Geospatial Techniques and their Role in Natural Resources Management

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Assessment of the availability and condition of the natural resources is the first step for the sustainable resources development plan. The assessment process follows a continuum that involves determining the baseline rates or levels of various phenomena, establishing the trends in these measurements or conditions, identifying the causes of rates and trends, and determining the type and impact of consequences of rates and trends. An additional element, mitigation, represents the required follow-on actions in terms of policies or directives. Four key functions that form the process needed to assess the continuum are:

- *Mapping:* collection of thematic and quantitative baseline data (contemporary or historical) in geographic format.

- *Measuring:* more rigorous mapping process by quantifying and documenting the attributes of phenomena.

- *Modeling:* process of describing a system under study through precise and typically mathematical relations of inputs and outputs, and to simulate the present, past or future behaviour.

- *Monitoring:* regular assessment of the conditions by recording the shifts or changes in natural phenomena and human activities.

The induction of modern technologies of geospatial tools like Remote Sensing (RS), Geographic Information System (GIS) and Global Positioning System (GPS) have provided very powerful methods of surveying, identifying, classifying, mapping, monitoring, characterization, and to track changes in the composition, extent, and distribution of several forms of earth resources both renewable and non renewable, living and non-living in nature. 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 assessment; 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.

GPS provides worldwide positionally accurate coordinates, thus, useful to establish geographic location and define the context. A way to acquire recent cost-effective in-situ data, GPS is an important tool for monitoring purpose by acquiring data repetitively about earth features and phenomena. GIS helps in visualization of geospatial data, and the visualization is a convenient and effective way to communicate complex information, e.g natural resource, and increase our level of understanding about these resources. Besides, GIS also allows data generation, editing, storage, and analysis of spatial data important in planning and decision-

making. The technology has been an instrumental breakthrough that permits examining natural resources and environment issues in a geographic context. The key point is that GIS provides a means to investigate problems by allowing modeling various phenomena and examining their relationship, e.g. cause and affect relationship, in a place-based context, meaning we can analyze complex, integrated issues from local to global scales.

All of these systems are useful in addressing the assessment, however, their relevance can vary depending upon the element of continuum (Table 1). As Remote Sensing offers enormous aid to assess rates and trends, GIS is especially functional in examining the causes and consequences. However, an integration of such spatial technologies with other analytical approaches is often desirable to produce better information thereby enhancing our understanding for better management of natural resources.

Table 1: Relevance of geospatial technologies for assessment continuum

Geo-spatial technologies	Rates	Trends	Causes	Consequences	Mitigation
Remote Sensing	High	High	Low	Medium	Medium
GPS	Low	Low	Medium	High	Medium
GIS	Medium	High	High	High	High

Source: Modified from Loveland *et al*., 2000.

Emerging Science of Geo-informatics

Geo-informatics is a fast emerging science encompassing the modern tools of Remote Sensing, Geographic Information System (GIS), Global Positioning System (GPS) and simulation models. The combination of these technologies provide a cost effective means of acquiring high resolution real time data through remote sensing, data management and analysis through GIS and geo-referencing the ground truth data with GPS, putting all data in an information system and utilisation of the information for a specific purpose. It is a new discipline that integrates elements of various disciplines dealing with geographic data. The key element that differentiates geo-informatics from other areas of information technology is that all input data being geo-coded i.e. has an address in 3-D space and linked to some locality on the surface of earth. Thus, geo-informatics is nothing but application of information technology for the study and management of earth resources.

Technology of Remote Sensing

Remote Sensing is the process of sensing, identification, delineation, measurement of surface features and their processes from a distance without directly coming into physical contact. Remote Sensing measures Electro Magnetic Energy (EME) from the sun or emitted by the sensor itself (microwave sensor) which is reflected, scattered or emitted by different surface features on the earth. It 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). The radiation from the scene or a particular area that a remote sensor detects is measured as radiance not reflectance. Detection and measurement of spectral signatures enable identification of the surface features by remote sensing satellites. Remote Sensing provides multi-spectral, multi-sensor and multi-temporal data which help in the generation of accurate, timely and cost effective information on natural resources.

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.

Aerial Photography

Aerial photography is the original form of remote sensing and remains the most widely used method. Aerial photographs are the pictures taken by camera fitted in an aircraft and flying over the terrain at predetermined height depending on the scale of aerial photography and focal length of the camera. Typically, successive photographs contain 50 to 65 per cent overlap which is essential for stereoscopic viewing and analysis of stereo-pairs.

One of the biggest advantages of aerial photographs is that one can see three dimensional view of the area/object using stereoscope. There are different types of aerial photographs, viz vertical/oblique, black and white, infrared, multi-spectral, low or high altitude aerial photographs. Depending upon the objective of study, a particular scale and type of aerial photographs are chosen. Aerial photographs are extremely useful in micro-level investigations when the area involved is small. In India, the Survey of India and other organisations have been using aerial remote sensing (aerial photography) for preparing topographical, geological, soils, forests and land degradation maps.

Satellite Remote Sensing

The satellite remote sensing began with the launch of Television and Infrared Observation Satellite (TIROS-1) in 1960 carrying a single band TV camera which sent back first cloud images of the earth. This was first weather satellite operated by National Oceanic and Atmospheric Administration (NOAA) of USA from April 1960 to July 1966. Successful launch of the Earth Resources Technology Satellite (ERTS-1) by USA in 1972, later renamed as LANDSAT heralded the beginning of the era of satellite remote sensing for natural resources survey and monitoring.

Applications of remote sensing are numerous and expanding. With the availability of variety of satellites including Indian Remote Sensing (IRS) Satellite with increasing range and sensitivity of their sensors and the sophisticated image processing and interpretation facilities, the future of remote sensing looks very promising. Remote Sensing is now accepted as a basic working tool in meteorology, agriculture, crop damage and stress assessment, geology, hydrology, land use planning, urban development, ecology and pollution monitoring. The relatively low cost of remote sensing data has transformed the approach of land use mapping, soil resource inventory and terrain analysis.

With the advent of satellite Remote Sensing in the early 70s after launching of Landsat series of satellites by NASA, USA; SPOT satellite by France and Indian Remote Sensing Satellite (IRS) by Indian Space Research Organization (ISRO), Deptt. of Space, Government of India, there has been an increasing utilisation of satellite imagery for inventory and monitoring of natural resources in India and abroad.

The National Remote Sensing Agency (NRSA) Data Reception Station at Shadnagar near Hyderabad receives data from IRS Satellites in operation, viz. IRS-1C, IRS-1D, IRS-P3, IRS-P4 (OCEANSAT), IRS-P6, (RESOURCESAT-1) and TES (Technology Experiment Satellite) apart from foreign satellites.

Microwave Remote Sensing

One of the major problems faced in the use of optical remote sensing data available from IRS, Landsat, SPOT, etc. in India is the persistent cloud cover during monsoon season. In this context remote sensing data collected in microwave region through RADARSAT-SAR and other satellites is found to have the following advantages:

- All weather capability, specifically it can collect data even in cloudy conditions which is not possible using optical remote sensing sensors/cameras
- Day and night observing capability
- Soil depth penetration in ideal conditions is possible to certain extent

Geographic Information System (GIS)

Geographic Information System (GIS) is a data base management system which effectively stores, retrieves, manipulates analyses and displays spatial information of both cartographic and thematic origin. GIS is a computer based system which can handle large volumes of spatial data derived from a variety of sources such as field surveys, aerial surveys and space remote sensing, in addition to the already existing maps and reports. This involves bringing together diverse information from a variety of sources on a common platform. It requires effective matching of similar entities and demand information consistency across the data sets. Major components of GIS are: Data inputting, Data encoding, Data management, Data analysis and manipulation, Data presentation or output.

Any data that can be mapped has both locational and non-locational characteristics. For example, a feature may exist at an X, Y location and possess an attribute, Z. The attributes can be both qualitative (e.g. land use, geology, etc.) or quantitative (e.g. elevation, population, etc.) and it may sometime vary with time (e.g. temperature, land use, population etc.). These three components viz., location, attribute and time represent the content of most GIS. The real value of any information, derived from any source, depends on whether or not it can be interrelated with other spatially distributed (cartographic) information. This is possible only when the varied information is stored in GIS format. The geographical reference cartesian or latitude/longitude co-ordinate has proved to be an effective means of linkage of data sets and this principle, perhaps more than any other is the reason for the success of GIS.

Most of the GIS have a very useful utility of querying the data sets. By performing query across the data sets of information at random more complex questions can be answered and a far broader range of problems can be solved. GIS are frequently used to answer many types of generic questions e.g. location, condition, pattern routing, modelling, etc. The location question involves querying a data base to determine the types of features which occur at a given place (e.g. what is the population of a given place or tract?). The condition question is really the converse, since it involves finding the location of sites which have certain characteristics (e.g. what is the change in the traffic flow along roads?). The other questions are more complex and involve some type of spatial analysis. The routing question requires calculation of the best (fastest, quickest shortest, more scenic, etc.) route between places (e.g. which is the nearest surgeon specialist). The pattern question allows environmental and social scientists and planners to describe and compare the distribution of phenomena and to understand the processes which account for their distribution (e.g. is there some pattern in the distribution of diseases which are thought to be caused by exposure to radiation?). The final question allows different models of the world to be evaluated (for example, which areas of the earth will be affected by 20 centimetre rise in sea level?).

Geographic Information System (GIS) has been used for integration of spatial data on various resource themes and generate alternate development plan showing site specific primary production activities. Suitability of various combinations of land parameters such as soil, ground water quality, slope, landform, land use/land cover etc., are linked to primary production activities through rule based decision capabilities of GIS package.

Global Positioning System (GPS)

Global Positioning System (GPS) has revolutionized positioning concepts though it started primarily as a navigation system. The Navigation System with Time and Ranging Global Positioning System (NAVSTAR GPS) is a satellite based radio navigation system providing precise three-dimensional position, navigation and time information to suitably equipped users. GPS receivers passively receive signals but they do not transmit.

There are atleast 24 operational GPS satellites at all times. The US Air Force, with an orbital period of 12 hours, operates the satellites. Ground stations are used to precisely track

each satellite in orbit. Each GPS satellite has atomic clock on board and transmits data that indicates it's location and time. All the GPS satellites synchronize operations so that these repeated signals are transmitted at the same instance. The distance to the GPS satellites can be determined by estimating amount of time it takes for their signals to reach the receiver. When the receiver estimates distance to at least four GPS satellites, it can calculate its position in three dimensions.

Most hand held GPS units have about 10-20 meter locational accuracy. To obtain better accuracy a technique called Differential GPS (DGPS) is used. DGPS requires an additional receiver fixed at a "known" location nearby. Observations made by stationary receiver (Base station) are used to correct position recorded by rovering units, resulting in an accuracy greater than one meter. Earlier in order to limit the accuracy for civilian user, the US Government in 1990 deliberately introduced an error in the orbit data and clock accuracy for L1 signals. This part of GPS operation is called "Selective Availability" and has been discontinued since May, 2000 due to wider civilian applications of GPS.

GPS being an all weather, real time, continuously available, economic and very precise positioning technique; with the well established high accuracy achievable with GPS in positioning of points separated by a few hundred of meters to a few thousand of kilometers, this unique surveying technique has wide range of applications in various fields . Some of the important applications are as under:
i)   Geodetic control surveys i.e. location of precise control points
ii)   Geodynamics surveys i.e. determination of recent crustal movements
iii)   Setting out local network for the control of engineering projects
iv)   Monitoring mass movements i.e. ground subsidence and land slides
v)   Geophysical and cadastral surveys
vi)   Precise navigation, Marine geodesy and hydrography

National (Natural) Resources Information System (NRIS)

In order to achieve an environmentally benign development and optimal utilisation of natural resources, it was felt that the National (Natural) Resources Management System (NNRMS) be supported by a comprehensive information system for decision makers. To achieve this, the Department of Space launched an ambitious programme called National (Natural) Resources Information System (NRIS), which is oriented towards providing information on natural resources related to land, water, forests, minerals, soils and socio-economic information such as demographic data, amenities, infrastructure etc. to the decision makers. The integration of these sets of data would aid the decision making process and help in achieving sustainable development goals of Integrated Mission for Sustainable Development (IMSD). NRIS is being implemented on a nation-wide scale by the Department of Space in collaboration with a number of agencies, like centres of ISRO, Deptt. of Space, State Remote Sensing Centres and private entrepreneurs which are geographically spread all over India. The NRIS is visualised as a network of GIS - based nodes covering resource information in spatial domain. NRIS node (district/state) consists of integrated spatial/non-spatial data elements comprising of the map inputs from remote sensing as well as conventional sources and village-wise non-spatial data on socio-economic and infrastructure aspects.

Remote Sensing and GIS Application Areas

Some of the broad natural resource management application areas where in considerable progress has been made in the last few years in the country are

- Crop studies

- Drought monitoring and assessment
- Soil moisture determination
- Soil survey and mapping
- Landuse /land cover mapping
- Waste land mapping
- Exploration and monitoring of water resources
- Watershed management
- Urban and regional planning
- Weather and climate studies
- Flood mapping and damage assessment
- Generation of potential fishery prospect charts

Crop Studies

The role of remote sensing and GIS in crop studies can be broadly categorized into two groups - inventorying/mapping and management. While RS data alone is mostly used for inventorying purposes (crop acreage estimation, crop condition assessment, crop yield forecasting, etc.) and management (cropping system analysis, precision farming etc.) In addition, it needs various other spatial agro-physical/environmental information has to be integrated with RS data, where the functionalities of GIS are used.

Use of remote sensing (RS) data in making crop production forecast has been actively investigated in India and many other parts of the world. Monitoring Agriculture with Remote Sensing (MARS) programme, developed at the Joint Research Centre (JRC) for the General Directorate for the Agriculture of the Commission of European Communities (EEC), provides up-to-date agricultural information to European agricultural policy makers have demonstrated the integrated use of Remote Sensing, Geographical Information System (GIS) and historical database for improving cropland classification. Some of the specific activities in which Remote Sensing data and technology, alone or along with GIS, have been extensively used, are discussed here:

(a) Crop production forecasting

Crop production forecasting comprises identification of crops, acreage estimation and forecasting their yield. Crop identification and discrimination are based upon the fact that each crop has a unique spectral signature. Typical spectral reflectance of a crop shows absorption due to pigments in the visible region, high reflectance in the near infrared region because of internal cellular structure of the leaves, and absorption in the short wave infrared region due to water content. Spectral response of a crop canopy is influenced by (i) the leaf area index (LAI) and per cent ground cover, (ii) growth stage, (iii) differences in cultural practices, (iv) stress conditions and (v) canopy architecture. Background soil/water is an important influencing factor. Each crop has its own architecture, growing period etc., thus enabling discrimination through RS data.

If there are two crops with similar spectral signatures on a given date (confusion crops), multi-date data may be used to discriminate them. It has been observed that the ratio of near infrared to red radiance is a good indicator to red radiance is a good indicator of the vigour of the crop. Some of these properties are utilized in crop identification, yield forecasting and crop condition assessment.

(b) Acreage estimation

Identification and discrimination of various crops/land cover classes require quantitative use of subtle differences in their spectral data, and hence rely mostly on digital image processing techniques. The acreage estimation procedure broadly consists of

identifying representative sites of various crops/land cover classes on the image based on the ground truth collected, generation of signatures for different training sites and classifying the image, using training statistics. Most of the work carried out so far has single-date data corresponding to the near maximum vegetative growth stage of the crop. District level acreage estimation has been generally carried out by analyzing the complete data. Estimation of crop acreage for large areas, like states require handling of a very large volume of data, larger efforts in ground truth data collection etc. In such a case, sampling technique based procedures have been developed and successfully used. Based on the crop concentration statistics, agro-physical and / or agro-climatic conditions, the study area is divided into homogenous strata and sample segments from each stratum are analyzed. For digital data analysis, generally ten percent of the total population is used. Appropriate statistical methods are employed to aggregate results at stratum and study area/state levels. In addition, national level forecast for wheat production in major wheat growing states of India has been made since 1995-96 season using multi-date IRS-1C/1D, WiFS and LISS-III data employing supervised hierarchical classification approach and agro-meteorological yield models. Availability of cloud free optical sensor data is a major problem especially during kharif season. The potential of microwave sensor data acquired in C-band at large incidence angles has been studied for acreage estimation and monitoring of rice crop during **kharif** (monsoon) season.

Temporal data acquired during transplanting, vegetative and grain filling stages of rice had resulted in classifications of all types of lowland cultivars to the tune of 90 per cent accuracy. Many horticultural crops, viz. mango, coconut, areca nut, orange and banana could also be identified and their acreage estimated using high spatial resolution LISS-III data.

(c) Yield forecasting

Yield is influenced by a large number of factors such as crop genotype, soil characteristics, cultural practices adopted (e.g. irrigation, fertilizer), weather conditions, and biotic influences, such as weeds, diseases, pests, etc.

Spectral data of a crop is an integrated manifestation of the effect of all these factors on its growth. The two approaches adopted for yield modeling using RS data are :

- RS data or derived parameters are directly related to yield and
- RS data are used to estimate some of the biometric parameters, which in turn are input parameters to a yield model. Spectral index of the crop canopy (NIR/Red, Greenness, and NDVI) at any given point of time reveals the crop growth and its decay as affected by various factors in the time domain.

Efforts have been made to develop a relationship between yield and spectral index using space borne data at maximum vegetative cover, and using different parameters of the growth profile like leaf area index (LAI).

(d) FASAL

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, Agro-meteorology and Land-based observations (FASAL) has been conceptualized and is being institutionalized. A pilot study of FASAL multiple forecasting systems has been implemented in Orissa. As a part of the techniques development for FASAL project, national level rice and wheat forecasts are being provided using multi-date microwave and optimal data, respectively, following a hierarchical classification approach. Presently, FASAL has been extended in eight other states of India.

(e) Crop condition assessment

Efforts have been made to develop procedure for crop stress detection and condition monitoring using satellite data at Space Applications Centre (SAC), Ahmedabad. Landsat MSS data has been used to detect the moisture stress in groundnut crop in Vanthali taluk of Junagadh district. Resource satellites like IRS or Landsat can provide detailed spatial information on the condition of the crop but the utility of such data to regional or large area crop condition study is restricted because of their comparatively long repetition cycles and the substantial volume of data. To handle the problem of crop condition assessment, Ajai and Sahai (1986) have proposed a hybrid approach, which uses both the comparatively high resolution earth resources satellite data together with the coarse-resolution meteorological satellite data (NOAA-AVHRR). Liu and Kogan (1996) have used the NDVI images generated from NOAA-AVHRR GVI (Global Vegetation Index) data to monitor large-scale drought patterns and their climatic impact on vegetation. Kogan (1994) has developed two indices, like. VCI (Vegetation Condition Index) and TCI (Temperature Condition Index) for monitoring drought. While VCI is the percentage of NDVI with respect to its maximum amplitude, TCI is the percentage in brightness temperature (derived from channel 4 of NOAA-AVHRR) with respect to its maximum amplitude. In India a National Agricultural Drought Assessment and Monitoring System (NADAMS) was initiated in 1986, using RS data from the NOAA satellite and ground observations of rainfall and agricultural conditions.

(f) Cropping system analysis

In Mid 80's it was realized that component approach of crop research is not sufficient to sustain agriculture production level achieved during Green Revolution era. A system approach that takes into account the interaction of biotic and abiotic components of agriculture in time and space is considered as the viable alternative to sustainable agriculture production. This has given rise to cropping system approach which encompasses the study of cropping patterns and their management needs to derive maximum benefits from a given resource base under specific environmental conditions. A sustainable cropping system needs to be adopted keeping in view the available water, suitability to sustain a long term growth in productivity in a particular agro-climatic zone, keeping in view the domestic need, market demand and price. The scope of cropping systems study, include:
1. Describing the present cropping system
2. Monitoring the long-term changes in the cropping system
3. Evaluation of the long-term effects of present cropping system, and
4. Prescribing the alternate cropping system.

Cropping pattern of an area is the manifestation of the climate, the soil, available facilities like irrigation, fertilizer, mechanization etc. and the socio-economic factors.
Changes in cropping pattern are also caused in response to change in one or more of the same factors. However, many times, the socio economic factors play a dominant role for adopting a new cropping system and thereby neglecting/degrading the parameters essential for agro-ecological balance. This information when integrated with other physical, environmental and economic resources, through GIS based simulation models, long-term performance of the cropping system can be evaluated.

Investigations carried out at SAC, Ahmedabad using temporal remote sensing data from IRS sensors gave promising results for cropping system studies. Panigrahy and Sharma (1995) first generated crop rotation map using IRS data. Spatial database of parameters like crop area, cropping pattern, crop rotation, crop calendar, crop vigour etc. was created using multi temporal, mutispectral data. Panigrahy & Sharma (1997) while studying the crop rotation in Bardhaman district of West Bengal using multi-temporal IRS LISS-III data, concluded that the number of data sets required can be reduced by taking into account of crop

calendars and including data of transitional phases. Based on this experience, cropping system analysis using remote sensing and GIS was conceptualized .

Using this methodology, Cropping System Analysis in Punjab was undertaken by Punjab Remote Sensing Centre, Ludhiana and Space Applications Centre, Ahmedabad under Jai Vigyan National Science and Technology Mission. Similar studies were undertaken for West Bengal and Assam states. Multi-date, multi-year and multi sensor satellite based remote sensing data along with various spatial and non-spatial collateral data was used to create spatial database and generate the cropping pattern and crop rotation maps for Punjab state. In addition, maps depicting cropping calendar and cropping intensity were also derived from remote sensing data. Various efficiency indices, such as Multiple Cropping Index (MCI), Area Diversity Index (ADI), Cultivated Land Utilization Index (CLUI), have been worked out for the year 1998-99 & 2004-05 using multi-date remote sensing data to characterize the cropping systems. The study has been undertaken at district level. Attempt has been made to generate agro-physically, the most suitable cropping system based on the variation in soil, physiography and rainfall.

(g) Precision agriculture

The area available for agriculture is getting reduced day-to-day because of rapid industrialization and urbanization. The problem in front of the modern day farmer is to produce more from less area. Hence, the grower has to treat different grids of its large field differently for input application. In recent years the expanded use of GPS and GIS has given rise to agricultural advances in spatial data management that have revolutionized the way many growers manage their fields (Anderson et. al., 1999). In near future, a farmer will go to the field with a spreader or combine equipped with a GPS that records positional information related to variable rate of fertilizer application or yield at harvest for his farm. This ability to monitor the variability in the field and then to pinpoint areas for input application using variable rate method is known as precision farming. Many growers in developed countries use this information for time and site specific field analysis with the assistance of farm management systems. Farm management systems are essentially GIS based with functions tailored to the activities of farming. Satellite based RS data has a great role to play in precision farming, in the way of mapping the variability.

Drought monitoring and assessment

Monitoring the crop conditions at regular intervals during the crop growth cycle is essential to take appropriate curative measures and to assess the probable loss in production. Vegetation index (VI) derived from space borne data is sensitive to moisture stress in crops and serves as surrogate measures to assess agricultural drought. A nation-wide project titled "National Agricultural Drought Assessment and Monitoring System (NADAMS)" is being implemented since 1987 to monitor the drought during **kharif** (south-west monsoon) season by generating Normalized Difference Vegetation Index (NDVI) from temporal NOAA-AVHRR data. NDVI profile of the current season is compared with the normal year to infer stress conditions. This is complemented by *in-situ* observations on rainfall and other agricultural practices with availability of AWiFS data. Presently, with the availability of microwave satellite data, drought assessment accuracy has been improved to a great extent. A National Agricultural Drought Monitoring System (NADAMS) project gives fortnightly information during monsoon season at district level using satellite-derived NDVI information as input.

Soil moisture determination

The soil moisture determinations are paramount in a variety of ways. While the remote sensing techniques can be used in identifying and delineating areas of different grades

of soil moisture, the microwave remote sensing holds promise for sub soil moisture measurements. Such information is vital not only for irrigation engineers but also to the agriculturists. Models for soil moisture estimation using single frequency, polarization and look angle SAR data had also been developed.

Soil survey and mapping

Information on soils is a pre-requisite to agricultural planning. It is a three dimensional quantity and it requires not only interpretation of imagery but also soil profile studies at many places. Satellite data helps in reducing the number of profile studies, optimizing their location and in delineating soil association boundaries.

Satellite remote sensing data in both analog (picture) and digital forms have been used mostly on experimental basis. Current satellite data can be very efficient tool for small scale mapping approaching rapid reconnaissance and reconnaissance levels. These two approaches of interpretation of satellite data viz. visual interpretation and computer aided approach. Visual interpretation techniques were used in India to delineate soil associations. A combination of physiographic and photo element approach supported by limited field check has been widely used because of its adaptability to different terrain conditions and varying scales of mapping. A mix of satellite and aerial data has been advantageously used in India and soil maps showing association of Great groups, association of sub groups and association of families have been prepared by state and national level organisations.

Conjunctive use of remote sensing data and collateral information like lithology, physiography has enabled mapping soils at different scales, ranging from 1:250,000 to 1:50,000 with the abstraction level of subgroups/association thereof and association of families, have been prepared using satellite data.

High resolution stereo data are found useful for generating information on soil resources at 1:12,500 scales, necessary for micro-level optimal land-use planning. Furthermore, derivative information, such as land capability, land irrigability, erodibility, reclamability, and suitability for different crops which in turn enable preparing the optimal land use plan and in taking up land reclamation measures, wherever required, have also been generated.

Landuse /cover mapping

The technology of remote sensing has opened the floodgates of information on a wide variety of applications. Earth observation satellites are the basic tools for mapping and monitoring changes associated with urbanization, identification of sites for tourism development and its impact on flora and fauna, mining, transportation network etc. In addition, with the remote sensing techniques one can study the complex land use/land cover system of a difficult terrain and prepare comprehensive management plans.

Space borne multi-spectral data from IRS-1A/1B/1C/1D satellites has been used to generate district-wise landuse / land cover maps for the entire country. IRS IC/ID have enhanced capability as compared to IRS IA/IB in terms of spatial resolution, provision of additional spectral bands, ability to acquire stereoscopic images and improved temporal resolution. IRS-IC/ID satellites have three Imaging Sensors namely Panchromatic camera with 5.8 meters resolution, Linear Imaging Self-Scanner (LISS-III) with 235 metre resolution and Wide Field Sensor (WiFs) with 188 meter spatial resolutions. The PAN + LISS-III merged data is being used for landuse /land cover mapping on 1:50,000 scale under various projects namely National (Natural) Resource Information System (NRIS) of Department of Space, Natural Resources Development Management System (NRDMS) of Department of Science and Technology. The IRS-P6 (Resourcesat-1) launched in October 2003 with LISS-IV camera on board is now providing 5.8 metre spatial resolution multi-spectral data. This data will be very useful for land use, mapping at Level-III and IV, which is difficult with IRS-LISS-III data.

The purpose of a landuse/land cover classification system is to enable and arrange/group the array of information available under a suitable framework to facilitate systematic inventory and mapping, besides incorporating landuse details obtained from satellite and other sources. The present framework of land use/land cover classification developed is amenable to remotely sensed satellite data on 1:25,000 scale. The landuse/land cover classification system developed by NRSA (NRSA, 1989) using satellite data discusses the division of land use/land cover classes as Level-I, Level-II and Level-III. The Level-I gives a broad categorization of different landuse classes and Level-II and III gives sub details of land use classes. The landuse/land cover classification is given in Table 2.

Land use / land cover change analysis in a mountainous terrain

In mountainous region, difficult terrain and inaccessibility makes it almost impractical to obtain information required for efficient management of the natural resources with reasonable accuracy. Remote Sensing has proved its potential for providing such information. Ghosh *et al*. (1996) studied the land use changes in the Pranmati watershed in the catchment area of river Ganga in Chamoli district. Integration of remote sensing data with other spatial/non-spatial data was carried out using ARC/INFO software package. A simple classification technique was adopted for land cover/land use change analysis in relation to elevation, slope, aspect and bio-climatic classes. Suitability assessment of land where agricultural extension occurred between 1963 and 1993 was made using GIS software package.

Table 2. Landuse/land covers classification system

S. No.	Level-I	Level-II
1	Built up land	1.1 Built up land

2	Agricultural land	2.1 Crop Land
		    (i) Kharif
		    (ii) Rabi
		    (iii) Kharif+rabi
		2.2 Fallow Land
		2.3 Plantation

3	Forest	3.1 Evergreen/semi-evergreen forest 3.2 Deciduous forest 3.3 Degraded or scrub land 3.4 Forest blank 3.5 Forest plantation 3.6 Mangroves
4	Wastelands	4.1 Salt-affected land 4.2 Waterlogged land 4.3 Marshy/swampy Land 4.4 Gullied/ravinous Land 4.5 Land with or without scrub 4.6 Sandy area (coastal & desertic) 4.7 Barren rocky/stony waste/sheet rock area
5	Water bodies	5.1 River/stream 5.2 Lake/reservoir/tank/canal

6	Others	6.1 Shifting cultivation
		6.2 Grassland/grazing land
		6.3 Snow covered/glacial area

Expansion of agricultural land was found to be of maximum in 2200-2400 m elevation zone and 20-30° slope classes. When topographic aspects were considered, expansion was maximum on south-east and west facing slopes. The loss of vegetal cover is estimated to be 15 per cent between 1963-1993. However, regeneration of forest cover was found to be maximum in elevation ranges of 1600-2000 metre and mostly having 20-30° average slopes.

Wasteland mapping

Planning for development of degraded lands including erosion affected and waterlogged soils calls for up-to-date information on their geographical location, aerial extent and spatial distribution, conventionally the information on different categories of wastelands is arrived at by compilation from village records, which is primarily statistical in nature. In recent years, there has been an increased concern among planners in the country, on the types of wastelands and their precise spatial distribution and timely availability of the information. With the advent of remote sensing, a major technological breakthrough has happened in the method of acquiring information about natural resources. Land degradation study requires an accurate assessment of how wide spread it is, how severe the damage is and whether or not it is practically controllable or reversible.

Inventory of wastelands in India

Using space-borne multi-spectral data, maps, showing extent, spatial distribution and magnitude of eroded lands, salt-affected soils, waterlogged areas, shifting cultivation, to name a few, at 1:250,000 and 1:50,000 scales have been generated. A thirteen-fold classification comprising both culturable and un-culturable wastelands has been adopted. A digital atlas for India has been prepared. This information is being used for planning land reclamation and soil conservation programmes. Estimated area of wastelands in the country stands at 63.85 million hectares. Each maps shows village, forest compartment and micro watershed boundaries.

Following 13 categories of wastelands can be identified and mapped on 1:50, 0000 scale using Remote Sensing technology.

- Gullied and/or ravinous land
- Land with or without scrub
- Waterlogged and marshy land
- Land affected by salinity/alkalinity coastal/inland
- Shifting cultivation area
- Under utilized /degraded notified forest land
- Degraded pastures/grazing land
- Degraded land under plantation crops
- Sands-Desertic/coastal
- Mining/industrial wastelands
- Barren rocky/stony waste/sheet rock area
- Steep sloping area
- Snow covered and/or glacial area

Methodology for mapping of wastelands in India

For mapping wastelands, both visual as well as digital analysis of satellite data were undertaken. In all 532 districts out of 584 districts were covered by visual analysis of satellite data and remaining 52 districts were mapped using digital analysis. Various categories of wastelands were identified and mapped based on image characteristics such as tone, colour, texture, pattern, shape, size and association. Apart from the wasteland categories, transport network (roads, railways), habitations and village boundaries were shown on the final maps so that the planners can easily locate various wastelands on the ground at the time of formulation and execution of various projects related to management and reclamation of wastelands.

Distribution of wastelands in India using satellite data

Out of the 328.72 million ha geographical area of the country, 316.64 million ha area comprising 584 districts of the country was covered under the countrywide wasteland mapping project. Uncovered area (12.1 m ha) was in Jammu & Kashmir. The wastelands accounted for 63.85 million ha farming 20.17 per cent of the total geographical area of the 584 districts covered. The category wise area of wastelands is given in Table 3.

The category-wise distribution of wastelands shows that highest percentage (6.13%) belongs to the category land with or without scrub followed by under utilised forestland (4.44%). The former is mainly distributed in the southern states of India whereas the later is distributed throughout the country. The distribution of wastelands under different categories is given in Table 3.

The state wise wasteland area estimation (table is not given) shows that very high percentage of area under wasteland in Jammu & Kashmir (64.55%), Himachal Pradesh (56.87%), are due to snow cover and degraded forest; Nagaland (50.69%), Assam (25.52%), Manipur (58%), Meghalaya (44.16%), Mizoram (19.31%) are due to shifting cultivation, Sikkim (50.30%) is due to degraded forest and in Rajasthan (30.87%) due to Sandy area. Among all the states, Kerala has a minimum 3.73 per cent and Jammu & Kashmir has a maximum 64.55 per cent of area under wastelands.

Exploration and monitoring of water resources

Mapping and monitoring aerial extent of surface water bodies/reservoirs using multi-spectral data has been well established. Multi-date satellite imageries are used to update area capacity curves of reservoirs to facilitate computing storage capacity. The current satellite remote sensing capabilities for irrigation water management include end-of-season evaluation of canal command areas at the disaggregated level and diagnostic analysis of problem distributaries to

Table 3: Category-wise area (Sq. km) of wastelands in India

S. No.	Category	Total wasteland	% to total geographical area covered
1.	Gullied and/or ravinous land	20553.35	0.65
2.	Land with or without scrub	194014.29	6.13
3.	Waterlogged and marshy land	16568.45	0.52
4.	Land affected by salinity/alkalinity Coastal/inland	20477.38	0.65
5.	Shifting cultivation area	35142.20	1.11

6.	Under utilized /degraded notified forest land	140652.31	4.44
7.	Degraded pastures/grazing land	25978.91	0.82
8.	Degraded land under plantation crop	5828.09	0.18
9.	Sands-inland/coastal	50021.65	1.58
10.	Mining/industrial wastelands	1252.13	0.04
11.	Barren rocky/stony waste/sheet rock area	64584.77	2.04
12.	Steep sloping area	7656.29	0.24
13.	Snow covered and/or glacial area	55788.49	1.76
	Total Wasteland Area	**638518.31**	**20.17**

Source: 1:50,000 scale wasteland maps prepared from Landsat Thematic Mapper/IRS LISS II/III Data
Note:1, 20,849.00 sq.Kms. in Jammu & Kashmir is not mapped and   hence not considered for calculating the percentage.

enable follow-up corrective management. A methodology for the assessment of crop water requirement using remote sensing and GIS techniques along with the collateral data has been demonstrated for two command areas in the Indira Gandhi Nagar Pariyojana.

For tapping subsurface/groundwater, hydro-geo-morphological maps showing ground water prospect areas on as large as 1:25,000 scale can be prepared. 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 and recharge conditions, which ultimately define the groundwater regime. Groundwater prospect maps showing probable regions, where wells can be drilled has 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 villages38. Following national level hydro-geomorphic mapping showing groundwater prospect areas on 1: 250000 scale, more detailed maps for ten priority states on 1: 50,000 scales 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. 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.

Watershed management

Development programmes concerning optimum utilisation of natural resources are being implemented on watershed bases. Watershed, as normally defined, is a natural hydrological entity that covers a specific area within which the entire rainfall runoff, ultimately passes through a specific channel at a particular point. The information about the natural resources of the watershed is very important for watershed management planning.

The various parameters of the watershed, i.e. stream network (drainage), physiography, land use, vegetation/forest cover and snow cover can be mapped and monitored using remote sensing data.

The strategic planning adopted for watershed development comprises of , a) delineation and codification of watershed, b) prioritisation of watersheds c) detailed soil inventory of very high and high priority watersheds in the catchments, d) treatment of very high and high priority watersheds in the catchments, and e) evaluation and monitoring of the impact of the treatment. This is essential for the conservation and management of water and land resources of watersheds for optimum productivity. In general, the remote sensing techniques can be applied for:

- Delineation and codification of watershed area
- Watershed characterization and assessing watershed priority, evaluation of problems, potentials and management requirements of various watersheds
- Erosion intensity mapping and identification of erosion prone areas
- Soil, land use/land cover mapping
- Drainage pattern mapping
- Evolving water conservation strategies in a watershed
- Selection of sites for the construction of check dams/reservoirs on streams or streamlets.
- Suggesting sites for rain water harvesting structures
- Evaluation and monitoring of the impact of the treatment

Urban and regional planning

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.

Case study

The Mumbai-Navi Mumbai cities are among the highest populated cities in the country. The population pressure has caused drastic land use change in the last seventy years. Multi-date data from survey of India (SOI) topographical maps and Landsat TM digital data were used to study the landuse change. GIS was used for the digitization and data analysis. The area within the various landuse categories were also calculated by using the spatial analysis module in the GIS software. The methodology adopted for determining the effect of built-up land on the drainage network and drainage basins was a simple overlay technique. The area under built-up land in the ten drainage basins, which fall in the study area, and the stream length in built-up land was also found by using the map overlay and spatial analysis module of GIS software. It was observed that 55 percent reduction in forest/ agricultural land, while 300 percentincrease in built up land has taken place in last seventy years. This has affected the natural drainage system of the cities, causing flooding during monsoon. The quantum of drainage basin area and stream length in the ten basins, which drain the area, under influence of built-up land, was found by using a map over lay of the drainage network

map and landuse map. The results shed light on the extent of drainage network disruption with in these two neighboring cities (Samant and Subramanyam, 1998).

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.

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.

Floods/cyclones

The 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 from available satellite data. However, comprehensive flood monitoring would call for integration of ground measurements and aerial/satellite remote sensing data along in a GIS on the flood plain characteristics including topography in a GIS domain. The flood risk zone needs to be redefined with high spatial resolution data and digital elevation models based on contour information. A Disaster Management Support Programme (DMSP) has been initiated with the setting up of a Decision Support Centre (DSC) at National Remote Sensing Agency (NRSA) 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.

Remote sensing data have 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.

Marine fisheries:

Advance information on probable areas of fish aggregation is useful in planning fishing exercises. Aggregation of fishes in a particular place is influenced by a number of physical, biological and environmental parameters such as sea surface temperature, ocean biology as manifested by chlorophyll concentration, currents, mixed layer depth, internal waves, winds, oxygen, salinity, predator-prey relationship etc.

During the last several years, fishery prospect charts have been generated and disseminated by creating anomalies / gradients in sea surface temperature (SST). This is generally done by bringing nutrient rich cooler water to the surface leading to enhanced biological activity. Though this approach has yielded satisfactorily, there is a problem of detecting SST gradients relevant to fishery, particularly during summer when surface waters are thermally homogenous. In addition, SST is only a surface phenomenon.

On the other hand, ocean colour /chlorophyll concentration is a direct variable in the marine food chain. So, it is expected that oceanic features derived from the colour should provide information on biological productivity of water masses. In view of this, an integrated approach for improved fishery forecast using both SST and ocean colour is being developed. Different types of oceanic features such as coastal fronts, rings, mushrooms, meanders, features such as tongue – shaped fronts, jets are identified on composite images for generating fishery prospect charts.

Data available from the IRS-P4 (Oceansat-1) Ocean Colour Monitor data and NOAA-AVHRR are being used for these investigations. Feedback received in terms of catch per unit efforts shows that significant observations both at 50-100 m depth zone and in 30-50 m depth are found to be positive.

Chlorophyll derived from ocean colour data is also used in estimating primary productivity. This in turn facilitates fish stock assessment. Use of spaceborne data for identifying schools of fish has been more successful for pelagic fishes rather than dimmersal variety.

Space technology helps in sustaining the resources by the following way:
- Identification of potential fishing areas for deep-sea fisheries.
- Identification of 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.
- In monitoring harmful algal blooms, the discharge of industrial effluents and their pattern of dispersal over space and time scales. This will help in mitigating the effects caused to the exploited vulnerable stocks from further depletion, reducing mortalities in the nursery grounds.

Future thrust areas

Although data available from various earth observation systems have been routinely used in many areas of natural resource managements, there are still gaps exist. Data needs of application at different level of details have not been met. Some of these are:
i)   Identification and area estimation of short duration and marginal crops grown in fragmented land holdings, particularly during **kharif** season.
ii)   More accurate yield models.
iii) Detection of crop stress due to nutrients, diseases, and quantification of its effect on crop yield.
iv)   Information on soil sub-surface horizons.
v)   Quantification of soil loss, identification of lands undergoing sheet and rill erosion.
vi)   Estimation of depth of water in reservoirs, depth and quality of ground water and

vii)   Better than 1m contours of watershed development plans at the micro level.

However, with the launch of satellites (some of them are already in operations) like IKNOS-II, Quick Bird-2, Resourcesat-1, Cartosats- 1&2, SPOT-5, RISAT, Advanced Land Observation Satellite (ALOS) and Hyperion may enable in 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.

References

Ajai and Sahai, B. 1986. Drought detection and quantification by remote sensing. *Jal Vigyan*
Sameksha. **1**: 138-152.

Anderson, J.E. 1999. Remote Sensing and precision agriculture: Ready for harvest or still maturing? *Photogrammetric Engineering and Remote Sensing*, **65** (10): 1118-1123.

Anon.1990. Watershed Atlas of India published by All India Soil and Land Use Survey, New Delhi

Barrow, C.J. 199). Land degradation - Development and break down of Terrestrial Environment. Cambridge University Press, Cambridge, pp 1-9.

Burrough, P.A. 1986. Principles of Geographical Information Systems for Land Resource Assessment Clarendon Press, Oxford, U.K.

Chakraborty, M. and Panigrahy, S. 2000. A processing and software system for rice crop inventory using multi-date Radarsat ScanSAR data. *ISPRS Journal of Photogrammetry and Remote Sensing*, **55** (2): 119-128.

Colwel, R.N. 1983. Manual of Remote Sensing (Vol. II). *Am. Soc. Photogrammetry*. Virginia, New York.

Das, S.N. 2001. Soil and Land information for Watershded Development. All India Soil and Land Use Survey. Technical Bulletin-1/2001.

Foresman, T. W. 1998. "GIS Early Years and the Threads of Evolution", in Foresman, T.W. (ed.), The History of Geographic Information Systems: Perspectives from the Pioneers, Prentice Hall, pp 3-18.

Ghosh, S., Sen, K.K., Rana, U, Rao, K.S. and Saxena K.G. 1996. Application of GIS for landuse/land covers change analysis in a mountainous terrain. *J. Indian Soc. Remote Sensing* **24** (3): 193-202.

Guo, F., Shengyue, Ji and Hu, G. 2002. Methods for improving the accuracy and reliability of vehicle-borne GPS Intelligence Navigation System. *GIS@Development.* **6** (11): 25-26.

Hanschak, G.A., Sigman, M., Craig, M., Ozga R., Luebbe, R., Cook, P., Kleweno, D., Miller, C. 1979. Obtaining timely crop area estimates using ground gathered and Landsat data. USDA, Economics, Statistics and Co-operative Service (ESCS), Technical Buletin., 1609, Washington D.C.

International Council for Science. 2002. "Making Science for Sustainable Development More Policy Relevant: New Tools for Analysis", ICSU Series of Science for Sustainable Development No. 8: pp.28.

Kogan, F.N. 1994. Application of vegetation index and brightness temperature for drought detection. *Advances in Space Research*. **15** (11): 91-100.

Liu, W.T. and Kogan, F.N. 1996. Monitoring regional drought using the vegetation condition index. *International Journal of Remote Sensing*. **17** (14): 2761-2782.

Loveland, T.R.., Estes, J.E., Foresman, T.W., Scepan, J., Kline, K.D., Hemphill, J. 2000. "Large-area land cover characterization", in Tateishi, R. & Hastings, D. (eds.), Global Environmental Databases: Present Situation; Future Direction. Hong Kong: Geocarto International. pp. 105-125.

MacDonald, R.B. and Hall, F.G., 1980. Global crop forecasting. *Science*. **280**: pp.670.

Madhavan Nair, G.2004. Space for disaster management: Indian perspectives, 55th International Astronautical Congress, 4–8 October. Vancouver, Canada.

Navalgund, R. R.2002. Pre-requisite for agriculture planting. The Hindu Survey of Indian Agriculture. Pp. 203-208.

Navalgund, R. R.2006. Indian earth observation system: An overview. *Asian J. Geoinf.*, **6**: 17–25.

Navalgund, R. R., Jayaraman, V. and Roy, P. S. 2007.Remote sensing applications: An overview. *Current Science*. **93**(12): 1747-1766.

NRSA.1989.Manual of Nationwide landuse/land cover mapping using visual interpretation on techniques. Part-I, Hyderabad pp 1-58.

Oza, M.P., Vyas, S.P., Rajak, D.R., Bhagia, N., Singh, A.K., Dadhwal, V.K. 1999. National wheat production forecast (1998-99) using multidate WiFs and meteorological data. Scientific Note.RSAM/SAC/FASAL-TD/SN/01/99, July 1999, Space Applications Centre, Ahmedabad 270.

Panigrahy, S. and Sharma, S.A. 1995. Approach to map crop rotations using temporal IRS LISS-I data: A case study for Bardhaman district (West Bengal). Proceedings of National Symposium on Remote Sensing of Environment with Special Emphasis on Green Revolution, Ludhiana. Nov. 22-24, 1995 pp. 35-39.

Panigrahy, S. and Sharma, S.A. 1997. Crop rotation mapping using multidate IRS digital data. *International Society of Photogrammetry and Remote Sensing Journal of Photogrammetry*. **52**: 85-91.

Panigrahy, S., Chakraborty, M. and Parihar, J.S. 1996 Cropping system analysis – An approach using satellite remote sensing data. Technical Report. RSAM/SAC/ CAPE II/TR/61/96. Space Applications Centre, ISRO, Ahmedabad. Pp.27.

Panigrahy, S., Ray, S.S., Sharma, P.K., Sood, A.K. and Patel, L.B. and Parihar, J.S. 2003. Cropping system analysis of Punjab using remote sensing and GIS. RSAM/SAC/CS/SR/04/2003. Space Applications Centre, Ahmedabad and Punjab Remote Sensing Centre, Ludhiana, pp.81.

Samant, H.P. and Subramanyam, V. 1998. Landuse/land cover changes in Mumbai-Navi Mumbai cities and its effects on the drainage basins and channels - A study using GIS. *J. Indian Soc. Remote Sensing*. **26** (1&2): 1-6.

Sharma,P.K.2004. Emerging technologies of remote sensing and GIS for the development of spatial data infrastructure. The 2nd Dr. R.R.Agarwal Memorial Lecture. (Delivered on 25th September, 2004 at CSK Himachal Pradesh Krishi Vishavvidalaya, Palampur, HP and organized by Palampur Chapter of the Indian Society of Soil Science).