) observations. These data could be used for a number of applications, such as crop inventory and forecasts; drought and flood damage assess-

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Table 1. Major specifications of present IRS series of satellites

Satellites (year)	Sensor	Spectral bands (μm)	Spatial res. (m)	Swath (km)	Radiometric res. (bits)	Repeat cycle (days)
IRS-1A/1B	LISS I	0.45–0.52 (B)	72.5	148	7	22
(1988, 1991)		0.52–0.59 (G)				
		0.62–0.68 (R)				
		0.77–0.86 (NIR)				
	LISS-II	Same as LISS-I	36.25	74	7	22
IRS-P2 (1994)	LISS-II	Same as LISS-I	36.25	74	7	24
IRS-1C/1D	LISS-III	0.52–0.59 (G),	23.5	141		
(1995, 1997)		0.62–0.68 (R)				
		0.77–0.86 (NIR)			7	24
		1.55–1.70 (SWIR)	70.5 (SWIR)	148		
	WiFS	0.62–0.68 (R)	188	810	7	24 (5)
		0.77–0.86 (NIR)				
	PAN	0.50–0.75	5.8	70	6	24 (5)
IRS-P3 (1996)	MOS-A	0.755–0.768(4 bands)	1570 × 1400	195	16	24
	MOS-B	0.408–1.010(13 bands)	520 × 520	200	16	24
	MOS-C	1.6 (1 band)	520 × 640	192	16	24
	WiFS	0.62–0.68 (R)	188	810	7	5
		0.77–0.86 (NIR)				
		1.55–1.70 (SWIR)				
IRS-P4 (1999)	OCM	0.402–0.885 (8 bands)	360 × 236	1420	12	2
	MSMR	6.6, 10.65, 18, 21 GHz (V & H)	150, 75, 50 and 50 km respectively	1360	–	2
IRS-P6 (2003)	LISS-IV	0.52–0.59 (G)				
		0.62–0.68 (R)				
		0.77–0.86 (NIR)	5.8	70	10 (7)	24 (5)
	LISS-III	0.52–0.59 (G),				
		0.62–0.68 (R)	23.5	141	7	24
		0.77–0.86 (NIR)				
		1.55–1.70 (SWIR)				
	AWiFS	0.52–0.59 (G),				
		0.62–0.68 (R)	56	737	10	24(5)
		0.77–0.86 (NIR)				
		1.55–1.70 (SWIR)				
IRS-P5 (Cartosat-1) 2005	PAN (Fore (+26°) & Aft (–5°)	0.50–0.85	2.5	30	10	5
Cartosat-2 (2007)	PAN	0.50–0.85	0.8	9.6	10	5

ment; land use monitoring and management, etc. Today, India is one of the major providers of the earth observation data in the world in a variety of spatial, spectral and temporal resolutions, meeting the needs of many applications of relevance to national development[1,2] (see Tables 1 and 2 for details of Indian RS satellites, and the global source for RS data is provided in Table 3). This paper, briefly, presents the scientific rationale of RS, evolution of Indian earth observation systems, image processing techniques, details on various application themes, observation gaps and future perspectives of Indian RS applications programme.

Scientific rationale

Remote sensing usually refers to the technology of acquiring information about the earth's surface (land and ocean) and atmosphere, using sensors onboard airborne (aircraft, balloons) or space-borne (satellites, space shuttles) platforms. The electromagnetic radiation is normally used as an information carrier in RS. Remote sensing employs passive and/or active sensors. Passive sensors are those which sense natural radiations, either reflected or emitted from the earth. On the other hand, the sensors which produce their own electromagnetic radiation, are called active sensors (e.g. LIDAR, RADAR). Remote sensing can also be broadly classified as optical and microwave. In optical remote sensing, sensors detect solar radiation in the visible, near-, middle- and thermal-infrared wavelength regions, reflected/scattered or emitted from the earth, forming images resembling photographs taken by a camera/sensor located high up in space.

Different land cover features, such as water, soil, vegetation, cloud and snow reflect visible and infrared light in different ways. Interpretation of optical images requires

Table 2. Satellites planned for near-future launching and their major sensor characteristics

Satellite	Sensor	Spectral bands (μm) frequency (GHz)	Spatial resolution (m)
TWSAT	Multi-spectral camera	0.45–0.52 (B) 0.52–0.59 (G) 0.62–0.68 (R) 0.77–0.86 (NIR)	37
RISAT	SAR	5.3 GHz, HH, VV, HV	3–50
Megha Tropiques	MADRAS SAPHIR SCARAB	18.7, 23.8, 36.5, 89.0, 157 GHz 183.31 ± 0.2, 1.2, 2.7, 4.2, 6.8, 11 GHz 0.55–0.65, 0.2–4.0, 0.2–50, 10.5–12.5	50, 40, 25, 10, 6 km
Oceansat-2	Scatterometer OCM	13.4 GHz 0.402–0.885 (8 bands)	50 km 360 × 236
INSAT-3D	Imager Sounder	6 Channels 19 channels	1–4 km 10 km

Table 3. Description of current major imaging earth observation satellites available in the world*

Country/organization	Satellite	Major sensors	Description (Spatial resolution, spectral bands)
USA/NASA	Terra	ASTER	15 m (VNIR), 30 m (SWIR), 90 m (TIR); 14 XS (VNIR, SWIR, TIR)
	Terra/Aqua	MODIS	250–1000 m, 36 bands (VIS–TIR)
	NMP EO-1	ALI	10 m (Pan), 30 m (VNIR/SWIR); Pan & 9 XS (VNIR/SWIR)
		Hyperion	30 m, 220 band, hyperspectral
USA/USGS	Landsat-7	ETM+	15 m (Pan), 30 m (Vis-SWIR), 60 m (TIR), Pan & 8 XS (VIS-TIR)
EU/ESA	Envisat	ASAR MERIS	C Band, multi-polarization, multi-imaging mode SAR 260 m–1200 m, 15 bands (VNIR)
Canada/CSA	Radarsat-1	SAR	C-Band SAR, HH polarization and multi-imaging modes
France/CNES	SPOT-5	HRG HRS VEGETATION	2, 5 m (Pan), 10 m (MS); Pan + 4 XS (VNIR/SWIR) High resolution (10 m, pan) stereo 1.15 km, 3 XS(VNIR/SWIR)
China/CAST	CBERS-2	CCD IR-MSS WFI	20 m, Pan + 4 XS (VNIR) 78 m (VNIR/SWIR), 156 m (TIR), 4 XS (Vis-TIR) 258 m, 2 XS (VNIR)
Japan/JAXA	ALOS	AVNIR-2 PALSAR PRISM	10 m, 4 XS (VNIR) Multi-imaging mode L band radar 2.5 m panchromatic

*This list is not exhaustive, but just an indicative list. For detailed list the readers are referred to CEOS (2005)[46]
VNIR – Visible and near infrared; SWIR – short-wave infrared, TIR – Thermal Infrared, XS – Multispectral bands.

the knowledge of the spectral reflectance patterns of various materials (natural or man-made) covering the surface of the earth. It is essential to understand the effects of atmosphere on the electromagnetic radiation travelling from the Sun to the Earth and back to the sensor through the atmosphere. In case of green vegetation, there is low reflectance in the blue and red region and relatively high reflectance in green and a marked increase of leaf reflectance in the near infrared region (Figure 1). In the visible and near infrared regions, soil reflectance shows a generally increasing trend with wavelength. Water absorbs most of the radiation in the near IR and middle IR regions. Snow has very high reflectance, up to 0.8 μm, and then decreases rapidly afterwards. In case of clouds, there is non-selective scattering and they appear uniformly bright throughout the range 0.3–3 μm.

The atmospheric constituents cause wavelength-dependent absorption and scattering of radiation. These effects degrade the quality of images. Some of the atmospheric effects can be corrected before the images are subjected to further analysis and interpretation. A consequence of atmospheric absorption is that certain wavelength bands in the electromagnetic spectrum are strongly absorbed and effectively blocked by the atmosphere. The wavelength regions in the electromagnetic spectrum, whether usable for remote sensing, are determined by their ability to penetrate the atmosphere. These regions are known as atmospheric transmission windows. Atmospheric windows used for remote sensing are 0.4–1.3, 1.5–1.8, 2.2–2.6, 3.0–3.6, 4.2–5.0, 7.0–15.0 µm and 10 mm to 10 cm wavelength regions of the electromagnetic spectrum. Remote sensing systems are often designed to operate within one or more of the atmospheric windows[3,4].

There are also infrared sensors, which measure the thermal infrared radiation emitted from the earth, from which, the land or sea surface temperatures and thermal inertia properties can be derived. It is observed that all bodies at temperatures above zero degrees absolute, emit electromagnetic radiation at different wavelengths, as per Planck's law, which relates the spectral radiant exitance $E(\lambda, T)$ with the temperature, T of the object.

$$E(\lambda,T) = \frac{2hc^2}{\lambda^5}\frac{1}{e^{hc/\lambda kT}-1}$$

where $h = 6.625 \times 10^{-27}$ erg s (Planck's constant); $k = 1.38 \times 10^{16}$ erg/K (Boltzmann constant); $c = 3 \times 10^{10}$ cm/s (speed of light).

Concept of signature

Signature of any object and/or its condition comprises a set of observable characteristics, which directly or indirectly lead to the identification of an object and/or its condition (Figure 2). There are four principal characteristics of signatures to identify an object.

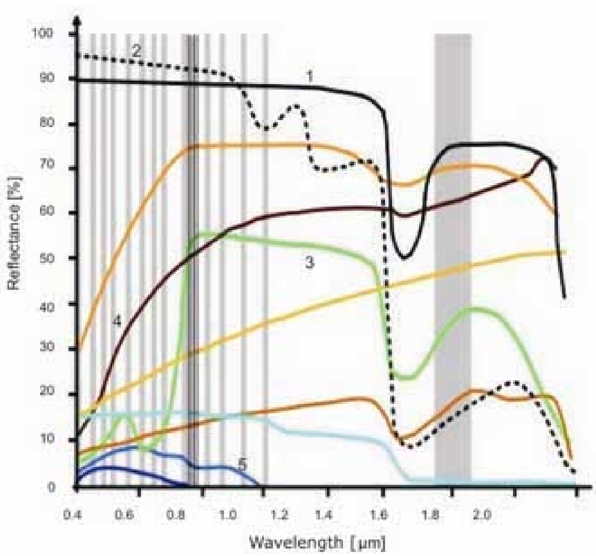

Figure 1. Spectral reflectance signature of different targets including (1) cloud, (2) snow, (3) vegetation, (4) soil and (5) water along with location of IRS-P3 MOS-A, B & C sensor channels (Courtesy; DLR, Germany).

- Spectral variations: Changes in the reflectance or emittance as a function of wavelength
- Spatial variations: Variations in the reflectance/emittance determined by the shape, size and texture of the target
- Temporal variations: Diurnal and/or seasonal changes in reflectance or emittance
- Polarization variations: Changes in the polarization of the radiation reflected or emitted by an object.

Microwave remote sensing

Microwave remote sensing is highly useful, as it provides observation of the earth's surface, regardless of day/night and the atmospheric conditions. The microwaves are the electromagnetic waves with frequencies between 10^9 and 10^{12} Hz. Radar is an active microwave remote sensing system. The system illuminates the terrain with electromagnetic energy, detects the scattered energy returning from the terrain (called radar return) and then records it as an image. Intensity of radar return, for both aircraft and satellite-based systems, depends upon radar system properties and terrain properties. The radar equation expresses the fundamental relationship between the radar parameters, the target characteristics and the received signal. For monostatic radars, it is given as

$$P_{\mathrm{r}} = \frac{\lambda^2}{(4\pi)^3}\int \frac{P_{\mathrm{t}} G^2 \sigma^0}{R^4} \mathrm{d}A$$

where P_{r} is the average power returned to the radar antenna from an extended target, P_{t} is the power transmitted by the radar, G is the gain of the antenna, R is the distance from the antenna to the target, λ is the wavelength of the radar, σ^0 is the radar scattering coefficient of the target. In the active microwave remote sensing, information about the object's physical structure and electrical property is retrieved by analysing the backscattering field. The microwave signatures of the object are governed by the sensor parameters (frequency, polarization, incidence angle) and the physical (surface roughness, feature orientation) and electrical (dielectric constant) property of the target. The influence of frequency on radar scattering is governed by terrain properties. A given surface will appear very rough at higher frequency, compared to lower frequency. Thus, generally, backscattering coefficient increases with increasing frequency. In addition, the signal penetration depth increases with wavelength in microwave region. The use of multi-frequency data allows distinction between the roughness types. The backscattering also depends on the polarization of the incident wave. A vegetation canopy consisting of short vertical linear scatter over a rough surface can be considered as short vertical dipoles. In such case, vertically polarized incident wave interact strongly with canopy. The multiple scattering and volume scattering from a complex surface,

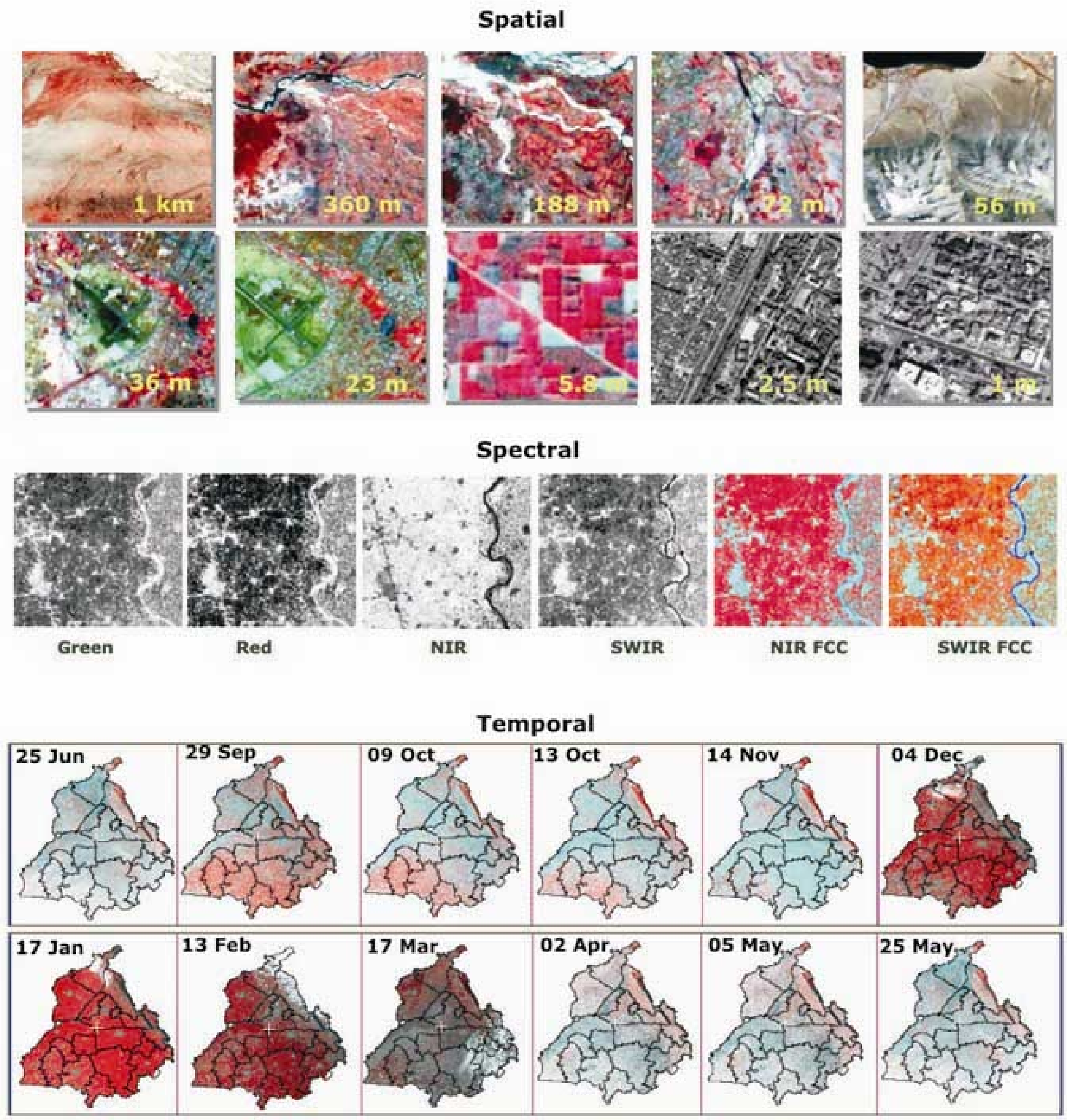

Figure 2. Spatial, spectral and temporal variations of remote sensing data.

such as forest cause depolarization. The radar backscattering coefficient from a terrain is strongly dependent on angle of incidence. The angular dependency of the backscattering coefficient is primarily due to surface roughness.

The aforesaid interaction of microwave is exploited for carrying out different applications. Surface water extent during flood is detectable on radar backscatter image due to the high contrast between smooth water and rough land surface. Synthetic Aperture Radar (SAR) sensitivity to the wave damping effect of oil spill on water surface ensures that spill is easily detected as dark patches in the imagery. The characteristic temporal increase in backscattering coefficient from rice transplanting stage to maximum vegetative stage observed over different sites in India[5–7] formed the physical basis, by which the rice area is estimated regularly at a national scale[8]. The basis of the microwave applications in estimation of soil moisture lies in the strong dependence of radar backscatter on dielectric constant of soil. The dielectric constant of water at microwave frequencies is about 80, while dry soil is about 3. The increase in moisture content in soil linearly increases the backscattering coefficient. Many site-specific empirical models have been developed, between backscattering coefficient and soil moisture content. The generalization of these empirical models over large area suffers from the limitations of sensitivity of other target parameters like soil texture, surface roughness and vegetation cover. The development of the operational scheme of soil moisture by making use of multi-parameter SAR (multi-incidence angle, multi-frequency, multi-polarization) data is still under experimental stage[9]. The sub-surface penetration capability of radar has helped in detection of palaeo-channel having high moisture content at a depth of 45–75 cm covered by dry sand in Western Rajasthan[10].

The optimal sensor configuration for soil moisture and vegetation applications was studied[11] based on various ground-based scatterometer data. Broadly, it was found that low frequency (C, L band) and low incidence angle (7°–17°) are required for soil moisture applications. Higher incidence angle (>40°), high frequency (X, C) with multi-polarization (HH, VV, HV) capability is required for crop inventory. However, L band is also needed to study the forest canopies and estimation of woody biomass.

Based on these studies, a C-band (5.35 GHz) space borne SAR has been conceptualized in a future IRS mission. The Radar Imaging Satellite (RISAT) would be the first Indian satellite to carry the space-borne SAR system, which is being developed to meet the needs of monitoring crops during the monsoon period and flood-inundation mapping. RISAT with the day and night capability, as well as imaging under cloud conditions will be an important system to complement a series of electro-optical sensors launched from IRS satellites so far.

SAR interferometry is a technique based on combining two SAR images of the same scene acquired from different positions and/or times used for topographic mapping [Digital Elevation Model (DEM) generation] and detection of small coherent movements (differential interferometry). Over the past two decades, significant progress has been made in microwave remote sensing in India, through development of advanced airborne SAR system and space-borne passive microwave radiometer. Passive microwave remote sensing involves the measurements of natural emission from surface in microwave spectral region. The passive microwave radiometers such as SAMIR onboard Bhaskara-1 and 2 satellites and MSMR onboard IRS-P4 were indigenously developed for atmospheric and oceanographic applications. The operational algorithms were developed to estimate atmospheric water vapour content, rain rate, sea surface wind speed and sea surface temperature using passive radiometer data[12].

Hyperspectral remote sensing

Hyperspectral remote sensing deals with imaging at narrow spectral bands over a contiguous spectral range, and produces the spectra of all pixels in the scene. Hyperspectral signature can detect the individual absorption features, since all the materials are bound by chemical bonds, thus they can be identified by their spectral characteristics more accurately as compared to broadband multi-spectral imagers. Hence, hyperspectral data is being used to detect the subtle changes in vegetation, soil, water and mineral reflectance.

Analysis techniques

The output of a remote sensing system is usually an image representing the scene being observed. Many further steps of digital image processing and modelling are required in order to extract useful information from the image. Suitable techniques are adopted for a given theme, depending on the requirements of the specific problem. Since remote sensing may not provide all the information needed for a full-fledged assessment, many other spatial attributes from various sources are needed to be integrated with remote sensing data. This integration of spatial data and their combined analysis is performed through a set of computer software/hardware, known as Geographical Information System (GIS).

Digital image processing

It comprises the following four basic steps:

(a) *Image correction/restoration*: Image data recorded by sensors on a satellite or aircraft contain errors related to geometry and brightness values of the pixels. These errors are corrected using suitable mathematical models, which are either definite or statistical models.

(b) *Image enhancement:* Image enhancement is the modification of image, by changing the pixel brightness values, to improve its visual impact. Image enhancement techniques are performed by deriving the new brightness value for a pixel either from its existing value or from the brightness values of a set of surrounding pixels.

(c) *Image transformation*: The multi-spectral character of image data allows it to be spectrally transformed to a new set of image components or bands with a purpose to get some information more evident or to preserve the essential information content of the image (for a given application), with a reduced number of transformed dimensions. The pixel values of the new components are related to the original set of spectral bands via a linear operation.

(d) *Image classification:* The overall objective of image classification procedures is to automatically categorize all pixels in an image into land cover classes or themes. A pixel is characterized by its spectral signature, which is determined by the relative reflectance in different wavelength bands. Multi-spectral classification is an information extraction process that analyses these spectral signatures and assigns the pixels to classes based on similar signatures.

There are two major approaches to multi-spectral classification: unsupervised and supervised. The unsupervised classification is the identification of natural groups, or structures, within multi-spectral data. The supervised classification is the process of using samples of known identity (ground truth sites) to classify pixels of unknown identity (i.e. to assign unclassified pixels to one of several informational classes). There are many classifiers used for supervised classification. One of the most common is maximum likelihood classifier.

The maximum likelihood classifier relies upon the assumption that the populations from which the training samples are drawn are multivariate-normal in their distribution. Clearly this is not the case in remote sensing, for the image pixel values are non-negative, discrete and have an upper bound of 255, 1023 or some other value depending upon the characteristics of the instrument, which acquired the data, whereas the normal distribution relates to continuously measured and unbounded data[13]. To overcome the problem of normality, the currently favoured alternatives are non-parametric classifiers.

A nonparametric classifier uses a set of nonparametric signatures to assign pixels to a class based on their location, either inside or outside the area in the feature space image. To overcome difficulties in conventional digital classification, new approaches like context classifiers, decision tree classifiers, neural network algorithms, etc., are being developed. Another technique is fuzzy classification in which, each pixel is assigned a number for each class, ranging from 0 to 1, which indicates the proportions of the different classes, which have contributed to the observed spectral signature. These classifiers are mainly used, when the spectral reflectance of different features do not follow normal distribution.

For a detailed study on digital image processing, readers may see references 14 and 15. A schematic diagram of commonly followed digital image processing procedures by resource scientists is presented in Figure 3.

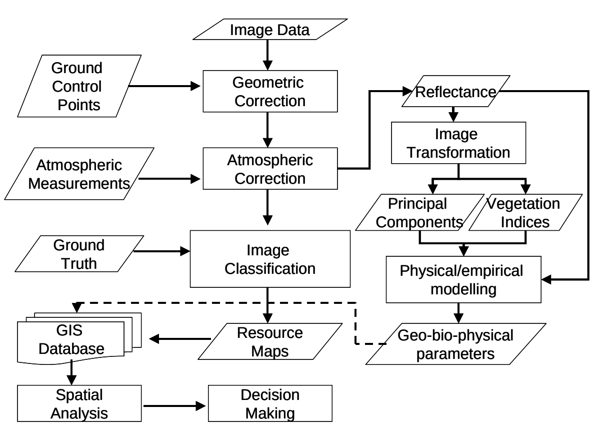

Figure 3. A schematic diagram of general image processing procedures.

Multi-source data fusion

Remote sensing satellites carry sensors of varied characteristics. Many times data are complementary in nature, for example, panchromatic data with high spatial resolution and multispectral data with low spatial resolution. Fine spatial resolution is necessary for an accurate description of shapes, features and structures, whereas fine spectral resolution allows better discrimination between attributes (e.g. to classify land cover). Hence, merging of these two types of data to form multi-spectral images with high spatial resolution, is beneficial for various applications like vegetation mapping, land cover classification, precision farming and urban management to name only a few. Image fusion can be performed at three different processing levels, according to the stage at which the fusion takes place, namely, pixel, feature and decision level. Various techniques are available for merging multi-sensor image data at pixel level. Methods of merging can be divided into two categories[16]. The first consists of methods, which simultaneously take into account all bands in the merging process, whereas the second category groups together those methods, which deal separately with the spatial information and each spectral band. The most commonly used methods like IHS (Intensity-Hue-Saturation) and PCS (Principal Component Substitution) belong to the first category. Methods like Brovey, HPF (High Pass Filter), etc., belong to the second category. While classification of multi-source data (e.g. microwave and optical, together) is feature level data merging, the integration of various thematic layers in GIS to arrive at a common plan is a decision-level merging technique.

Geographical information system

Geographical Information System (GIS) is a computer-assisted system for capture, storage, retrieval, analysis and display of spatial data and non-spatial attribute data. Analysis models comprise simple user defined views to complex stochastic models. Some of these are reclassifications, aggregation, overlays, suitability analysis, network and route analysis, optimization, allocation/siting, etc. The data can be derived from alternative sources such as survey data, geographical/topographical/aerial maps or archived data. Data can be in the form of locational data (such as latitudes/longitudes) or tabular (attribute) data. Applications of GIS range from simple database query systems to complex analysis and decision support systems. Areas of applications range from natural resources management to crime control and near real time application like flood warning. GIS techniques are playing an increasing role in facilitating integration of multi-layer spatial information with statistical attribute data to arrive at alternate developmental scenarios[17].

Development of the software for analysis of remote sensing data has been a thrust area of ISRO, which have progressed gradually with improvements in sensor characteristics and user requirements. The algorithms and software were developed to derive geophysical parameters as well as for data fusion, automatic geo-registration and classification, etc. Many of the project outputs and associated knowledge base needs have been disseminated in the form of a composite package (GIS and applications tools) among the collaborating agencies. The Space Applications Centre has taken a lead role to develop indigenous GIS (IGIS) software with open geodata model. The IGIS is developed for planning various natural resources and avoid the dependency on commercial software to meet the needs of users across the country. The OGC open geodata model with PostGre RDBMS has been adopted for the development of IGIS software. The IGIS is a modular package and different modules are used to create geospatial databases, editing, creating topologies, analysis, query, retrieval, map composition, coordinate transformation, data conversion facilities, database validations, image restoration, geo-processing, image enhancements, image classification, etc.

Evolution of Indian earth observation systems

The choice of sensor parameters is one of the most critical concerns for both users of the data and designers of the sensors. The observational requirements in terms of spatial and temporal resolution are different for different applications as time and spatial scales vary significantly with regard to land, ocean and atmospheric phenomenon. In order to meet the observational requirements pertaining to assessment of natural resources, a series of Earth Observation (EO) systems have been launched in both polar and geosynchronous orbits. Detailed specifications of all the sensors and satellites are given in Table 1. Joseph[18] has reviewed different types of sensors, along with their principles of operation and various tradeoffs. Kasturirangan[19] has discussed the technological issues associated with the designing of optical remote sensing sensors. Navalgund[4] has given an overview of Indian EO system from the perspective of observational requirements and evolution of present and future sensor systems. A brief summary of evolution of different IRS sensors is as follows.

Starting from Bhaskara, the first experimental EO satellite launched in 1979, to the recently launched Cartosat-2 in 2007, a range of spatial resolution ability from 1 km to better than 1 m has been achieved and operationalized. India entered operational remote sensing arena by launching indigenously built satellite IRS-1A in 1988. The evolution of the Indian EO satellites can be classified into three broad categories, viz. first generation of experimental satellites (Bhaskara-1 and 2), second-generation of operational satellites (IRS series) and present generation of theme-specific satellites (Oceansat-1, Resourcesat-1, Cartosat-1 and 2). The Bhaskara-1 and 2 satellites provided necessary experience in handling a total remote sensing system. It carried two payloads, viz. a Television Camera and a Microwave Radiometer. IRS-1A and IRS-1B with identical payloads (LISS-I and LISS-II sensor) were the first operational satellites launched for both marine and land applications. While LISS-I and LISS-II systems were found useful in many national level natural resource management studies, a need was felt to have panchromatic sensor with high spatial resolution for urban mapping. Considering these needs, as a followup to IRS-1A and IRS-1B satellites, IRS-1C and IRS-1D satellites were launched with newer payloads such as Panchromatic camera (PAN), LISS-III camera and a Wide field sensor (WiFS). The PAN camera was the highest spatial resolution (5.8 m) civilian system in the world at the time of launch of IRS-1C satellite in 1995. The four-band multispectral camera LISS-I/LISS-II was modified into four-band multi-spectral LISS-III camera with inclusion of SWIR band in place of the blue band. The SWIR band was included due to need for detection of moisture stress in crops and discrimination of snow from clouds. The WiFS camera was conceptualized from the need of frequent observation for monitoring of crops at national scale. The WiFS camera provided large area information at a temporal resolution of five days, which was found highly useful in national level wheat area and production forecast and cropping system analysis.

While availability of data from the operational EO systems starting from IRS-1A/1B to IRS-1C/1D facilitated applications in the fields of agriculture, forestry, land use, coastal zone, etc., strong need was felt to design application-specific sensors for ocean observations, cartography and land resources. This started the era of theme-specific missions such as Oceansat-1, Resourcesat-1 and Cartosat-1 and 2. Experience gained in ocean colour studies from IRS-P3 MOS data helped to formulate the sensor specifications of IRS-P4 (Oceansat-1), which became the first Indian satellite, primarily built for ocean applications. Oceansat-1 carried Ocean Colour Monitor (OCM) sensor and Multi-Frequency Scanning Microwave Radiometer (MSMR). Resourcesat-1 (IRS-P6) is a mission primarily dedicated to agricultural applications in India. It caries three cameras, viz. LISS-IV, LISS-III and Advanced WiFS (AWiFS). The selection of Resourcesat-1 sensor parameters was based on the experience gained from earlier satellites as well as experimental campaigns conducted over agricultural region. Cartosat-1 and recently launched Cartosat-2 satellites are state-of-the-art remote sensing satellites intended for cartographic applications. The present IRS systems discussed so far, gave an idea of application-driven development of imaging technology, within a span of two and half decades. In addition to the present EO missions, there are specific remote sensing satellites planned in future to address issues of monitoring disasters, ocean observations, atmospheric profiles and global change. The planned EO missions include Oceansat-2, INSAT-3D, RISAT, Megha-Tropiques and Resourcesat-2. The improved OCM, Ku-band Scatterometer, C-band SAR, Imagers and Sounders are some of the important sensors planned in future missions (Table 2).

Applications

Starting from the coconut root wilt disease detection using colour infrared imageries in 1970, Indian remote sensing applications have matured to the present status of operational use in resource management. It is difficult to discuss all these useful applications within the limitation of a single article. We have tried to group the applications into different categories. Scope of remote sensing data under each category and details of a few national level applications has been discussed. Future trends in each application area are indicated.

Towards sustainable agriculture

Agriculture is the world's major user of land, water and biological resources. It is the major source of livelihood of more than 70% of the people of the country. Present day agriculture has two major challenges: increasing productivity to feed the growing population and reducing the environmental degradation caused by the input-intensive agriculture. Earth observation data has enabled achieving sustainable agriculture in the following aspects:

- Increase area under agriculture by identifying culturable wastelands/marginal lands
- Increase cropping intensity through improvised cropping practices like cultivation in kharif/post-kharif fallows
- Increase productivity by providing inputs for retention/improvement of soil fertility, site-specific management of agriculture and increase area under high yielding varieties (HYVs)
- Preservation of eco-diversity
- Create supportive infrastructure (irrigation potential).

The agricultural applications started with field experiments, proceeded to district level estimations and matured into national level programme on an operational mode. One of the major activities in agriculture, which has been very successfully carried out using remote sensing data in the country, is the Crop Acreage and Production Estimation (CAPE) programme. The CAPE project is aimed at preharvest district level crop area estimation and yield-forecasting (six crops in 15 states) using the stratified random sampling approach[20]. It used mainly 5×5 km segments with 10 per cent sampling fraction and single acquisition at optimal bio-window. The CAPE procedures were continuously revised and upgraded to improve upon accuracy and timeliness of crop estimates. The efforts were related to improving (a) sampling design, (b) optimization of date of acquisition, (c) including data from additional spectral region (SWIR), (d) multi-date analysis, (e) use of high spatial resolution data, and (f) use of microwave data in kharif season. A detailed review of the work is given by Navalgund *et al.*[20] and Dadhwal *et al.*[21]. The significant achievements and associated advances in sensor system for improvements in crop production forecasting are summarized as below:

(1) As part of the joint experiments programme, field-based spectral signature measurements over different crops during entire growth were carried out to find the optimal bands of IRS sensors. The availability of LISS-I and LISS-II sensor onboard IRA-1A and IRS-1B mission started the operational utilization of satellite data for crop inventory, in the form of CAPE.

(2) With experience of CAPE in phase-I period, it was found that 22-day repetivity of LISS-I and LISS-II data has limited potential for homogenous single crop-dominated region and is inadequate for capturing the crop growth profile. The studies carried out at different sites in India found that additional SWIR band can improve classification accuracy for wheat gram, mustard[22], groundnut[23] and rice[24].

(3) The improvement in sensor configuration in terms of spatial resolution (23.5 m LISS-III), temporal resolution (5 days WiFS) and inclusion of SWIR band (LISS-III) in subsequent satellites, viz. IRS-1C and IRS-1D showed a new dimension in crop discrimination analysis. The wide swath coverage and the ability to quantify distinct crop growth temporal patterns of different crops using WiFS sensor led to national level wheat production forecasting programme (Figure 4).

(4) Studies were carried out[25,26] to arrive at optimal sensor resolution based on field size considerations (Figure 5) and classification accuracy assessment (Figure 6). It was observed that better than 70 m spatial resolution is required to identify field size of 3 ha assuming 0.5 pixel border effect and geometric error effect of 0.25 pixels to account multi-date registration. Inter sensor evaluations of IRS-LISS-I, LISS-II, LISS-III and WiFS sensor data showed considerable increase in classification accuracy (~11%) from 188 m to 72 m resolution with only modest increase in accuracy (~5%) between 72 m and 23 m. It was decided to have Advanced WiFS (AWiFS) sensor with 56 m spatial high with high temporal (5 days) and radiometric (10 bit) resolution for regular crop monitoring (Figure 7) over India to meet the need for national scale multiple crop inventories.

(5) The Resourcesat-1 satellite was exclusively designed to have continuity of LISS-III sensor, added with capability of resolving within-field variability using multi-spectral

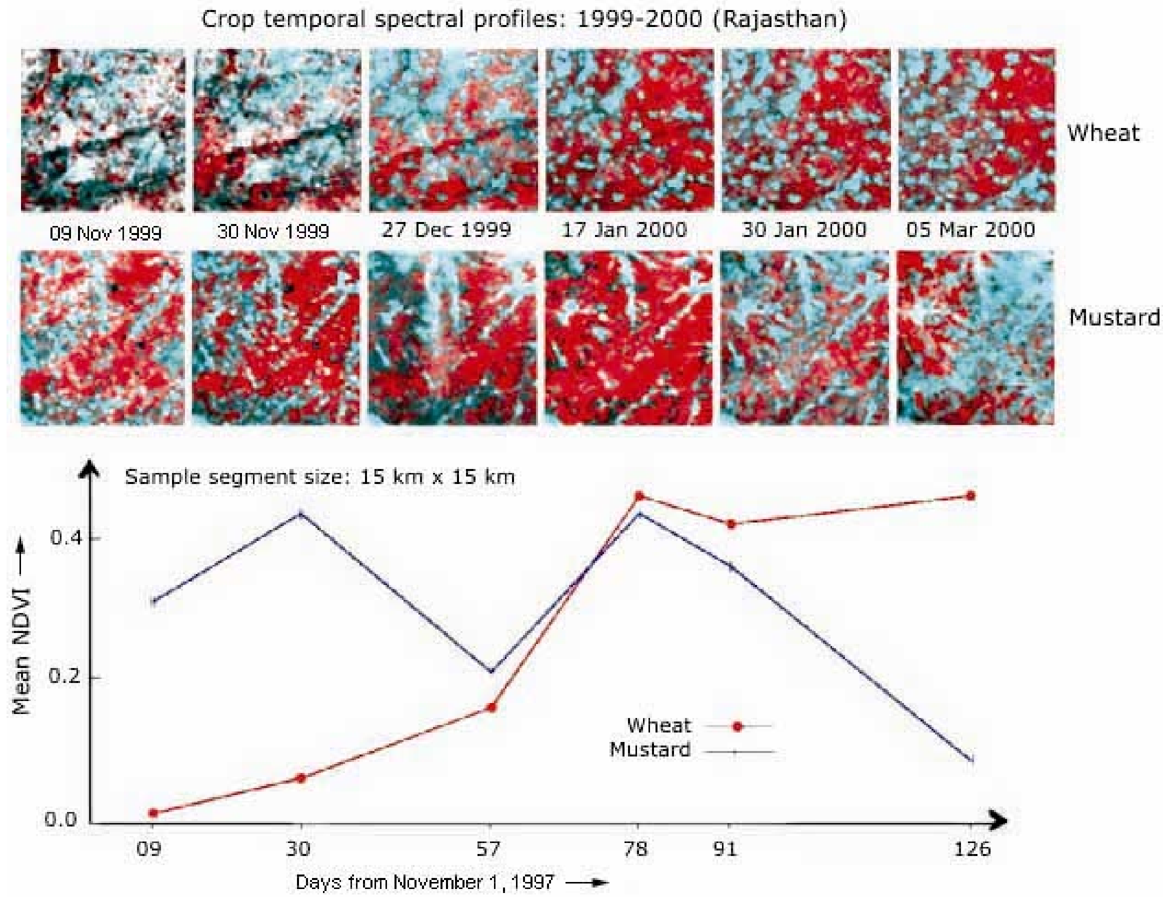

Figure 4. Multi temporal observations over agricultural region showing different growing pattern of wheat and mustard crops in India.

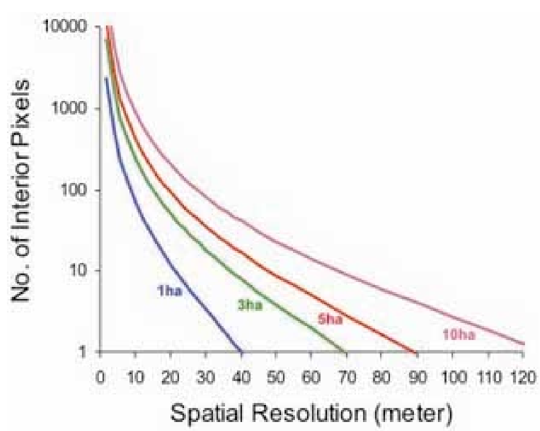

Figure 5. Number of pixels, which can be accommodated for a given field size at different spatial resolution, considering 0.50 and 0.25 pixel, border and geometric error respectively[25].

LISS-IV sensor (improved PAN with 5.8 m spatial resolution) as well as capturing the temporal dynamics of crops with moderate spatial resolution AWiFS sensor from the same platform. Currently multi-temporal IRS-AWiFS data is regularly used to make national level wheat production forecast (Table 4).

(6) As most of the rice crop is grown in kharif season (monsoon), coinciding with the overcast cloudy conditions of the sky most of the time, microwave SAR data is being used to generate national level rice estimates[27].

(7) Realizing that remote sensing data cannot provide a stand-alone system for making multiple and reliable forecasts[28], a novel programme, viz. FASAL (Forecasting Agriculture using Space, Agrometeorology and Land-based observations) has been conceptualized and being institutionalized[8].

Wastelands both unutilized culturable and nonculturable lands have been mapped for the entire country identifying 55.27 m ha (17.45 per cent of geographical area). This has triggered initiating various afforestation, watershed development and land reclamation programmes. Another important activity towards sustainable agriculture is integrated watershed development. Various steps involved in this programme are: generation of thematic maps, generation

Table 4. National wheat production forecast using remote sensing data[8]

Year	Date of forecast	Remote sensing*		DES	
		Area (mha)	Production (m tonne)	Area (mha)	Production (m tonne)
1996–97	02–Apr–97	26.09	64.98	25.89	69.35
1997–98	30–Mar–98	26.28	67.20	26.70	66.35
1998–99	31–Mar–99	26.60	72.88	27.52	71.29
1999–00	31–Mar–00	26.88	70.20	27.49	76.37
2000–01	28–Mar–01	24.29	68.37	25.73	69.68
2001–02	01–Apr–02	26.42	73.57	25.92	71.81
2002–03	31–Mar–03	25.25	70.71	25.24	69.32
2003–04	30–Mar–04/27–Apr–04[$]	26.39	73.08	26.62	72.10
2004–05	28–Mar–05	26.43	72.93	26.49	72.00
2005–06	29–Mar–06	26.30	70.67	26.9[#]	69.48[#]

*The area is estimated using multidate remote sensing data. Production is the area multiplied by yield, which is forecast using agrometeorlogical models.

[$]Revised forecast given using weather data up to March end.

[#]As on December, 2006.

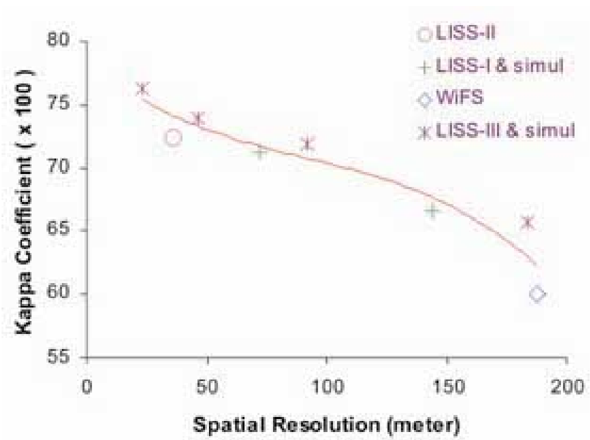

Figure 6. Effect of spatial resolution on classification accuracy assessed using different sensors onboard IRS satellite[26].

and implementation of action plans through participative management and impact assessment[29]. The entire work was carried out in three phases covering 175 districts in different agro-climatic zones covering about 84 m ha (25% of the total geographical area[30]). Studying cropping patterns, crop rotation and adopting cropping system approach towards sustainable agriculture has been another important area of application[31].

Mapping salt-affected soils, monitoring their reclamation[32], identification of post-kharif fallow lands, identification of suitable sites for horticulture cultivation, evaluation of irrigation performance of command areas[33], environmental impact assessment of agriculture, especially methane emission from rice crop[34] are some of the other applications carried out which aim towards sustainable agricultural development.

Development of better crop models using RS and GIS, crop insurance product development, physiological process-based models for crop condition assessment, carbon auditing from agricultural areas, development of a food security system, farm variability and precision farming, crop production functions for different cropping systems, nutrient cycling in agro-ecosystems, impact of climate change on agriculture and fish-stock assessment are a few of the R&D areas which need to be taken up.

Ocean colour and fishery

The operational OCM sensor onboard IRS-P4 has provided excellent opportunity to monitor and study the bio-geological character of ocean around India. Algorithms have been developed to correct the OCM radiance data for atmospheric interferences (Figure 8) and for the retrieval of chlorophyll pigment and total suspended matter, characterization of coloured dissolved organic carbon, underwater diffuse attenuation coefficient and marine atmospheric aerosol optical depth. The total signal received at the satellite altitude over ocean is dominated by radiance contribution through atmospheric scattering processes, and only 8–10% signal corresponds to oceanic reflectance. In a signal scattering approach, the reflectance received by a satellite sensor at the top of the atmosphere (TOA) in a spectral band located at a wavelength λ, $\rho_t(\lambda,)$ is divided into the following components:

$$\rho_t(\lambda) = \rho_a(\lambda) + \rho_r(\lambda) + T(\lambda)\rho_g(\lambda) + t(\lambda)\rho_w(\lambda)$$

where ρ_a and ρ_r are reflectance generated along the optical path by scattering in the atmosphere due to aerosol and Rayleigh scattering, ρ_g is the specular reflection or sun glitter component and ρ_w is desired water leaving radiance. The T and t are the direct and diffuse transmittance terms respectively. The reflectance ρ is defined as

$$\rho = \pi L / \mu_0 F_0,$$

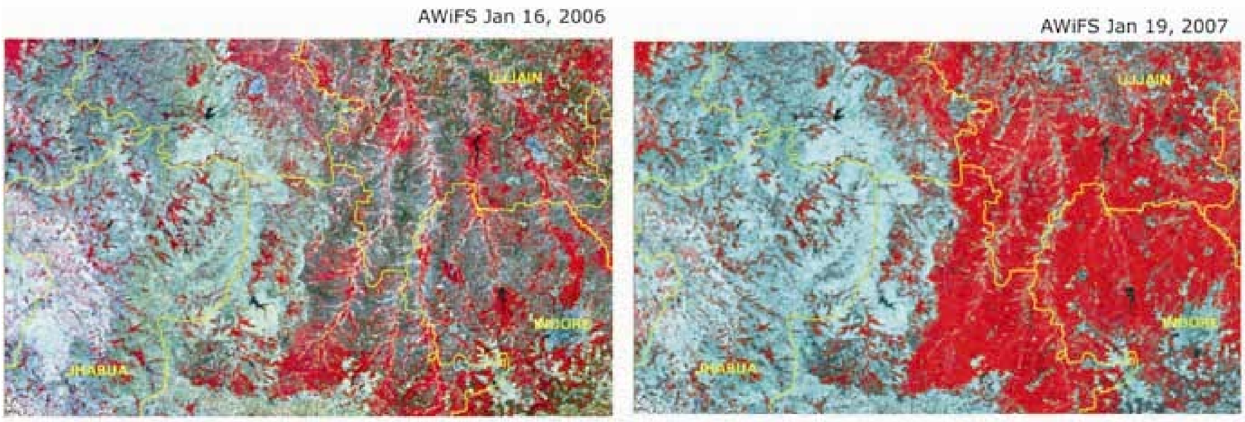

Figure 7. Change in wheat growing area in Western M. P. as seen using AWiFS data.

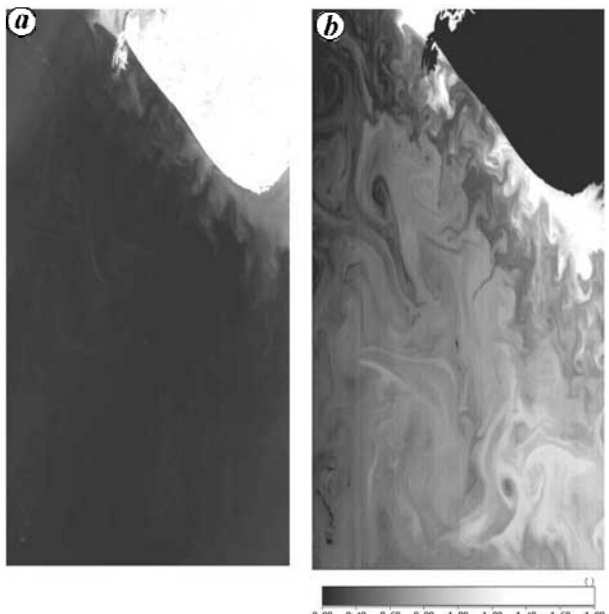

Figure 8. The effect of atmospheric correction in Ocean Colour Monitor (OCM) data (Off Gujarat, February 27, 2000). The image (***a***) refers to uncorrected and (***b***) refers to atmospherically corrected data.

where L is the radiance in a given solar and viewing geometry, F_0 is extra-terrestrial solar irradiance and μ_0 is the cosine of the solar zenith angle.

Biophysical features and processes act as catalysts for the accumulation of fish in a given zone in ocean. 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 (Figure 9), currents, mixed layer depth, internal waves, winds, oxygen, salinity, predator–prey relationship, etc. Upwelling results in bringing nutrient-rich cooler water to surface leading to enhanced biological activity. This phenomenon manifests in the form of anomalies/gradient in SST pattern.

The technique developed for the PFZ (potential fishing zone) forecast (up to 2–3 days in advance), which combines chlorophyll information from OCM and SST from NOAA–AVHRR has been validated with a number of ship campaigns in the Indian waters. Results have shown 70–90% success in PFZ identification. Ocean colour data conjunctively with SST are operationally used to prepare fishery prospect charts to help fishermen[35]. The sensor characteristic of OCM was designed by keeping in mind the requirements of applications like PFZ, scale features of eddies, sediment transport near ports harbours, and dispersal of industrial pollutants in the coastal waters, shoreline changes, etc. High radiometric accuracy (12 bit), eight spectral channels (bandwidth ~20 nm) and spatial resolution of ~350 m with the repetivity of two days was designed to meet the above goals. Algorithm details and other sensor-related issues of OCM are reported by Chauhan *et al*.[36] and Mohan and Chauhan[37].

Water security

Information needs for water security and management are of diverse nature ranging from mere inventory of surface water bodies to more complex irrigation performance, groundwater exploration, snow-melt run-off forecast, flood forecasting, reservoir sedimentation, etc. Providing safe drinking water to hundred thousands of villages is a priority. Groundwater distribution is subject to wide spatio-temporal variations, depending on the underlying rock formations, their structural fabric and geometry, and surface expression. The remote sensing data in conjunction with sufficient ground truth information provides information on the geology, geomorphology, structural pattern

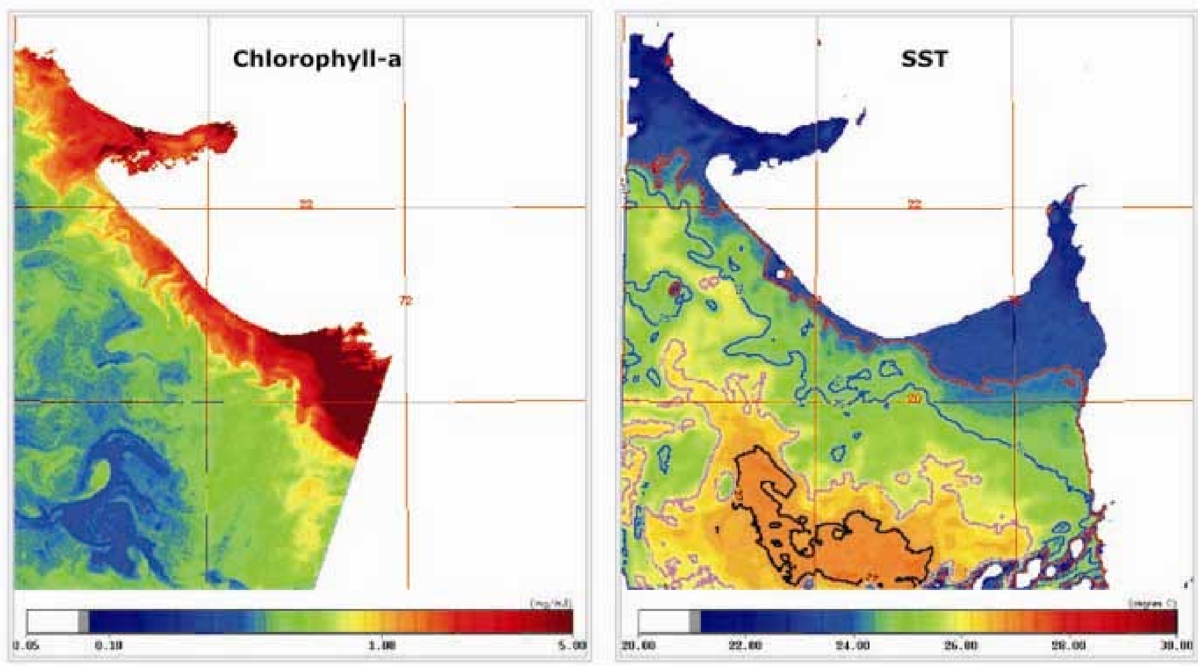

Figure 9. Estimation of Chlorophyll-*a* using OCM data and Sea Surface Temperature (SST) using AVHRR data for fishery management.

Table 5. Success rate of remote sensing based groundwater prospect mapping under Rajiv Gandhi National Drinking Water Mission (RGNDWM)[38]

State	No. of wells drilled as per groundwater prospect maps	Success rate (%)
Andhra Pradesh	29,873	90.0
Chattisgarh	19,503	90.0
Gujarat	34	100.0
Karnataka	5213	93.0
Madhya Pradesh	7730	92.0
Kerala	10,430	90.0

and recharge conditions which ultimately define the groundwater regime (Figure 10). Groundwater prospect maps showing probable regions, where wells can be drilled have been generated, using satellite data conjunctively with ground information. These maps show yield range at different depths besides indicating sites for recharging aquifers and water harvesting structures. Such work has facilitated identifying sources of drinking water for deprived villages[38]. Following national level hydrogeomorphic mapping showing groundwater prospect areas on 1 : 250000 scale, more detailed maps for ten priority states on 1 : 50,000 scale have been generated in GIS environment, under the Rajiv Gandhi National Drinking Water Mission. The feedback has shown more than 90% success rate, when wells were drilled based on groundwater prospect maps generated using RS data (Table 5). These maps have been extensively used for locating prospective groundwater sites in and around problem villages. Through remote sensing, the suitable areas for recharging the aquifers can also be brought out as the better rechargeable areas, which have porous lithologies, maximum fractures, highly weathered region, flood plains, regions of null slope, etc.

Synoptic and repetitive information provided by EO satellite data has been extensively used to map surface water bodies, monitor their spread and empirically estimate volume of water. Monitoring reservoir spread through seasons has helped irrigation scheduling. Snowmelt runoff forecasts are being made using IRS-AWiFS and NOAA–AVHRR data. These forecasts have enabled better planning of water resources by the respective reservoir management boards.

Inventory of the Himalayan glaciers and monitoring their retreat is another important area of study related with global climate change and water security. Identification and mapping of glacier boundary and terminus is an important aspect of estimation of retreat (Figure 11). The changes in glacial extent and their influence on river runoff are used to plan strategy of power generation. Satellite data helps in identification of snow, ice and rock due to substantial differences in spectral reflection of these surface features. Glacial depth is required in knowing volume of glaciers and are normally estimated using radio-echo sounding method. Glacier depth can also be inferred using geomorphological classification and glacial aerial extent using the remote sensing data. A recent study[39] has shown an overall reduction in glacier area of Chenab,

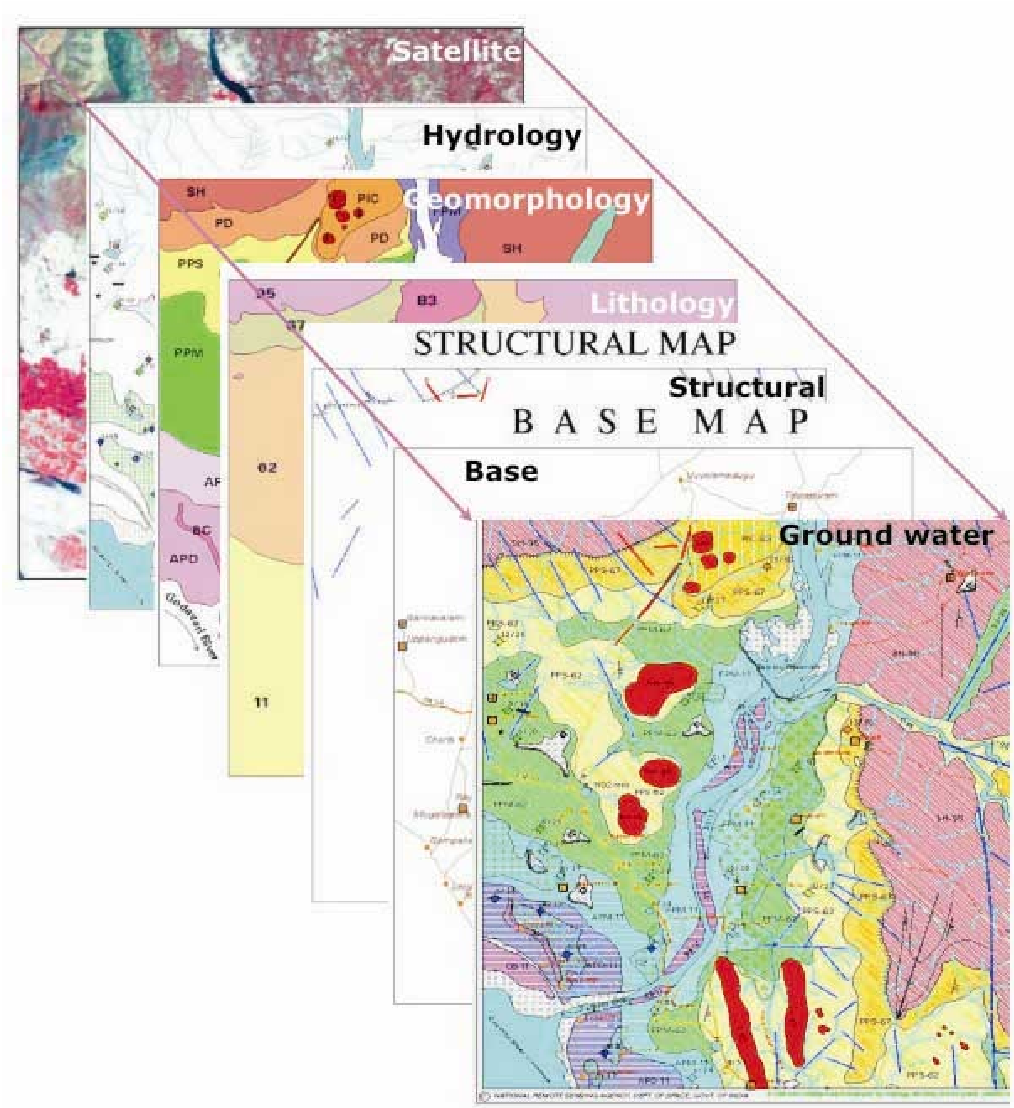

Figure 10. Satellite image and various derived geo-spatial inputs used in generation of groundwater prospect map in GIS environment. VIBGYOR colour code is used in denoting degree of ground water prospect. While, violet indicates high prospect for ground water occurrence, red coloured region shows no prospect for groundwater. The digital map also shows position of no-source villages and sites for recharge structures.

Parbati and Baspa basins from 2077 sq. km in 1962 to 1628 sq. km at present, with an overall deglaciation of 21% (Table 6).

Study of performance of hydrological models under different hydrologic and hydraulic conditions, modelling of catchment sediment erosion and deposition into storage reservoirs, inter-basin water transfer for optimum utilization of water resources, two-dimensional and three-dimensional sub-surface modelling in groundwater studies, study of palaeochannels in desertic regions, groundwater budgeting and impact of climate change on the Himalayan glaciers are some of the areas, which need to be addressed.

Environmental assessment and monitoring

The main thrust of environmental studies aims at monitoring and understanding of structure, composition and function of different vulnerable ecosystems to regulate the impact of developmental activities and sustain the delivery of natural ecosystem functions and services.

One of the important missions has been the first national level remote sensing-based mapping of forest cover of the country in 1983. Since then, the Forest Survey of India is carrying out biennial forest cover mapping. The advent of high resolution IRS-P6 Resourcesat has enhanced the capacity to prepare forest type and density

Table 6. Basin-wise loss in glacier area in Himalayas[39]

Basin	Glacier number	Glacier area (km^2)			Volume (km^3)		
		1962	2001–04	Loss (%)	1962	2001–04	Loss (%)
Chenab	359	1414	1110	21	157.6	105.03	33.3
Parbati	88	488	379	22	58.5	43.0	26.5
Baspa	19	173	140	19	19.1	23.0	23.0
Total	466	2077	1628	21	235.2	30.8	30.8

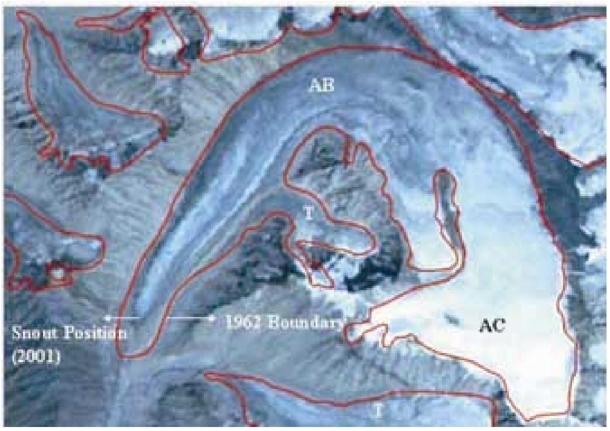

Figure 11. IRS-LISS-III FCC (bands 1, 2, 3) showing glacier boundary of 1962 and retreating glacier. The fragmentation of the tributary glacier from the main trunk glacier is also seen on the image. AB – Ablation zone, AC – Accumulation zone, T – Tributary glacier.

Table 7. Mangrove area (km^2) in different states as monitored using satellite data[47]

Region	Area (1986)	Area (1990–93)
Andaman & Nicobar	922.0	762.0
West Bengal	2067.0	1838.0
Orissa	203.0	187.0
Andhra Pradesh	322.0	380.0
Tamil Nadu	30.0	23.0
Karnataka	11.3	8.7
Goa	5.5	6.7
Maharashtra	124.0	222.0
Gujarat	767.0	1012.0
Total	4451.8	4439.4

maps and generate forest-working plans. Afforestation and deforestation could also be assessed using multi-temporal satellite data. Vegetation mapping for the South Central Asian Region, using multi-temporal SPOT-4 VEGETATION, Biome level vegetation characterization for entire India using multi-temporal IRS WiFS data[40] and broad level vegetation type mapping for the entire country on 1 : 50,000 scale using IRS LISS III data have been carried out. The information generated by the aforesaid programmes is extensively used in conjunction with ground based related information in geospatial domain for spatial explicit quantification and process understanding related to biodiversity assessment, landscape change and simulation, carbon sequestration, hydrology, generic ecosystem patterns, EIA studies and regional climate models. One of the important studies undertaken in this regard is the collaborative effort on landscape level characterization of biodiversity using remote sensing and GIS[41]. The study has focused on identification of disturbance areas and biological richness areas for conservation and bioprospecting over North East region, Western Ghats, Andaman and Nicobar islands, Central India, Eastern Ghats and the East coast.

Mangrove forests, coral reefs and wetlands are critical habitats of the coastal zone. Information required for the purpose of coral reefs includes spatial distribution of the reefs, vegetation cover, reef zones and reef morphology, biodiversity of fauna and condition assessment[42]. EO data have been used to prepare maps showing the extent and condition of coral reefs and the extent, density, condition and diversity of the mangroves. Table 7 shows the mangrove area in different states monitored using remote sensing data.

Land use/land cover dynamics and its prediction, retrieval of forest parameters using high-spatial resolution and hyperspectral data, species identification, biodiversity monitoring and change modelling, vegetation stress analysis, disease detection, forest ecosystem responses to climate change and anthropogenic impacts and ecological foot printing analysis for sustainable development are a few important R&D areas which need to be addressed.

Disaster monitoring and mitigation

The country is vulnerable to several types of disasters causing widescale human and financial losses, every year. Hence disaster mitigation has been one of the prime concerns of remote sensing applications of the country. A Disaster Management Support Programme (DMSP) has been initiated with the setting up of a Decision Support Centre (DSC) at NRSA[43] in 2003. IRS series of satellites and available microwave data from the international satellite missions as well as aerial photography/Airborne Laser Terrain Mapper (ALTM)/Airborne SAR (ASAR) provide necessary data.

Using aerospace data, near-real time flood monitoring is operationally carried out, wherein administrative (village) and current land use layers are overlaid in GIS on the satellite-data-derived inundation layers to identify affected settlements, damage assessment and for relief purposes. Agricultural drought is another important weather-related natural disaster. A National Agricultural Drought Monitoring System (NADAMS) project gives fortnightly information during monsoon season at district level using satellite-derived NDVI information as input[44].

Remote sensing data has also helped in the preparation of landslide hazard zonation maps using databases on lithology, geological structures, slope, vegetation and land use. For earthquakes, seismic hazard zonation is an important step. Space data provide critical spatial inputs, like geological structures, lithology, geomorphology, etc., for integrating with other databases for hazard zonation. Availability of high-resolution data provides necessary inputs for micro-seismic hazard zonation.

Towards meeting these national requirements, necessary National Databases for Emergency Management (NDEM) are being created as a GIS-based repository of data to support disaster/emergency management in the country. The information generated in the DSC is operationally disseminated to various state relief commissionerates, including the Ministry of Home Affairs, Government of India through a Virtual Private Network (VPN) using INSAT communication capability. DSC also provides IRS data to the disaster-affected countries around the world through the International Charter on Space and Major Disasters, wherein many space agencies are partners.

Weather and climate studies

Pursuing high quality research in meteorology using satellite inputs from the Kalpana, INSAT-3A and upcoming INSAT-3D and Megha-Tropiques missions to arrive at weather forecasting models is yet another area of importance. The efforts focus on the retrieval of parameters from satellite data and their validation and use in the application areas of monsoon dynamics, numerical weather prediction, ocean state forecasting, tropical cyclone intensity and track prediction. Towards densifying the networking on ground to provide *in-situ* data for appropriate integration with the weather models, development of Automatic Weather Stations (AWS), AgroMet Towers and Doppler Weather radars (DWR) has also been taken up with the help of industry, besides launching efforts to develop appropriate meso-scale weather models to provide local level weather information.

Infrastructure development

Infrastructure development is essential to improve the quality of life for any country, more so for a developing country like India. With the integration of high spatial resolution remote sensing data with advanced image analysis techniques, GIS and GPS, the country has carried out many infrastructure development projects. Some of the physical infrastructure projects include perspective and development plans for urban areas, road alignment and rural road connectivity, ranking of micro-hydel sites for power plants and detailed facility and utility planning.

Urban flood modelling, urban environment and impact assessment, automated feature extraction techniques for roads, urban drainage planning and modelling, 3D city models for disaster, peri-urban area mapping and monitoring, solid waste/land fill sites, identification of archaeology and heritage building sites, utility GIS are some of the other important areas being addressed.

Community-centric applications

Some of the recent initiatives towards community-centric applications harnessing the convergence of various geospatial technologies and satellite communication are briefly mentioned here.

Village resource centre

To address the changing and critical needs of the rural community, a unique experiment of setting up Village Resource Centres (VRCs) in partnership with the reputed NGOs and others has been initiated recently. Capabilities in satellite communication and satellite-based earth observation are aptly integrated to disseminate a variety of services emanating from the space systems and other IT tools. VRCs are envisaged as the single window delivery mechanism for a variety of space-enabled services and deliverables such as telemedicine; tele-education; information on natural resources for planning and development at local level; interactive advisories on agriculture, fisheries, and land and water resources management; livestock management; interactive vocational training towards skill improvement, alternate livelihood; e-governance services; weather information, etc. More than 170 VRCs have been setup with active NGOs and many more are in the offing in the coming years.

Tsunami GIS for relief and rehabilitation

Remote sensing inputs are used in mapping tsunami-affected areas and generating GIS digital database for planning relief and rehabilitation measures. The focus of the entire work was to map the inundation and to relate with land use/land cover, geomorphology, transport and settlement etc. Vectorized cadastral maps were integrated with the other GIS layers to enable the state to make parcel-wise assessment of land use and geomorphology for

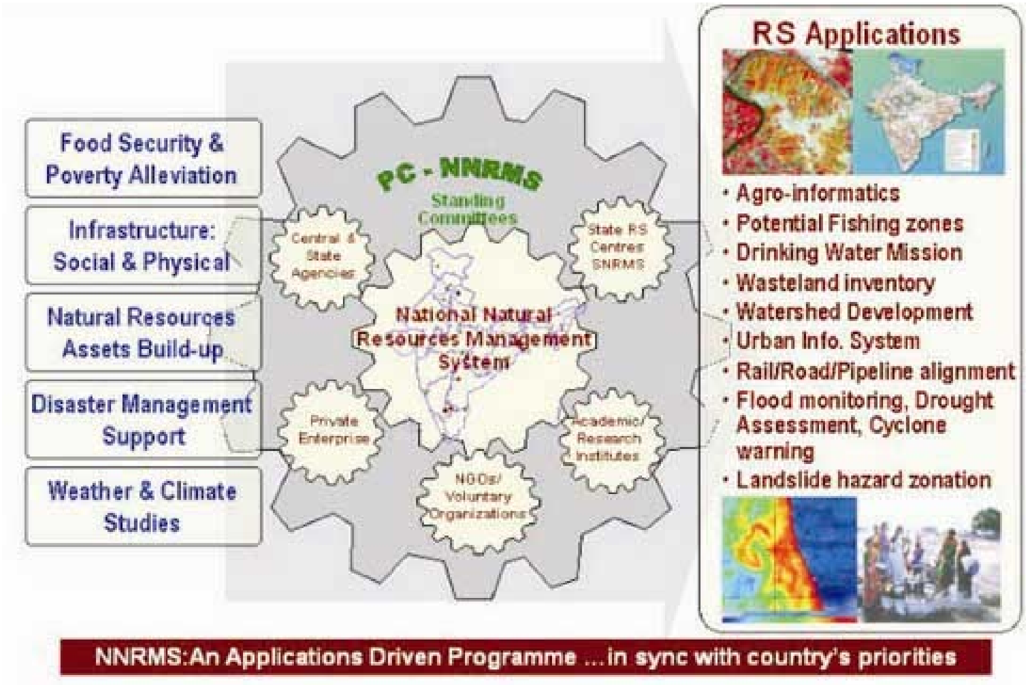

Figure 12. Indian EO programme addresses national priorities through institutional framework of NNRMS.

every village for the entire coastal areas of Nagapattinam. Corresponding statistics related to parcel-wise inundation are also provided for taking up necessary relief measures.

Other such community-centric applications include the Sujala Watershed Project, where remote sensing derived maps/inputs at cadastral level along with socio-economic data are used to assist the implementing agencies in generating action plans and monitoring the social and environmental changes in Karnataka and the Chhattisgarh GIS Project, which envisages generation of a comprehensive database for a variety of applications, development of land information system through georeferencing of village maps and creation of road information system. The latter project is funded by the village panchayat itself.

National natural resources management system: Institutional framework

The National Natural Resources Management System (NNRMS) set up under the Planning Commission, with the Department of Space as the nodal agency is envisaged to provide necessary guidance/support to the user community to take up various projects of direct relevance to national development, by integrating remote sensing and GIS into the conventional practices (Figure 12). Towards this, extensive infrastructural facilities have been established which include five Regional Remote Sensing Service Centres (RRSSCs) and a number of State Remote Sensing Applications Centres. To take care of the coordination of remote sensing activities in the country, the Planning Commission has formed ten high power Standing Committees on various themes like: Agriculture and Soils; Bio-Resources and Environment; Geology and Mineral Resources; Oceanography; Rural Development; Urban Management; Water Resources; Training and Technology; Cartography and Mapping; and Meteorology. A planning committee of NNRMS chaired by Member (Science and Technology), Planning Commission, Government of India provides overall policy guidelines to its activities. The Indian Earth Observation Programme continues to serve as the mainstay of NNRMS, with planned missions both in IRS and INSAT series of satellites[45].

The NNRMS activities have been restructured in the recent times to reflect the changing technological and applications dimensions in the country and elsewhere. Accordingly, a 3-tier strategy is being considered with (a) user funded projects meeting the objectives/goals of the user departments/agencies both at the national and regional/local scale; (ii) organizing the spatial databases with GIS capabilities and working towards a Natural Resources Repository with a front-end NNRMS portal for data and value-added services; and (iii) taking cognizance of the convergent technologies, integrating satellite communications and remote sensing applications for disaster management and Village Resource Centres with the concept of working with the community. It is envisaged that such an integrated approach with closer inter-related horizontal and vertical connectivity will provide an organized NNRMS data and value added services directly to the community/PRIs for grassroot level development.

Natural resources database and national spatial data infrastructure

In order to facilitate e-governance, there is a need for creating a system of information, both spatial and aspatial, which can be retrieved, queried and networked. Such a system can be used for planning at local to regional level. Keeping this in view, a Natural Resources Database (NRDB) has been created, which consists of databases of spatial information, with common standards and accessible to all. These databases include 21 primary layers, viz. landuse, geomorphology, soil, etc., and eight derived layers and action plans. NRDB integrates the databases created under various projects and plans to make them available to the user community through a portal. The Department of Science and Technology (DST) had set up a task force for preparing strategy for National Spatial Data Infrastructure (NSDI) for the availability of and access to organized spatial data and use of this infrastructure at community, local, state, regional and national level towards sustainable economic growth. The NSDI involves 16 agencies in the country (DOS, DST, SOI, GSI, FSI, NIC, CGWB, CD, NATMO, NRSA, CWC, DOD, NCAER, MoEF, CPCB and IMD) with an objective to provide gateway for dissemination of spatial data, being generated by different government agencies. As a part of NSDI, digital databases of different natural resources created under NRDB will cater to the needs of user communities in the country.

Observational gaps

Although data available from various EO systems have been routinely used in many resource management applications, there have been certain gaps and inadequacies in observational data. There is a need for high-resolution data to support infrastructure development, including risk mapping and providing real time support for natural and human-induced disasters. The present sensors on IRS satellites (LISS-IV, LISS-III and AWiFS), although provide valuable input for resource mapping and monitoring, are limited by the absence of thermal channel, which is needed for land surface temperature estimation and quantifying evapo-transpiration in land surface process modelling. The resource management applications, particularly crop assessment and monitoring, would involve inventory of multiple crops in a phased manner, for which the spatial resolution of AWiFS and temporal revisit of LISS-III are not adequate. Moreover, estimation of biophysical parameters such as LAI, fAPAR would require atmospherically corrected surface reflectance. Non-availability of co-existing sensor, which characterizes the atmospheric properties such as aerosol optical thickness and water vapour, is another gap area. In view of limited availability of optical data during monsoon period and the sensitivity of microwave data to volume scattering, there is an urgent need for space-borne SAR. Non-availability of hyperspectral data is a limitation for many applications.

The major gap areas in the field of ocean applications are in observations of ocean salinity, surface pressure, wave spectra, sea level anomaly and more frequent observations of wind vector and coastal ocean parameters and estimation of SST with better resolution especially in the Indian Ocean region. The major task in biological ocean application is algorithm development for case II waters and validation of ocean colour products and estimation of primary productivity and fish stock assessment. There is a need to carry out coastal processes study and develop coastal zone information system (CZIS). Major gap area in this field is simultaneous observation of ocean colour and sea surface temperature.

The major emphasis of the meteorological applications includes observation on atmospheric state variables, atmospheric composition, ocean characterization and study on land–ocean–atmospheric interaction. Development of the advanced technique for data assimilation in atmospheric models, extended range monsoon prediction and regional climate modelling are major research areas, which is limited by gaps in EO data from the Indian satellites. The gap areas include need for atmospheric sounders, with hyperspectral channels on INSAT platform and requirement of constellation of precipitation radar.

Future perspectives

Integrating EO products and services with multi-institutional framework and people's participation in decision-making process relevant to society stand as the principle for future direction of EO application programme. This would turn the direction of working from being a 'data provider' to 'service provider' by giving end-to-end solutions. As part of this, food security, water security, environmental monitoring and infrastructure development are going to be the mainstay of applications with a focus on rural development. On the other hand, the ecosystem responses and disaster monitoring and mitigation, and climate change studies would also stand as important activities as they would ultimately impact the overall development.

In order to achieve these, there is requirement for development of new sensors, some of which are defined in Table 8. India plans to launch many of these sensors in the near future[2]. The new missions would fill the gaps in terms of spectral, spatial and temporal resolutions in both optical and microwave regions. The constellation of polar and geosynchronous satellite missions is also envisaged

Table 8. Future requirements of earth observations sensors for land and ocean applications

Application area	Sensor requirement	Specifications	Possible applications
Land	High spatial and temporal resolution multispectral	4 bands in VNIR–SWIR; resolution: 20–30 m, 5 day repetivity, >700 km swath	Multiple crop forecasting
	High temporal and moderate spatial resolution sensor	VNIR, SWIR, MIR and TIR bands, Resolution: 50–100 m (VNIR), 250–500 m (TIR), Daily repetivity, wide swath ~1000 km	Regional vegetation monitoring; parameter retrieval
	Very high spatial resolution pan	Panchromatic, resolution: <40 cm, ~8 km swath, spot imaging stereo pairs	1 : 1000 scale mapping, urban and local area planning, facility management, city 3-D modelling
	Hyper-spectral sensors	Large number of narrowbands (0.4–2.5 μm), ~10 nm bandwidth, 20–30 m resolution, 20–25 day repetivity	Applications in forestry, agriculture, coastal zone and inland waters, soil, geology
	Atmospheric corrector	Coarse resolution (500 m); 4 bands (485, 940, 1625, 2100 nm).	Need for simultaneous measurement along with other multi-spectral sensors for atmospheric correction
	Synthetic aperture radar (SAR)	Dual frequency (L and C band) polarimetric system	Crop monitoring, soil moisture, tree canopy
Ocean	Scatterometer	Spatial resolution: 25 km (open), 1 km (coast); temporal resolution: 6 hourly	Wind speed and direction, sea ice
	Altimeter	Spatial: 3 km; 50–100 km (coast); temporal: daily	Sea level, wave height
	Thermal sensor	Bands at 11 and 12 μm; spatial resolution ~1 km and NEDT ~0.05 K	Sea surface temperature
	Synthetic aperture radar (SAR)		Bathymetry, wave-spectra, wave height
	Salinity sensor	Frequency: 1 GHz; spatial resolution: 50 km (open)	Ocean salinity
	Ocean colour monitor	12 bands between 400 and 1100 nm; 300 m spatial and daily temporal resolution	Retrieval of ocean bio-geo-chemical parameters; atmospheric correction

to improve detection, monitoring and assessment of disasters. The space-borne microwave and hyperspectral sensors would form the important basis in ecosystem quantification, retrieval of geophysical and biophysical parameters. In order to realize the above missions and derive maximum benefit from their use, a number of areas, especially related to ground segment need to be addressed simultaneously. The most important among these is to generate a large number of bio-geo-physical products on near-real time basis and disseminate to users through easily accessible means.

From Bhaskara to Cartosat, India's earth observation capability has increased manifold. Improvements are not only in spatial, spectral, temporal and radiometric resolutions, but also in their coverage and value-added products. We have also entered into the arena of passive and active microwave remote sensing, stereo viewing and viewing from the geo-synchronous platform at moderately high resolution. This sensor development has been complemented by many large applications of national importance, in the fields of sustainable agriculture, water security, environmental security, weather, climate change studies, infrastructure development, disaster monitoring and mitigation. However, there still exist gap areas. To overcome these, ambitious earth observation programme and ground support plans have been envisioned. Thus, the Indian remote sensing programme is geared up not only to achieve its prime goal of national development, but also, in meeting global needs and playing an important role in the Global Earth Observation System of Systems (GEOSS).

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