Remote sensing technique- a tool for environmental studies

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1. Introduction

Environment belongs to all and is important to all. As per definition of the Environment Protection Act, environment includes all the physical and biological surroundings and their interactions. The study of environment or rather environmental studies is a multi-disciplinary which needs knowledge interest from physical sciences (physics, chemistry, mathematics), biological sciences (botany, zoology, microbiology, biochemistry), social sciences, economics, sociology, education, geography) etc.

2. Scope of using remote sensing in environmental study

Remote sensing is a valuable tool for understanding the environment due to its capabilities of observation, analysis and measurement, mapping, monitoring over time and space and decision support. "Remote sensing is the science of deriving information about an object without actually coming in contact with it". Remote sensing platforms measure a number of biological and physical variables such as elevation, productivity, cloud type, land and water surfaces, temperature, precipitation, wind velocity, water quality, etc.The advances in technology and availability of Remote Sensing data at affordable prices made frequent monitoring of environmental changes possible. During past few decades, remotely sensed data have increasingly been used as a tool for a wide variety of applications ranging from monitoring of natural resources, to disaster management, to disease control and health management. The utilization of remotely sensed data for environmental monitoring has various advantages over traditional approaches. Remote sensing provides a continuous monitoring and mapping, both spatial and temporal, as opposed to a limited frequency point measurements. Therefore, the process of environmental decision-making where environmental changes and impacts are being monitored at a regular basis can be greatly enhanced using satellite data and techniques. The environmental monitoring techniques are further improved when satellite data is combined with information from other sources and ground observations.

Remote sensing data in the present day context of environmental application is widely being used in land use monitoring and planning activities, land use change analysis, forest change analysis, agriculture monitoring, water resource and fisheries, wetland and wasteland change analysis, biomass monitoring, climate impacts on rainfall pattern, fire risks, etc. Understanding fragmentation and landscape metrics provides insight into how land cover is distributed, which can in turn be used to predict suitability for different flora and fauna. Remotely sensed data and products can be used to calculate a number of different measures including composition and connectivity, fractal dimension and route networks. The satellite data is being used for planning, implementation, and monitoring of individual protected areas and in developing networks of protected areas in terrestrial as well as marine systems. The issue of integrating social and economic data into planning and monitoring is critical to the success of these initiatives.

2.1 Satellite remote sensing in drought monitoring

Droughts are one of the most catastrophic natural hazards in the world, which are causing large scale damage to agriculture along with human and wildlife. Recent studies have shown the importance of remotely sensed data coupled with meteorological data significantly contribute in improving drought and vegetation monitoring for risk management. Given the repeat coverage and spatially continuous measurements over a large area, satellite- based remote sensing plays a vital role in monitoring drought in detail at local level. In addition, advanced satellite technology products with high temporal resolution are cost effective and may serve to detect the onset of drought and its duration and magnitude, which is critical information for risk management and food security. Satellite information and products are expected to help in decision making for countries with a wide diversity of crops, ecosystems, and production systems. In drought monitoring, recent efforts have enabled use of soil moisture measurements derived from satellite remote sensing data for enhancing drought monitoring systems (Nghiem et al., 2010). In India, National Agricultural Drought Assessment and Monitoring System (NADAMS) was initiated towards the end of 1986, with the participation of National Remote Sensing Agency, Dept. of Space, Government of India, as nodal agency for execution, with the support of India Meteorological Department (IMD) and various state departments of agriculture. NADAMS was made operational in 1990 and has been providing agricultural drought information in terms of prevalence, severity and persistence at state, district and sub-district level.

2.2 Satellite remote sensing in hydrological study

Instruments on Earth Observation systems have been extensively used to measure hydrologic and hydraulic variables such as water spread area, elevation of water surface and temporal changes (Douglas et al., 2007). Glacier and permafrost hazards in high mountains include glacier- and permafrost-related floods, stable and unstable glacier length changes as well as glacier fluctuations, glacier and permafrost-related mass movements, permafrost thaw settlement and frost heave and hazards from glacier-clad volcanoes. Assessment and management of glacial and permafrost hazards require the application of modern integrative earth -observation technique. The mass losses of the Antarctic and Greenland ice-sheets have been estimated by measuring surface elevation changes from satellite altimetry data (collected by satellites such as ERS-1/-2, Envisat, ICESat and CryoSat-2) or by measuring ice-mass changes using the Gravity Recovery and Climate Experiment (GRACE) satellite data. For the utilization of Indian earth observation data and hydrological products, web based data archival and visualization systems are available on following major GeoPlatforms of Indian Space Research Organization viz., Visualization of Earth Observation Data and Archival System (HYPERLINK "http://vedas.sac.gov.in" http://vedas.sac.gov.in), Meteorological and Oceanographic Satellite Data Archival Centre (HYPERLINK "http://mosdac.gov.in" http://mosdac.gov.in), Bhuvan (http://bhuvan.nrsc.gov.in) and India Water Resources Information System (http://www.india-wris.nrsc.gov.in).

2.3 Satellite remote sensing in weather and climate study

Satellite remote sensing has provided major advances in understanding the climate system and its changes by quantifying processes and spatio-temporal states of the atmosphere, land and oceans. The Global Climate Observing System (GCOS) has listed 26 out of 50 essential climate variables (ECVs) as significantly dependent on satellite observations (GCOS, 2011). Data from SRS is also widely used for developing prevention, mitigation and adaptation measures to cope with the impact of climate change (Joyce, 2009). When we talk about climate, we often talk about average values of meteorological or oceanographic variables, such as air temperatures, precipitation, humidity, wind speed or ocean temperature at a given location at a given time of year. If the climate changes over time, it can directly affect human activities by altering the crops that can be grown, the supply of fresh water, or the mean level of the ocean. It can also affect natural ecosystems, causing deserts to expand, wildfires to become more prevalent, or permafrost to melt. Over the past two decades, there has been growing concern about the effects of human-produced greenhouse gases and other environmental pollutants on Earth's climate. These changes are predicted by climate models, which are also used to project changes into the next centuries. Satellite data records are beginning to be long enough to evaluate multi-decadal changes. These changes can be examined for evidence of climate change, and used to see if climate models can do a good job when used to "predict" the changes that have already occurred. Six different satellite systems are being used in weather studies: 1) Visible/ Infrared/Water Vapor Imagers, 2) Infrared Sounders, 3)Microwave Imagers, 4) Microwave Sounders, 5) Scatterometers and 6) Radar Altimeters. Satellite data provides an independent way to investigate global temperature trends, particularly at the ocean surface and in the atmosphere. It is important to track changes in the sun's luminosity (measured in Total Solar Irradiance; TSI), to determine whether the natural variation in solar radiation has contributed significantly to recent climate change. Measurements from the spectral irradiance monitor (SIM) on board the Solar Radiation and Climate Experiment (SORCE) satellite showed that ultraviolet radiation has decreased over the solar magnetic energy cycle four to six times more than had been expected from model calculations. Total Ozone Mapping Spectrometer (TOMS) launched in 1978 provides daily map of global ozone concentration. The Advanced Very High Resolution Radiometer on board the National Oceanic and Atmospheric Administration (NOAA) satellites allows us to monitor the Sea Surface Temperature worldwide. Particles in the atmosphere known as aerosols can generate a cooling effect on the climate system, counteracting the warming effects of anthropogenic greenhouse gases by affecting both atmospheric radiation and cloud–precipitation processes. Recent changes in atmospheric aerosol concentration have been identified through aerosol optical depth (AOD), which is derived from observations recorded by visible and infrared optical sensors on board various satellites. Climate forcing and feedback of clouds adjust the energy flow throughout the Earth's system. Net cloud forcing (NCF) is estimated to be −21 W m–2 by combining model simulations with the Earth Radiation Budget Experiment (ERBE) and Clouds and the Earth's Radiant Energy System (CERES) observations. Water vapor is an important greenhouse gas as it contributes around 50% of the present-day global greenhouse effect. High-Resolution Infrared Radiation Sounder (HIRS) records from 1979 to 2009 showed an average increase in watervapor content in the upper troposphere over the equatorial tropics. The spatial and temporal variability of precipitation on the global scale can be retrieved from observations made by infrared sensors on board geostationary satellites, passive microwave sensors carried by the polar-orbiting satellites and recently active radars on board the TRMM satellite and its successors. Several international initiatives — notably the Global Observing Systems Information Center (GOSIC), the Global Geodetic Observing System (GGOS) and the Global Earth Observation System of Systems (GEOSS) — have been implemented to coordinate efforts to produce and disseminate high-quality satellite climate records. INSAT system is the primary satellite for weather surveillance. It is a multipurpose geostationary satellite that caters to the requirements of Meteorology and Communication. It carries a met payload called Very High Resolution Radiometer (VHRR) that enables us to have visible, infrared and now even water vapor images. A geostationary meteorological satellite (METSAT) system devoted totally to meteorology was launched in 2002. It has been renamed as Kalpana-1 and is currently the operational satellite system being used by India Meteorological Department. Satellite imagery is being extensively used by synoptic network in conjunction with other available conventional meteorological data for analysis and weather forecasting. Zones of cloudiness are identified from the satellite imagery as regions of upward velocity and hence potential areas for occurrence of rainfall. The INSAT and NOAA sounding data have brought out the unique nature of monsoon onset with large scale changes in wind and moisture profiles in lower troposphere prior to monsoon onset. The 16 parameter statistical model used by India Meteorological Department has several parameters that are provided by Satellite data such as the SST, Snow Cover, E1 Nino event etc. INSAT Meteorological Data Processing System (IMDPS) computes the numerical products viz., Cloud Motion Vectors (CMVs),. Quantitative Precipitation Estimates (QPEs), Outgoing Long-wave Radiation (OLR), Vertical Temperature Profiles (VTPRs), Sea Surface Temperatures (SSTs).

Some of the recently launched for weather monitoring includes SCATSAT-1 (Scatterometer Satellite-1) is a continuity mission for Oceansat-2 Sactterometer to provide wind vector products for weather forecasting, cyclone detection and tracking services to users. The Geostationary Operational Environmental Satellite-R Series (GOES-R) is the geosynchronous environmental satellite supporting weather forecasting, severe storm tracking, space weather monitoring and meteorological research.

2.4 Satellite remote sensing in land based studies

The land sciences community has made extensive use of satellite image data for mapping land cover, estimating geophysical and biophysical characteristics of terrain features, and monitoring changes in land cover. For example, in Applications of NOAA AVHRR 1-km Data for Environmental Monitoring, remote sensing application in environment studies mainly uses the optical band. Satellite-derived products are now being used for characterization of the urban thermal environment. Thermal infrared (TIR) remote sensing from satellites allows global and continuous monitoring of phenomena such as surface urban heat islands (SUHI) and heat waves. SUHI studies that involve satellite observations are based on land surface temperature (LST) estimations. LST is one of the most important geophysical parameters that can be remotely estimated by satellite observations and has been utilized in several applications related to SUHI such as surface fluxes and energy budget estimation.

Satellite data have been used to document landscape-level changes to the forest resource. The gradual reduction in the forest cover extent is a matter of concern. Vegetative conditions over the world are reported occasionally by NOAA National Environmental Satellite Data and Information System (NESDIS) using the Advanced Very High Resolution Radiometer (AVHRR) data (Kogan 2000). The biennial reports on forest cover of India (The State of Forest Reports) published from Forest Survey of India is made possible only with the availability of satellite remote sensing data. Satellite data is being widely used for monitoring and mapping land cover, biomass assessment, estimating geophysical and biophysical characteristics and biodiversity assessments. Vegetation type and landcover mapping of the entire North-East India, Western Himalayas and Western Ghats of India, were mapped on a 1:250,000 scale by using IRS LISS data (IIRS, 2002). Department of Space and Department of Biotechnology in its joint venture took up a study on biodiversity characterization at landscape level using remote sensing and GIS (IIRS, 1998). The study focussed on identification of disturbance areas and biological richness areas for conservation and bioprospecting over North East Region, Western Ghats, Andaman and Nicobar islands, Central India, Eastern Ghats and the East coast (Roy and Behera, 2002). Forest fire study using remote sensing supports in forest fire mitigation under disaster management program and NESAC has is providing forest fire value added services under its disaster risk reduction program.

One of the major applications of remote sensing is in the land use planning. It is widely used in identifying drivers of land use change (Fig.1)

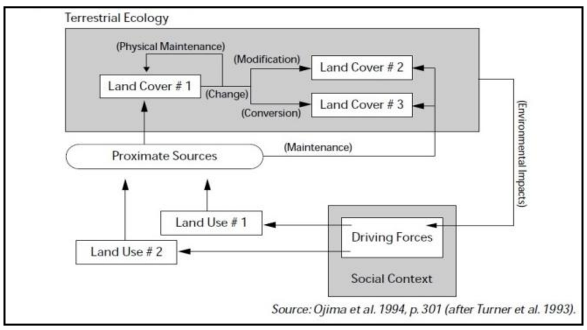

Figure.1 Driving forces of land use change

An estimate of forest cover change from 1930 to 2013 (Reddy et al., 2016) depicts the forest decline with the help of remote sensing studies in north eastern region (Fig.2).

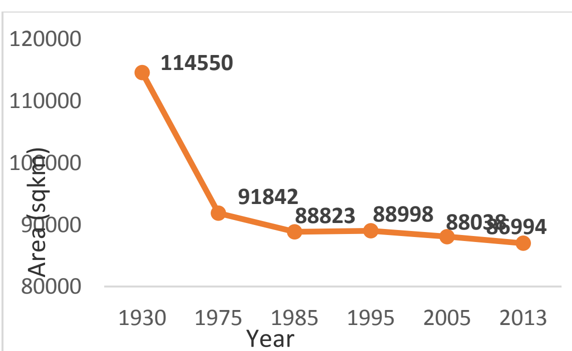

Figure.2 Areal extent of forest cover change in Northeast region (Adopted from Reddy et al., 2016)

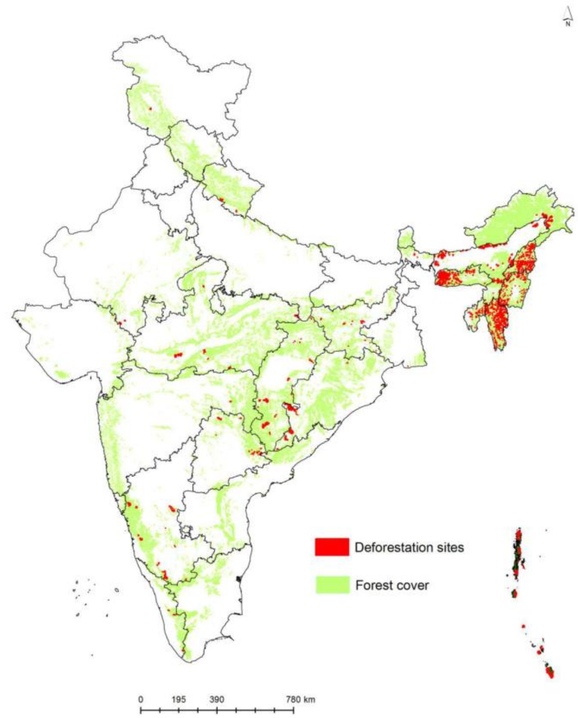

Figure 3. Major deforestation sites in India (Reddy et al., 2016)

3. Recent trend in environmental remote sensing

However, the present day remote sensing application is focussed in the microwave and LiDAR applications. Optical remote sensing uses the visible and infrared portion of the electromagnetic spectrum is often affected by weather conditions whereas, microwave Radar has its own advantage being not affected by weather condition and can also penetrate the vegetation crown cover. New technologies, such as LIght Detection And Ranging (lidar), offer the possibility of reducing inventory costs and increasing accuracy and can be deployed from space, aircraft, and on the ground. LIDAR (light detection and ranging), is a relatively recent innovative technique. Lidar remote sensing has been used to estimate the horizontal and vertical heterogeneity in forest structure. Aerial LiDAR is an active remote sensing technology that is able to penetrate the upper canopy, allowing accurate estimations of forest attributes including canopy structure, canopy bulk density, and leaf area index. Hyperspectral remote sensing is a relatively new technology. It is currently being investigated by researchers and scientists with regard to the detection and identification of minerals, terrestrial vegetation, and man-made materials and backgrounds. The ability of imaging sensor to acquire the reflectance spectrum of pixel in significant detail leads to substantial difference in the reflectance values of pixel belonging to disparate material of earth surface. The number of narrow bands in such data can also have more than 200 narrow channels.

4. Few examples of derived data products

Assessing and monitoring the state of the earth surface is a key requirement for global change research. The technology of remote sensing offers a practical and economical means to study vegetation cover changes, especially over large areas. A number of derived products are now available for environmental application that includes: MODIS Land Cover 500 m resolution, Global Cover: based on 300-m resolution imagery from MERIS sensor (ENVISAT). SRTM (Shuttle Radar Topography Mission) derived Digital Elevation Model (DEM): 30-m and 90-m resolution, ASTER Global Digital Elevation Map: 30-m pixel, MODIS Land Surface Temperature/Emissivity: available daily, 8-day, and monthly, at 1-km, 5.6-km resolutions, TRMM (Tropical Rainfall Measuring Mission): 16 times per day, multiple products describing rainfall at 2.4 km and 5-km pixel resolution, MODIS Cloud Product: daily product of cloud properties at 1-km and 5-km pixel resolution. MODIS Global Vegetation Phenology product (MCD12Q2): provides estimates of the timing of vegetation phenology at 500-m pixel resolution. SPOT Vegetation: provides NDVI global data since 1998 at a 1.15-km pixel resolution, MODIS Gross Primary Productivity (GPP) product (MOD17A2): 8-day composite at 1-km spatial resolution, MODIS Leaf Area Index (LAI) and Fractional Photo-synthetically Active Radiation (FPAR): 8-day composite at 1-km spatial resolution and so on. The Atmospheric Infrared Sounder (AIRS) project has generated decadal-length, global, gridded data sets of temperature and specific humidity for several standard levels in the troposphere. The cross-calibrated multi-platform wind vector analysis (CCMP) wind analysis is a near-global, high spatial and temporal resolution gridded dataset of surface wind vectors spanning 1987-present. The input data are a combination of inter-calibrated satellite data from numerous radiometers and scatterometers and in-situ data. The Clouds and Earth's Radiant Energy Systems- Energy Balanced and Fillied (CERES-EBAF) product provides 1-degree regional, zonal and global monthly mean Top-of-Atmosphere (TOA) and surface (SFC) longwave (LW), shortwave (SW), and net (NET) fluxes under clear and all-sky conditions. CMAP (CPC Merged Analysis of Precipitation) refers to a collection of precipitation data sets, though the 2.5°x2.5° global monthly version is probably the most widely used. This data set is constructed from an analysis of gauge data and satellite-derived precipitation estimates.

5. Conclusion

Conventional land-based observations are typically collected at fixed intervals with limited spatial coverage, whereas satellite remote sensing allows for continual monitoring on the global scale. Remote sensing applications has vast scope in environmental studies ranging from land use planning and change, forestry, agriculture, water resource and fisheries, climate change studies, disaster management and response. All applications have not been covered in details since satellite remote sensing has vast applications in each of the fields. One such example is the application of remote sensing in the spread of vector borne diseases is an important is field of study. India has the largest constellation of Remote Sensing Satellites, which are providing services both at the national and global levels. From the Indian Remote Sensing (IRS) Satellites, data is available in a variety of spatial resolutions starting from 360 metres and highest resolution being lesser than 2.5 metres . The future launch of GSAT will give a further boost to the environmental applications. The concept of Integrated Mission for Sustainable Development integrates with the socio-economic data obtained from conventional sources to achieve sustainable development. The accurate and reliable information about land areas and area changes is critically important for developing inventories that are consistent with IPCC good practice guidelines. In this context, remote sensing assumes great importance as a cost effective tool.

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