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Role of Earth Observations for Sustainable Development: Emerging Trends

(SS-1: ICORSE Earth Observation Systems for Sustainable Development)

R R Navalgund[#] and Satish C Jayanthi
[#]President, Technical Commission VII (2000-04), ISPRS
National Remote Sensing Agency
Hyderabad 500 037 (INDIA)
e-mail: rangnath@nrsa.gov.in and jayanthi_c@nrsa.gov.in

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ABSTRACT

Sustainable development aims at optimal use of natural resources, protection and conservation of ecological systems, and improving economic efficiency. It tries to provide food, fuel, fiber and shelter for the ever increasing world population on sustainable basis. Ecosystems like agro, coastal, forest, freshwater and grasslands, and natural disasters are some of the ideal facets for examining the magnitude of the problems and the plausible solutions that need to be generated. Decision-making for sustainable development is a complex process and involves studying trade-offs that need to be made among conflicting goals of different sectors. The present paper examines the scope for Earth Observation (EO) contributions towards the above, and tries to profile the EO capabilities vis-à-vis the systems' information needs. It further identifies the gaps, which EO needs to fulfill towards meeting either the imaging or processing needs of various applications. Considering these, in the next 6-7 years, a host of spacecraft systems carrying different sensors have been planned across the globe including India. Endeavours of NASA, ESA, India, JAXA etc. and complementary data sharing initiatives by International Charter on Space and Major Disasters and the UN agencies are expected to enlarge the scope for increased role of EO data towards the cause of sustainable development.

Resources and environment: global concerns

Optimal management of natural resources is vital for the world in general and to the developing nations, in particular. Resources of many developing countries have come under severe strain over the past few decades in view of the ever-increasing demographic pressure. Deforestation, desertification, soil erosion and salinisation have degraded the environment, threatening the food security and economic development of many countries. Over exploitation of resources to meet the burgeoning requirements is leading to crowded crop lands, falling water tables, declining biodiversity, over-fishing and increased pollution. The biggest global concern today is "Population explosion". It is expected to touch 11 billion by 2075 from 6.06 billion in 2000, i.e, each year 80 M people are getting added. Urban areas, which account for 4% of the land area, inhabit around half of the global populace. As against the estimated minimal need of 0.5 ha per capita, over all arable land of 1500 M ha in the world presently available for agricultural activities amounts to only 0.3 ha per capita. The per capita arable land is expected to dwindle to 0.13 ha by 2075. About 65% of cropped land is having significant soil degradation. Forests occupy about 25% of the land area, from which about 50% world's forest cover has shrunk due to logging; the estimated annual loss of about 5.8 M ha. Besides, 12.5% of total biodiversity is threatened. Forests are responsible for 2 Gt of Carbon/year contributing to 30% of the total carbon cycle. To the global atmospheric carbon of 720-800 GtC, another 3.3 GtC is added each year. Water is another precious resource, whose value is undermined. About 1.6 billion (28%) people lack safe drinking water; and about 5 M die each year. About 1.5 billion people depend on ground water for drinking purposes; the pumping or extraction of which outscores its recharge @ 160 m^3 a year.

About 40% of the global population lives within 100 km from the coast, i.e. on 22% of the land area. Corals, which are pristine and semi-precious, are spread over 255,000 km^2 are one of the threatened species. 58% of them are at some risk or the other due to destructive fishing practices, tourist pressures and pollution; while 27% of them under high risk. Among mangroves (181,000 km^2), 50% are destroyed. So also is the case of wetlands, both coastal as well as inland. It is appalling that about 75% of major marine fish stocks are either depleted from over-fishing or are being fished at their biological limit. Other major problems like depletion of ozone layer, glacial retreat and vulnerability to disasters need no emphasis. By these facts, it is imperative that these issues cut across geographical barriers and transcend national boundaries. Stretching the finite resources of the world to meet the basic requirements of ever increasing population growth that is conservatively expected to touch 11 billion by 2075, without impairing ecological and environmental conditions is the biggest challenge facing the world today (World Resources 2000-2001).

Concept and need for sustainable development

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

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

The Earth Summit at Rio de Janeiro in 1992 (UNCED 1992) defined principles on which the pathway to sustainable development can be based. It states that the only way to have long term economic progress is to link it with environmental protection. Caring for natural resources and making sustainable use of resources is essential for well-being of not only this generation but future generations. Land resources provide the basis for food, fuel, fiber and shelter for human populations worldwide. Expanding human requirements and economic activities are placing ever increasing pressures on land resources, creating competition and conflicts and resulting in suboptimal use of both land and land resources. Anthropogenic pressures on agro-ecosystems and marine resources are also well known. Integrated planning and management of land resources is required for sustainable use and development of natural resources (Agenda 21, Chapter 10). Modern technologies such as biotechnology, remote sensing, GIS, and computing capabilities can be effectively used to improve efficiency of land resource utilization, assess the condition of resources, and model their outputs spatially and to monitor them.

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

Major ecosystems and their characteristics

Solutions to the problem of sustainable development can be multi-pronged and from different perspectives. Ecosystem approach is perhaps the best. Some of the important ecosystems that need consideration are agro, coastal, forest, freshwater and grasslands among others. Globally, agro ecosystems are characterized by permanent pastures (account for about 69% of the ecosystem area) and cropland (around 31%). Sustainability of agriculture is often a function of its ability to feed the dependent population. It is possible through any combination of the three, viz. increase the area under crops, the cropping intensity, and its productivity. Aspects such as conservation of plant and animal bio-diversity, equitable access to the means of production, market information, consumer demands, and a suitable policy environment are equally important and form an integrated part of the approach. Forests are dynamic; their size and composition have evolved with changing climate. The magnitude and implications of deforestation are well-chronicled and widely debated all over the globe in many a forum. The underlying causes of forest loss have also been focus of many studies. From the sustainability of forest ecosystem viewpoint - timber production and consumption; fodder and fuel-wood production and consumption, watershed conservation, biodiversity and carbon sequestration take high priority. From the conservation and management perspective, on going fragmentation of forest stands, recurrence of forest fires and assessment of forest productivity and responses to climate change also pose severe challenges.

Grasslands can be described as areas (spread all over the globe, 40% of land surface area) dominated by grassy vegetation and characterized by grazing, and drought or freezing temperatures. They are home to about 17% of world population or 9.38 M people dwelling primarily in arid, semi-arid and sub-humid zones. These zones are predominantly dry and are susceptible to damage from human management and slower to recover from degradation such as overgrazing or improper cultivation practices (White et al. 2000). Across the continents grassland ecosystems are threatened to different degrees because of human intervention in various forms. To conserve and sustain these ecosystems, efforts are required to focus on the dependent food production systems adopted by the flora, fauna including mankind, its biological richness, degradation patterns in space and time etc.

Coastal ecosystem can be described as “inter-tidal and sub-tidal areas above continental shelf (to a depth of 200 m) and adjacent land area up to 100 km inland from the coast”. Sustainability of coastal ecosystem is dependent on its food production system, water quality, biodiversity, changes in the shoreline physiography, besides exposure to the vicissitudes of human intervention like tourism, construction, rapid industrial development and resources exploitation along the coast etc. The coastal ecosystems are the habitat for the largest part of the human population. The main challenge for both mankind and nature itself lies in staving off the different pressures on the coastal system like the population pressure, increasing pollution levels, over-harvesting of fish stocks (coupled with trawling, by-catch), global climate change etc. The mangroves and coral reefs are the most important and fragile components of the coastal ecosystems and act as a buffer between the ocean and terrestrial boundaries. With the built-up of large industrial infrastructure along the coasts, the frequent monitoring of the mangrove and coral reefs needs to be a mandatory activity.

Freshwater ecosystems encompass rivers, lakes and wetlands; and contain just a fraction- 1/100% of earth's water and occupy less than 1% of earth's surface (WRI 2000-2001). Fragmentation of river systems through dam construction or similar measures has the most significant impact on freshwater ecosystems. This has and is adversely impacting the ecosystem through changes in pattern of sediment and nutrient transport, affecting the migratory patterns of dependent fish species, altering the riparian habitat composition, creating migratory paths for exotic species, and in turn leading to changes in coastal ecosystems. To conserve and improve the freshwater ecosystems, holistic approaches are required addressing aspects like water scarcity (demand and supply), fragmentation and flows of freshwater systems, quality and quantity, dependent food systems, and biodiversity.

Besides, one of the biggest challenges to research towards attaining sustainable development is combating natural disasters in a multi-pronged way through prediction and forewarning mechanisms, improving mitigation procedures (relief, rescue and damage assessment).

Earth Observation Systems for Sustainable Development

Earth Observation Systems

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

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

Earth observation covers a wide field of remote sensing as well as of other sensing methods (in-situ), it encompasses the earth itself and also the enveloping environment. With the advent of parallel developments in the field of electronics, the important achievement is the ability *to observe earth and its environment in the entire breadth of the electromagnetic* spectrum. The first years of EO were dominated by overall requirements for repetitive coverage and the need for an operational capability (Kramer 2002). Since then, EO fraternity all over the world is contributing to the information needs for the cause of sustainable development. NASA pioneered the operationalisation of satellite-based EO through launch of Landsat-1/2/3 (1972/75/78; MSS & RBV). Subsequent launches of Landsat-4/5 (82/84; MSS & TM) taken up by NOAA enhanced the imaging capability through improved sensor technologies. NOAA also launched its workhorse radiometer, AVHRR onboard its POES series spanning during 1985-2001. In 1999, NASA again launched the Landsat-7 with ETM+. CNES, France commenced its operations way back in 1986 through SPOT-1 (2 HRV), and followed it up with SPOT-2/3/4 (1990/1993/1998). Its recent launch is that of SPOT-5 in 2002 (HRVIR, HRS, Vegetation). Canada launched RADARSAT-1 in 1995. The ESAs endeavours include ERS-1/2 (1991/94), and ENVISAT-1 (2000). Indian Earth Observation Programme started in 1979 with the launch of experimental satellite Bhaskara I. Operational programme began in 1988 with IRS-1A (LISS-I & II) and its sequel IRS-1B (1991). Its second generation satellites are IRS-1C/1D (1995/97; WiFS, LISS-III & PAN). This was interspersed by IRS-P3/P4 (1996/1999; WiFS/OCM & MSMR). Its recent launch is that of state-of-art IRS-P6 a k a Resourcesat-1 (AWiFS, LISS-III and LISS-IV). NASDA launched MOS-1a / 1b (1987/90), JERS-1 (1992; OPS) and followed this with ADEOS in 1996 (AVNIR) and ALOS (2003). Russia (erstwhile USSR) too is contributing through the launches of RESURS series starting from 1985, and followed up with RESURS-01-2 (1988), RESURS-0-3 (1994), and RESURS-0-4 (1998). Many other agencies and countries including private enterprise are also in the field of EO manufacturing and launching satellites. At present, there are some satellites like IKONOS-2 and Quickbird (high spatial resolution), Terra (multiple spectral channel), and Hyperion (hyperspectral) providing specific and focused information.

Agro ecosystem

In the field of agro ecosystem, first-hand information at periodic intervals is required on cultivable and non-cultivable wastelands, post-monsoon and post-winter agricultural fallows, and potential areas for improved crop intensity and area or region-specific cropping system for sustainable development. In addition, measures to minimize land degradation due to soil erosion, water-logging, salinity & alkalinity etc. and conservative use of irrigation by estimation and monitoring of evapotranspiration. State-of-art emerging technologies like precision farming help in improving agricultural production while optimizing inputs in an eco-friendly manner. This calls for an integrated approach that involves information acquisition through space (satellite, aerial remote sensing and GPS) and conventional techniques and analytical tools like GIS and SDSS for developing end-to-end solutions through in-situ observations, data analysis and modeling. Moderate resolution satellite imagery has been used to map entire India at district level for its prevalent land use and cover under the Agro Climatic Zone Planning project during 1988-91 with IRS-1A data. Another noteworthy example from India is National Wastelands Inventory on 1:50,000 scale at district level using optical RS data (1985-1999). The ability to identify saline /alkaline or acidic soils at micro-levels using space imagery is another example. The capability of microwave remote sensing to penetrate and measure soil moisture is of immense significance. EO data being spectrally sensitive to the plant biomass and chlorophyll, many a country has operationalised their pre-harvest crop production forecast procedures to a reasonable degree of confidence. Large Area Crop Inventory Experiment (LACIE:1974-78) carried out in US was a major study for estimating the acreage of wheat crop worldwide, and forecasting wheat crop production through agro-meteorological models. Crop monitoring for food security (MARS-FOOD) is a new project from the European Union. FAS/PECAD of USDA is responsible for global crop condition assessments and estimates of area, yield, and production for grains, oilseeds, and cotton; and is generating an objective and accurate assessment of the global agricultural production outlook and the conditions affecting food security in the world on a monthly basis through GIS using several different satellite data sources—climate data, crop models, and data extraction routines for yield and area estimates—to determine production (http://www.fas.usda.gov/ /pecad/). Starting with ARISE, Indian efforts have aimed at providing pre-harvest production forecasts for a much more complex system of fragmented land holdings, diverse cultural practices, co-existence of multiple crops etc. This is being done operationally for selected crops through Crop Acreage and Production Estimation (CAPE) project (Dadhwal, 1999). During last few years, this project has been enlarged to cover more crops and multiple forecasts through FASAL project.

Forest ecosystem

Forest ecosystems over the time have been subjected to severe biotic and abiotic pressures. In this context, Earth Observation Systems constituting diverse satellite and airborne sensors are contributing substantially in assessing the global, regional and local impacts on forest ecosystems and develop different means for sustainable development. Currently several countries are preparing inputs to monitor forest cover at regional and local scales, biodiversity assessments, forest degradation, forest fire mapping, biomass potential/carbon sequestration, inventories, forest hydrology etc using satellite data. The rapid forest fire response systems using MODIS, AATSR and VEGETATION sensors are being globally used for coarse scale assessment of fire locations and area assessments. FAO also utilizes the satellite remote sensing data to prepare global forest inventories and helps to provide the databases to the nations where such assessment is unavailable. In addition, several experimental campaigns involving intense field measurements, multi-sensor air / satellite borne programmes and Long Term Ecological initiatives (LTER) are in vogue else where in the world (LBA, SAFARI, OTTER and BOREAS etc). The Tropical Ecosystem Environment observation by Satellite (TREES) Project between JRC and ESA is oriented towards the study of tropical forest dynamics at regional to global scales using remote sensing techniques. In India, national mission on forest cover mapping was taken up during early 80's and since then eight biennial assessments were accomplished. Considering the importance of India being one of the global ecological hotspots, landscape level biodiversity characterization study was done for major part of the nation using remote sensing and field based phytosociological data. High resolution satellite is used to develop optimal sampling designs through stratification approach for assessment of forest timber volume and preparation of spatial inputs for forest working plan preparations. In addition, the satellite data is also operationally used in wildlife management, forest protection, forest fire management and Geosphere-Biospehere related studies.

Grassland ecosystem

The decline of the world's grasslands is due mainly to human-induced modifications. These include agriculture, urbanization, excessive fire, livestock grazing, fragmentation, and invasive plants and animals. Changes in grasslands have been brought about primarily by conversion of these ecosystems to agriculture, and more recently, the growth of towns and cities. This is especially true in central United States, Canada, and Europe. Answers to the above problems depend on information needs for revival of grassland ecosystems. EO systems from coarse to moderate spatial resolution multispectral data is proving to be the source in many a cases. Limited endeavours are reported for their revival. USGS initiated Sagebrush Assessment Project conducting research on landscape and habitats for species of conservation concern in the great basin region, Nevada of western United States. A national project aiming to protect grasslands from grazing also took off to improve China's grassland ecosystem. Under the project, 66.7 million hectares of seriously damaged grassland in north China's Inner Mongolia Autonomous Region, northwest China's Xinjiang Uygur Autonomous Region and Tibet Autonomous Region will be removed from grazing in the next five years, accounting for 40 percent of the endangered grasslands in western regions. In order to realize the project, it is important to delegate the responsibilities of protecting and managing grasslands to specific herdsmen (People's Daily Jan 11, 2003). In both the above, use of both remote sensing and GIS technologies is envisaged. In India, pastures, which account for nearly 80% of the grasslands (Approx. 12 million hectares), are in a degraded state. To feed the country's cattle (15% of the world cattle stock), radical steps are needed to revive the area and productivity of these grasslands to meet the fodder demands. A major project was completed by Dept. of Space for Ministry of Environment and Forests (MOEF), Govt. of India, through IRS-1C/1D (LISS-III) data to map the grasslands in three bio-climatic regions by making use of a 3-fold classification considering origin, edaphic/climatic, and local factors (NRSA. 2002).

Freshwater ecosystem

In the sphere of freshwater ecosystem, the information needs are of diverse nature ranging from mere inventory of surface waterbodies to more complex irrigation performance, snow-melt run-off forecast, flood forecasting and reservoir sedimentation etc. The role of EO inputs is also manifold right from information about surface water spread to grain size, properties and thickness of snow-pack with the help of both optical and microwave sensors. Globally many agencies are making use of EO data towards their water resources application needs. India too taking advantage of the EO data availability to answer its application needs. Nearly 3.3 M ha of irrigated cropland is annually monitored with moderate resolution multispectral data for irrigation performance evaluation across 14 river commands on an operational basis. 54,000 sq km area is annually covered in Sutlej river basin alone for computing and delivering the snow-melt run-off forecasts. Another major contribution of EO data has been towards exploration, recharge and prospecting of groundwater for providing safe drinking water in India. It took off as an operational programme for the entire country in a phased manner after detailed analyses of satellite data, generation of maps and positive feedback obtained from users departments, and at present ten states have been mapped with IRS-1D / P6 (LISS-III) data (NRSA, 2003).

Coastal ecosystem

In coastal ecosystem, the sustainability is dependent on human impact on the system constituents. To broadly outline, effects of population stress can be felt on the spatial spread of the system itself, besides its natural resources by means of depletion of ground water, fisheries, mangroves; or the water quality in terms of pollution and productivity; or its bio-diversity; or even the global change in the long term through rise in sea level. To address these issues, spatio-temporal information is needed about its land use and vegetation characteristics, its natural resources including pristine and vulnerable resources, water quality, and biological richness (including endemics) besides, the pressure factors like demographics, infrastructure etc. The current EO systems can provide majority of this information in scales ranging from global to local. In terms of human activity, information can be possible about either the extent of human occupation of the coastal areas, or by virtue of his planned actions through creation of infrastructure etc. Remotely sensed data have been used for marine habitat mapping, water quality monitoring, ship and ship-wake detection, oil spill detection, red tide monitoring, and mapping of reclamation activities. There have been instances when the EO derived information is considered mandatory by the law through gazette notification for the delineation of Coastal Regulation Zone (CRZ), like in India (Navalgund et al, 1999).

Disasters

The utility of EO data applications for disaster support is taken up by many countries in a big way, and many such efforts are still underway. For some of the disasters, part of information needs is met operationally through EO systems. Some of the contributions of EO data in different hazards are chronicled hereunder:

Two main fields of interest can be defined for the use of remote sensing data for flood disaster related applications: (1) a detailed mapping approach for production of hazard assessment maps, as input to various hydrogeological models; and (2) a large-scale approach that explores the flood situation within a system, with the aim of identifying risk vulnerability through prediction modeling etc. Microwave observations offer new insights into quantification of hydrological variables changing over time and space, which are very difficult to measure on ground. Its general information needs are land use, infrastructure status, vegetation, soil moisture, snow pack, DEM and near-shore bathymetry during pre and post-flood periods (CEOS). Current EO capability includes operational services of the above parameters. Efforts are also on to improve and develop the satellite-derived precipitation algorithms. In India, near-real time flood monitoring is being done, wherein, administrative (village) and current land use layers are being overlaid in GIS on top of satellite-based inundation layers to identify affected settlements, damage assessment and for relief purposes. All five flood-prone states, viz. Assam, Bihar, Uttar Pradesh, Orissa and Andhra Pradesh are under regular surveillance by a gamut of satellites (including Radarsat-1) during flood season covering nearly a third of India's geographical area; and information is disseminated to Relief Commissioners.

Drought is another important weather-related natural disaster. It is aggravated by human action, since it affects very large areas for months, even years, and thus has a serious impact on regional food production. Information needs related to drought are its early warning of onset, estimation of affected area, intensity and duration, plan for immediate relief and long-term management for drought mitigation etc. Currently drought monitoring mechanisms exist in most countries that use ground-based information on drought related parameters such as rainfall, weather, and crop condition and water availability. Satellite based EO are complimentary for the provision of synoptic, wide-area coverage and provision of frequent information on drought conditions. Being a semi-arid tropical country, India too faces severe agricultural drought periodically due to infrequent rainfall. In India, a National Agricultural Drought Monitoring Systems (NADAMS) project gives fortnightly information during monsoon season at district level using satellite-derived NDVI information as input. This is in operation for the last eighteen years.

EO data is useful in mapping landslide related factors; characterization of landslide deposits monitoring; preparedness (monitoring and mitigation); and response. EO data also helps in the preparation of spatial databases on lithology, faults, slope, vegetation and land use, including temporal changes. In the field of type of landslide mapping there is limitation to the operational use of EO data. During the preparedness phase (both in terms of monitoring, warning and prediction), EO data provides valuable inputs to supplement the in-situ monitoring systems by landslide hazard zonation approach. In early warning phase, new areas of approach especially SAR INTERFEROMETRY, GPS and ground data collection platform are gaining importance for understanding the movement of landslide. In the mitigation phase, high resolution satellite especially stereo is being used to suggest indicative management measures. Sections in the Kashmir and Garhwal Himalayas are susceptible to landslide risk. EO based efforts for landslide hazard zonation and mapping of affected areas is attemptrd and operationalized in GIS environment with the help of EO inputs.

For earthquakes, seismic hazard zonation is an important step during the warning phase. Space data provide critical spatial input like geological structure, lithology, geomorphology etc for integrating with other database for hazard zonation. In identifying the precursor activity before earthquake, geophysical satellite will be used in future for understanding the ionospheric disturbances before the event. The availability of high resolution data like IKONOS and CARTOSAT in future will provide the necessary input for Micro-seismic hazard zonation. Dinsar in combination with geodetic GPS has been used for detecting the microscale movements in the active fault zones.

Besides, EO is also providing significant information inputs towards managing hazards like forest (wild) fires, volcanism, oil spills etc.

Information gaps

Although data available from various EO systems have been routinely used in many agro ecological applications, there have been certain data gaps. Some of these are: i) identification and area estimation of short duration and marginal crops grown in fragmented holdings, ii) more accurate yield models, iii) detection of crop stress due to nutrient and diseases, and quantification of its effect on crop yield, iv) information on sub-soil horizons, v) quantification of soil loss, identification of lands undergoing sheet and rill erosion, vi) better than 1m contours for watershed development at micro level etc (Navalgund, 2002). For coastal ecosystems vital information about point-source and non-point source pollution, which flows into the coastal waters and through to sea; and its integration with spatio-temporal information is lacking. Still there is a need for comprehensive baseline studies of natural resources and habitats, and monitoring of the impacts of development on the coastal and marine environment. In some of the major areas like coastal fisheries, exploration of minerals and energy sources important data gaps exist. In case of forest ecosystem, information on key areas like forest hydrology, pest / disease outbreaks in tropical forests, community level biodiversity information, use of tree resources outside forests etc. are yet to be operationalised from EO platforms. Towards disaster related information needs, complementarity between space agencies could become a reality today courtesy International Charter on Space and Major Disasters. For flood, increase in time and frequency of coverage, improvement of coverage access and delivery, better DEM etc. are some of the gap areas. In case of earthquakes, the EO systems are yet to offer possible information on precursors.

Earth Observation Systems – Emerging Trends

Brief scenario of space technology development and applications mentioned above gives an idea of the tremendous role of EO satellite data for sustainable development. While contributing to the cause of sustainable development, the EO systems are continuously undergoing change resonating to bridge the information gaps. These are being made possible through developments in the areas of sensor technology and platforms. Yet, several improvements are further required to retrieve parameters in a refined manner using space technology.

Some of the imperative data needs felt acutely by the user community are: i) improved spatial resolution (< 1m) of RS data to provide terrain details on cadastral level (1:2,500), ii) stereo capability (< 1m height resolution) to help planning/execution of development plans, iii) high resolution (< 5m) multi-spectral data to facilitate identification of crops grown in small fields (~1acre), iv) high repetivity data (< 2days) to monitor dynamic phenomena such as flood, forest fires, changes in snow line, crop growth etc., v) data pertaining to physical and biological parameters of the ocean, and vi) constellation of satellites for monitoring disasters. Considering these, in the next 6-7 years, a host of spacecraft systems carrying different sensors have been planned across the globe including India.

New Millennium Program (NMP) is a cross-enterprise technology program jointly funded and managed by the National Aeronautics and Space Administration (NASA) Office of Space Science and Office of Earth Science. It was established in 1995 as an ambitious, exciting vision to speed up space exploration through the development of highly advanced technologies. Earth Observing-1 (EO-1) is the first satellite in NASA's New Millennium Program Earth Observing series. The EO-1 mission has developed and validated instruments and technologies for space-based Earth observations with unique spatial, spectral and temporal characteristics not previously available. Earth Observing 3 (EO-3) mission, called GIFTS (Geosynchronous Imaging Fourier Transform Spectrometer), is the first step in improving operational weather observing systems by NASA under NMP. This is expected to improve our ability to observe, analyze, and predict weather, enabling weather forecast to a higher level of accuracy in future.

Earth Observation Programme of India is also gearing up to meet the increasing EO needs. Its space programme is chalked out till 2007/8 with emphasis on a) provision of moderate spatial resolution multispectral sensor data continuity through LISS-III onboard Resourcesat-1&2, b) provision of high-spatial resolution stereo data for large-scale mapping needs (Cartosat-1 & 2), c) Global capability for climate and weather applications in Tropical regions, (Megha Tropiques), d) an exclusive satellite for ocean applications containing ‘C’ band scatterometer and ocean color monitor, and e) microwave satellite (RISAT) mainly for crops, terrain and flood inundation and damage assessment applications – specially during cloud season.

Living Planet Programme The European Space Agency (ESA) is making use of smaller satellites on shorter, cheaper, and focused missions. Within Living Planet Programme two types of Earth Observation mission have been adopted: Earth Explorers, which focus on research and Earth Watches, which are prototype operational missions serving operational applications. Missions like GOCE, ADM-Aeolus, Cryosat and SMOS are planned and being implemented under Earth Explorers; and TerraSat, FuegoSat, and Radarsat (near term), Ocean Earth Watch and Land Optical Earth Watch Missions are planned for Medium and Long term under Earth Watch programme (http://www.esa.int/export/esaLP/ /ASERBVNW9SC_index_0.html).

The **Japenese Aerospace Exploration Agency (JAXA)** is pursuing advances in EO programme through GOSAT, ALOS, AQUA and ADEOS-II satellites (http://www.jaxa.jp/missions//projects/sat/eos/index_e.html.

In addition, various countries like Argentina, Brazil, Canada, China, Korea, Russia, and Ukraine are also contributing significantly towards earth observations through CEOS.

With the availability of complementarity of remote sensing data from various missions by different agencies, some focused research towards disaster management is also taking place. The concept of virtual satellite like Tech21, missions like DEMETER and GRACE too have definite role to play.

Analytical Tools

Along with the technical developments in the imaging or sensor systems, advances are also necessary in devising new analytical tools and improving / developing process models (which may not be available off-the-shelf) by research teams. Efforts towards analyzing hyperspectral data in quantifying the physiology/stress related properties of plant, physicochemical properties of soil and water, understanding the impact of angular effect in remote sensing- detailed study on use of BRDF for biophysical parameter retrieval, development of suitable algorithms for deriving aerosol properties for a wide variety of situations for more accurate atmospheric correction, algorithms for retrieval of geophysical / biophysical parameters and SAR Polarimetry are quite important. Also in the data processing, developing appropriate data fusion techniques for high spatial resolution data with high spectral resolution data is also an emerging area. In the domain of feature extraction (information retrieval) evaluation of classifiers such as soft classifiers (e.g. fuzzy), knowledge based methods, textural/contextual methods, extraction of planimetric and 2.5-D/3-D features from remote sensing data, development of new image processing procedures, which incorporates photogrammetry, advanced classifiers and GIS based modeling are quite relevant. Very relevant to the agro ecosystems research are some research interests like development of sustainability indicators amenable to remote sensing, precision farming: efficacy of space inputs, development of expert systems for crop monitoring/forecasting, use of remote sensing to aid alternate sustainable cropping systems, characterization of and biodiversity at global and regional scale, and hydrological modeling to study runoff, water balance and soil moisture. Development of integrated monitoring systems using RS, GIS, GPS etc. is an important and interesting area across the EO systems. Towards disaster management, forecast / early warning systems, design of a total system for disaster forecast, monitoring, mitigation and damage assessment, constellation of satellite system is always going to be on the research forefront. For any global / regional level earth system research, creation of long-term global datasets useful in terms of seeking evidence of climate change, whether regionally or globally, assimilation of satellite data derived parameters for improving weather forecasts is going to be important. Similarly ocean state forecasting, polar research are also important thrust areas.

Concluding Remarks

Humankind in pursuit of its needs has put earth resources to a severe strain. This is resulting in degrading the environment thereby causing at times, irreversible damage to the very existence of life on this planet earth. Sustainable development is one approach, which attempts to find solutions to some of the self-induced human maladies. The present paper tried to tread the productive ecosystem approach to find probable solutions, and the role of EO systems towards providing the required information needs. Studies across the world are showing increased scope for use of EO data acquired in multiple dimensions by virtue of advances in space-based and in-situ measurement systems. Data availability from satellites like Hyperion, MODIS, QUCIKBIRD, IKONOS-II, Resourcesat-1, SPOT-5 etc. have opened new vistas in earth resources applications. Integration of complementary data sets from different spacecrafts, integration of data from multiple sensors / platforms like satellite and in-situ, and algorithms for processing different satellite data sets, techniques of data fusion etc. have become important. Development of integrated monitoring systems, forecast / early warning systems, design of a total system of constellation of satellites for disaster warning, monitoring, mitigation and damage assessment, are high on the agenda. Global level EO initiatives of CEOS, International Charter on Space and Major Disasters, IGOS-P, GEOSS are some of the programmatic endeavours in this direction. Thus, the new trends in EO strategies coupled with analytical techniques would further enhance our understanding of the Earth systems processes towards sustainable development.

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