Use of Satellite Data for Watershed Management and Impact Assessment

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Abstract

Over-exploitation of natural resources for meeting the increasing demand for food, fuel, and fiber of the ever growing population has led to environmental degradation and calls for their optimal utilization based on their potential and limitations. Information on the nature, extent, and spatial distribution of natural resources is essential. Spaceborne multispectral measurements made at regular intervals hold immense potential of providing such information in a timely and cost-effective manner, and facilitate studying dynamic phenomenon. The geographic information system (GIS) provides an ideal environment for integration of information on natural resources with the ancillary information for generating derivative information which is useful in decision making. The study was taken up to generate the action plan for land and water resources development and to monitor the progress of its implementation in the Adarsha watershed, Kothapally, Ranga Reddy district, Andhra Pradesh, India. The approach involves generation of thematic maps on various natural resources through a systematic visual interpretation of satellite data, integration of such data with the ancillary information and generation of action plan in the GIS environment, and monitoring vegetation development as a sequel to implementation of action plan by generating Normalized Difference Vegetation Index (NDVI) from the Indian Remote Sensing Satellite (IRS-1C/-1D) Linear Imaging Self-scanning Sensor (LISS-III) data. Soil erosion by water is the major land degradation process operating in the watershed. There has been an improvement in the vegetation cover owing to implementation of various soil and water conservation measures, which is reflected in the NDVI images of pre- and post-implementation periods.

Soil erosion by water and wind is the major land degradation process in the arid and semi-arid regions of the world. Globally, about 1.965 billion ha of land is subjected to some kind of degradation. Of this, 1.094 billion ha of land is subjected to soil erosion by water and 549 million ha of land to soil erosion by wind. On an average 25 billion tons of topsoil from croplands is being washed into oceans. In India alone, out of 329 million ha geographical area, 150 million ha land is affected by wind and water erosion (GOI 1976). Annually about 6000 million tons of soil is lost through soil erosion by water (Das 1985). Also, shifting cultivation, waterlogging, and salinization and/or alkalization have affected an estimated 4.36 million ha, 6 million ha, and 7.16 million ha of land respectively (GOI 1976). Frequent floods and drought further compound the problem. Soil degradation contributes to an increase in atmospheric carbon dioxide through rapid decomposition of organic matter. In addition, rapid industrialization and deforestation have led to building up of greenhouse gases in the atmosphere resulting in global warming. Degradation of vegetation by deforestation for timber and fuel wood, shifting cultivation, and occasionally forest fire is a very serious environmental problem. Biodiversity conservation is equally important for the sustainability of vegetation. Optimal utilization of natural resources based on their limitations and potential is, therefore, a prerequisite for sustained agricultural production.

The Role of Remote Sensing

For optimal utilization of natural resources, information on their nature, extent, and spatial distribution is a prerequisite. Until the 1920s, such information had been collected by conventional surveys, which are labor-intensive, cost-prohibitive,

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and impractical in the inhospitable terrain. During the 1920s and early 1970s, aerial photographs were used for deriving information on various natural resources including lands subject to degradation by various processes (Bushnell 1929, USDA 1951, Howard 1965, Iyer et al. 1975). Since the launch of the Earth Resources Technology Satellite (ERTS-1), later renamed as Landsat-1, in 1972, followed by Landsat-2, -3, -4, and -5, SPOT-1, -2, -3, and -4, and the Indian Remote Sensing Satellites (IRS-1A, -1B, -1C, and -1D) with Linear Imaging Self-scanning Sensors (LISS-I, -II, and -III), spaceborne multispectral data collected in the optical region of the electromagnetic spectrum have been extensively used in conjunction with the aerial photographs and other relevant information supported by ground truth, for deriving information on geological, geomorphological, and hydro-geomorphological features (Rao et al. 1996a, Reddy et al. 1996); soil resources (Singh and Dwivedi 1986); land use/land cover (Landgrebe 1979, Raghavaswamy et al. 1992, Rao et al. 1996b); forest resources (Dodge and Bryant 1976, Unni 1992, Roy et al. 1996); surface water resources (Thiruvengadachari et al. 1996); and degraded or wastelands (FAO 1978, Karale et al. 1988, Nagaraja et al. 1992, Dwivedi et al. 1997a, 1997b). Futhermore, spaceborne multi-spectral data have been operationally used for integrated assessment of natural resources and subsequent generation of action plans for land and water resources development and for assessment of the impact of their implementation.

Biomass has been used as a surrogate measure to evaluate the impact of the implementation of action plan for land and water resources development. High absorption of incident sunlight in the visible red (600–700 nm) portion and strong reflectance in the near-infrared (750–1350 nm) portion of the electro-magnetic spectrum has been used to derive vegetation indices, which indicate the abundance and condition of biomass. The index is typically a sum, difference, ratio, or other linear combination of reflectance factor or radiance observations from two or more wavelength intervals. The vegetation indices thus developed are highly correlated with the vegetation density or cover; photosynthetically active biomass (Tucker 1979, Wiegand and Richardson 1984); leaf area index (Wiegand et al. 1979); green leaf density (Tucker et al. 1985); photosynthesis rate (Sellers 1987); and amount of photosynthetically active tissue (Wiegand and Richardson 1987). Landsat-TM data have been used for deriving various vegetation indices which in turn were used to assess the impact of soil conservation measures in the treated watersheds (NRSA 1996, 1999). The study reported here was taken up to (i) generate the action plan for sustainable development of land and water resources, and (ii) assess the impact of the action plan in the Adarsha watershed using IRS-1B/-1C and -1D LISS-II and -III data (see Table 1).

Test Site

With an area of 1083 ha, Adarsha watershed in Kothapally is bound by geo-coordinates 17°21’ to 17°24’ N and 78°5’ to 78°8’ E and forms part of Shankarpally mandal (an administrative unit) of Ranga Reddy district, Andhra Pradesh, India. Vertisols and associated Vertic soils occupy 90% of the watershed area. However, Alfisols do occur to an extent of 10% of the watershed area. The main kharif (rainy season) crops grown are sorghum, maize, cotton, sunflower, mung bean, and pigeonpea. During rabi (postrainy season) wheat, rice, sorghum, sunflower, vegetables, and chickpea are grown. The mean annual rainfall is about 800 mm, which is received mainly during June to October.

Table 1. The details of remote sensing data used.

Satellite/sensor	Path/row nos.	Date of pass
IRS-1B LISS-II	26–56	25-11-1996
IRS-1C LISS-III	99–60	01-04-1996
IRS-1D LISS-III	99–60	02-04-2000 & 29-11-1999
IRS-1D PAN	99–60	01-12-1999

Database

We have used the Indian Remote Sensing Satellite (IRS-1B/-1C and -1D) Linear Imaging Self-scanning Sensor (LISS-II and -III) and Panchromatic sensor (PAN) data for deriving information on various natural resources and for generation of action plans for land and water resources development (Table 1). In addition, Survey of India topographical maps at 1:50,000 scale, and published soils and other resources maps and reports were also used as collateral information.

Methodology

The methodology involves database preparation, generation of thematic maps on natural resources, and their integration with the socioeconomic data to arrive at a locale-specific prescription for land and water resources development. The schematic diagram of the approach is given in Figure 1. Once action plan is implemented, the next logical step is to assess its impact on environment and the beneficiaries.

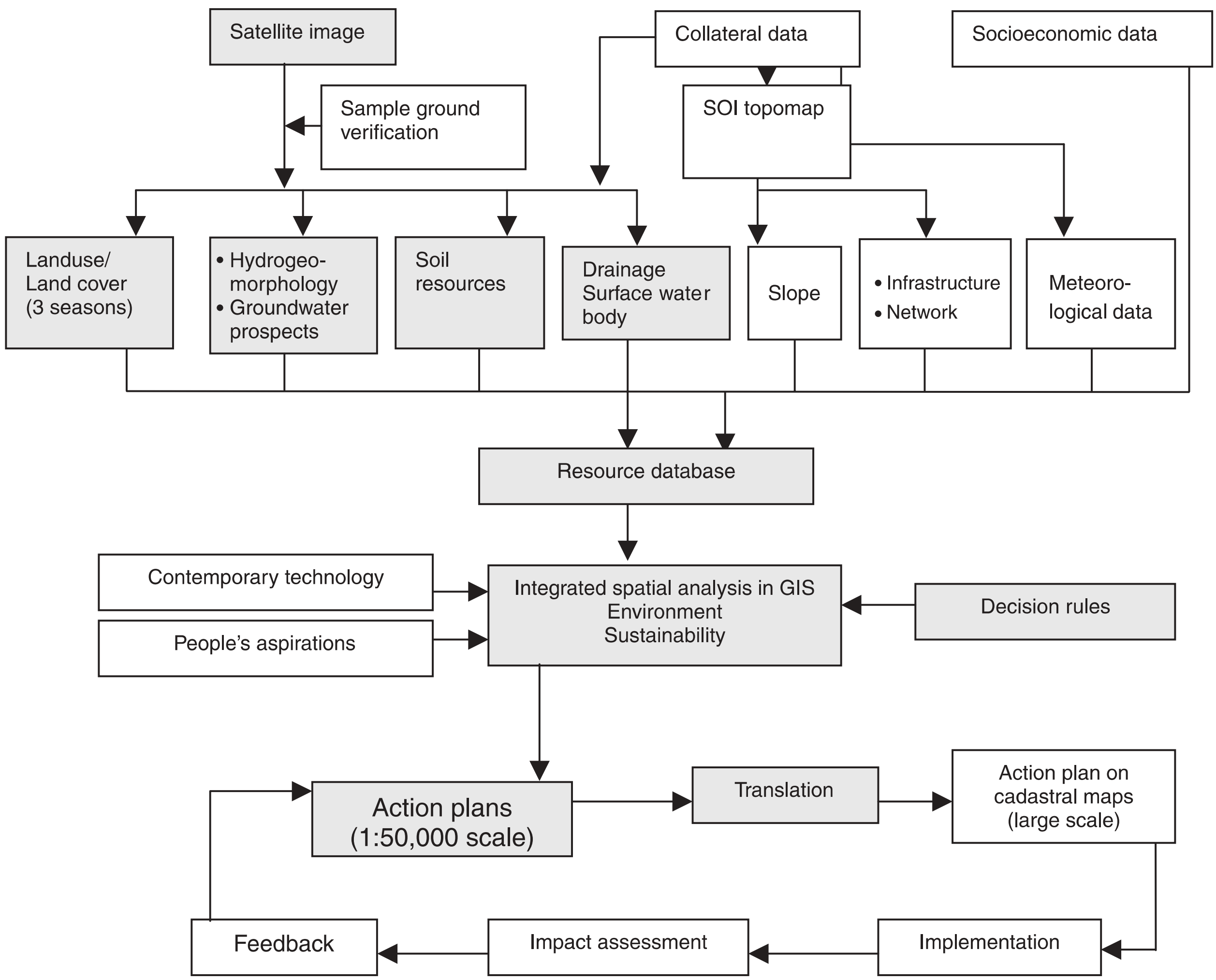

Figure 1. Schematic diagram of the approach.

Database preparation

The first step in generating the multi-sensor data sets is the geo-referencing of the image to a common map grid. When merging higher resolution data with the lower resolution images, usually high resolution image (here PAN data with 5.8 m spatial resolution) is used as a reference for respective enhancement of the lower resolution (LISS-III data with 23.5 m spatial resolution) data (Cliché et al. 1985). To begin with, the Survey of India topographical maps at 1:50,000 scale were scanned on a Contex FSS-800 scanner at 300 dots per square inch (dpi). The digital LISS-III was later co-registered to digital, topographic database on a Silicon Graphics Octane work station using 20 tie points (ground control point) and image-to-image registration algorithm. The IRS-1D PAN digital data was subsequently co-registered to LISS-III data following similar approach. Subsequently, the LISS-III data was resampled to 6 m pixel dimension using nearest neighborhood algorithms for further processing. The IRS-LISS-II data was also digitally co-registered to IRS-1C LISS-III data and resampled to 24 m pixel dimension. The three bands, namely 0.52–0.59 μm, 0.62–0.68 μm, and 0.77–0.86 μm of LISS-III data were digitally merged with PAN using Brovey transformation algorithm. The Brovey transformation is a formula-based process that works by dividing the band to display in a given color by the sum of all the color layers, i.e., red, green, and blue and then multiplying by the intensity layer.

Generation of thematic maps

Thematic maps on hydrogeomorphological conditions, soil resources, and present land use/land cover have been generated through a systematic visual interpretation of IRS-1B/-1C/-1D LISS-II and -III data in conjunction with the collateral information in the form of published maps, reports, wisdom of the local people, etc. supported by ground truth. The information derived on the lithology of the area and geomorphic and structural features in conjunction with recharge condition and precipitation was used to infer groundwater potential of each lithological unit. Soil resource maps of the area have been prepared by delineating sub-divisions within each geomorphic unit based on erosion status, land use/land cover, and image elements, namely color, texture, shape, pattern, and association. Soil composition of each geomorphic unit was defined by studying soil profiles in the field and classifying them based on morphological characteristics and chemical analyses data (USDA 1975, 1998).

In addition, derivative maps, namely land capability and land irrigability maps were generated based on information on soils and terrain conditions according to criteria from the All India Soil and Land Use Survey Organization (All India Soil and Land Use Survey 1970). Land capability classification is an interpretative grouping of soils mainly based on: (i) inherent soil characteristics, (ii) external land features, and (iii) environmental factors. The groupings enable one to get a picture of (i) the hazards of the soils to various factors which cause soil damage and deterioration or lowering in fertility, and (ii) its potentiality for production. The interpretation of soil and land conditions for irrigation is concerned primarily with predicting the behavior of soils under the greatly altered water regime brought about by the introduction of irrigation. For arriving at land irrigability classes, soil characteristics, namely, effective soil depth, texture of the surface soil, permeability, water-holding capacity, course fragments, salinity and/alkalinity, presence of hard pan in the surface, topography, and surface and sub-surface drainage are considered.

Land use/land cover maps have been prepared using monsoon (kharif) and winter (rabi) crop growing seasons and summer period satellite data for delineating single-cropped and double-cropped areas apart from other land use and land cover categories. Furthermore, micro-watersheds and water bodies have been delineated and the drainage networks have also been mapped. Slope maps showing various slope categories have been prepared based on contour information available at 1:50,000 scale topographical sheets. Rainfall data were analyzed to study the rainfall distribution pattern in time and space. Demographic and socioeconomic data were analyzed to generate information on population density, literacy status, economic backwardness, and the availability of basic amenities.

Generation of action plan

The generation of an action plan essentially involves a careful study of thematic maps on land and water resources, both individually as well as in combination, to identify various land and water resources regions or Composite Land Development Units (CLDU) and their spatial distribution, potential and limitations for sustained agriculture and other uses, and development of an integration key. It was achieved by scanning the thematic maps on a CONTEX FSS 800 black and white scanner at 400 dpi. It was followed by vectorization, projection to real world coordinates, editing map compilation and unionizing the thematic boundaries in a geographic information system (GIS) domain using ARC/INFO version-7 software. Each CLDU was studied carefully and a specific land use and soil and water conservation practice was suggested based on its sustainability. Subsequently, taking landform as a base an integration key in terms of potential/ limitations of soils, present land use/land cover, and groundwater potential, and suggested alternate land use/action plan was developed.

Implementation of action plan

The action plan and/alternate land use practices and drought-proofing activities emerging from this approach have been implemented by the district/mandal authorities using the state-of-the-art technology for each action item to fully exploit the contemporary developments in agriculture, science, and technology.

Impact assessment

Since vegetation condition is the reflection of soils and hydrological conditions which are altered in the event of implementation of suggested action plan, it has been taken as a surrogate parameter for assessment of the impact of such treatment in the watershed. The Normalized Difference Vegetation Index (NDVI) values from near infrared (NIR) and red (R) band responses in the IRS-1B/-1C/-1D LISS-II and -III data were generated on a Silicon Graphics work station as follows:

$$\text{NDVI (output DN)} = \frac{\text{NIR (DN)} - \text{R (DN)}}{\text{NIR (DN)} + \text{R (DN)}}$$

DN represents digital number in respective spectral bands. The equation produces NDVI values in the range of –1.0 to 1.0, where negative values generally represent clouds, snow, water, and other non-vegetated surfaces, and positive values represent vegetated surfaces.

Results

Natural resources

Lithologically, the watershed comprises of basalt and laterites. The moderately dissected plateau which is interspersed with structural valleys constitutes the major landform. While the undissected plateau has poor groundwater potential, the dissected plateau has poor to moderate potential. Structural valley has good groundwater potential depending on the nature of the fracture. Whereas Vertic Haplaquepts have developed over structural valleys the dissected plateau support the development of shallow soils namely Lithic Ustochrepts and Lithic Ustorthents. Vertic Ustochrepts, however, do occur in local depressions within the dissected plateau. The watershed is mainly used for raising both kharif and rabi crops. A few pockets of land, however, is wasteland mostly in the form of land with/without scrub. The land under kharif crops constitute the major land use and land cover category followed by double cropped land (Fig. 2).

Action plan

Since the watershed very often experiences drought, apart from alternate land use based on potential and limitations of natural resources, various drought-proofing measures such as vegetative barriers, contour bunding, stone check-dams, irrigation water management, horticulture, groundwater development with conservation measures, and fodder and silvipasture in marginal lands have been undertaken. The suggested optimal land use practices are intensive agriculture, intercropping system, improved land configuration, agro-horticulture, horticulture with groundwater development, and silvipasture.

Implementation of action plan

Various soil and water and conservation measures, e.g., broad-bed and furrows, contour planting,

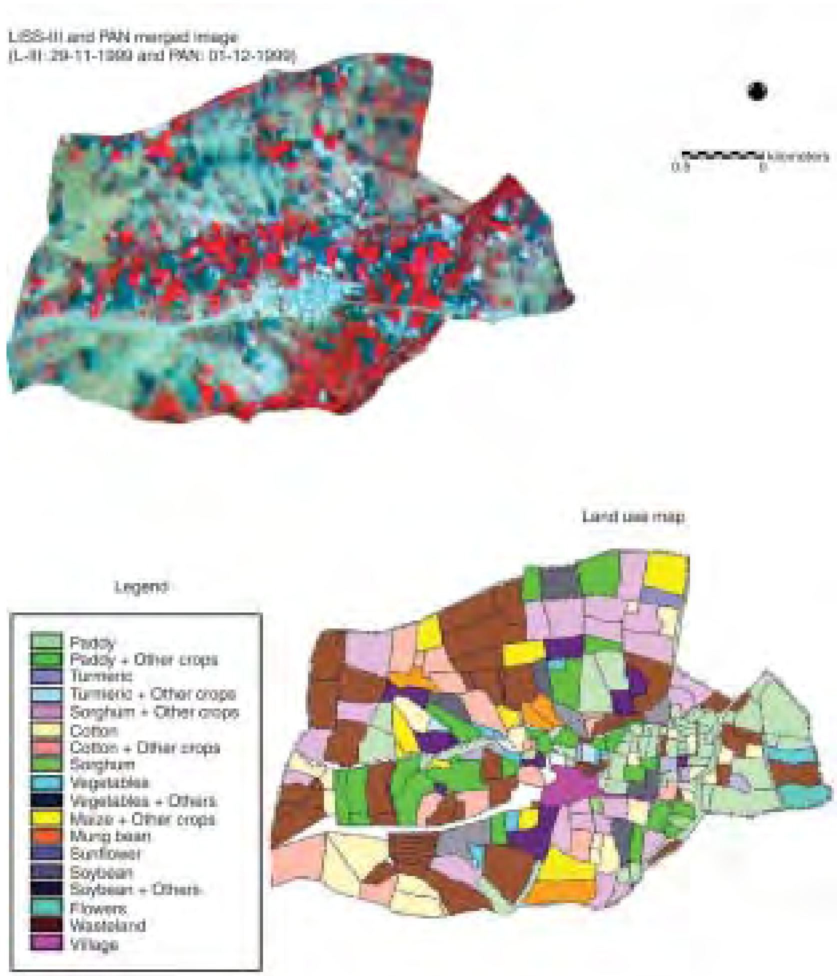

Figure 2. LISS-III and PAN merged image and land use map of Adarsha watershed, Kothapally, India.

waterways and drainage channels, field bunding, wasteland development, storage of excess water through construction of check-dams, dug out ponds, gabion structures, gully plugging, and increased cropping intensity have been undertaken in the watershed. In addition, integrated nutrient and pest management trials have also been conducted.

Impact assessment

Soon after implementation of the suggested action plan, the area undergoes transformation, which is monitored regularly. Such an exercise not only helps in studying the impact of the program, but also enables resorting to mid-course corrections, if required. Parameters included under monitoring activities are land use/land cover, extent of irrigated area, vegetation density and condition, fluctuation of groundwater level, well density and yield, cropping pattern and crop yield, occurrence of hazards, and socioeconomic conditions. Land use/land cover parameters include: changes in the number and aerial extent of surface water bodies, spatial extent of forest and other plantations, wastelands, and cropped area.

As mentioned earlier, NDVI has been used to monitor the impact of the implementation of action plan. A close look at the NDVI images of 1996 and 2000 reveals an increase in the vegetation cover which is reflected in improvement in the vegetation cover (Fig. 3). The changes in the vegetation cover can be seen in the satellite image as variations in the red-colored patches, and in the NDVI images as changes in yellow and pink colors. The spatial extent of moderately dense vegetation cover which was 129 ha in 1996 has risen to 152 ha in 2000. Though the satellite data used in the study depicts the terrain conditions during 1996, implementation activities started only in 1998. It is, therefore, obvious that it will take considerable time for detectable changes in the terrain and vegetation conditions.

Conclusions

The study vividly demonstrates the potential of spaceborne multispectral data in deriving information on natural resources. The GIS provides an ideal environment for integration of data on natural resources with the ancillary information and facilitates generation of action plan for development of land and water resources. After implementation of action plan, multi-temporal satellite data help in monitoring its success and progress. The change in vegetation cover in the Adarsha watershed as a result of adopting soil conservation measures during 1996 to 2000, is an indicator of the success of implementation of such action plans. High spatial resolution panchromatic and multispectral data from IKONOS-II and the future earth observation missions such as Resourcesat-1, Cartosat-1 and -2, Quick Bird, Almaz-1B, etc. may further enhance our capability of generating farm-level action plan for land and water resources development, and to study the success and progress of the implementation of such action plans.

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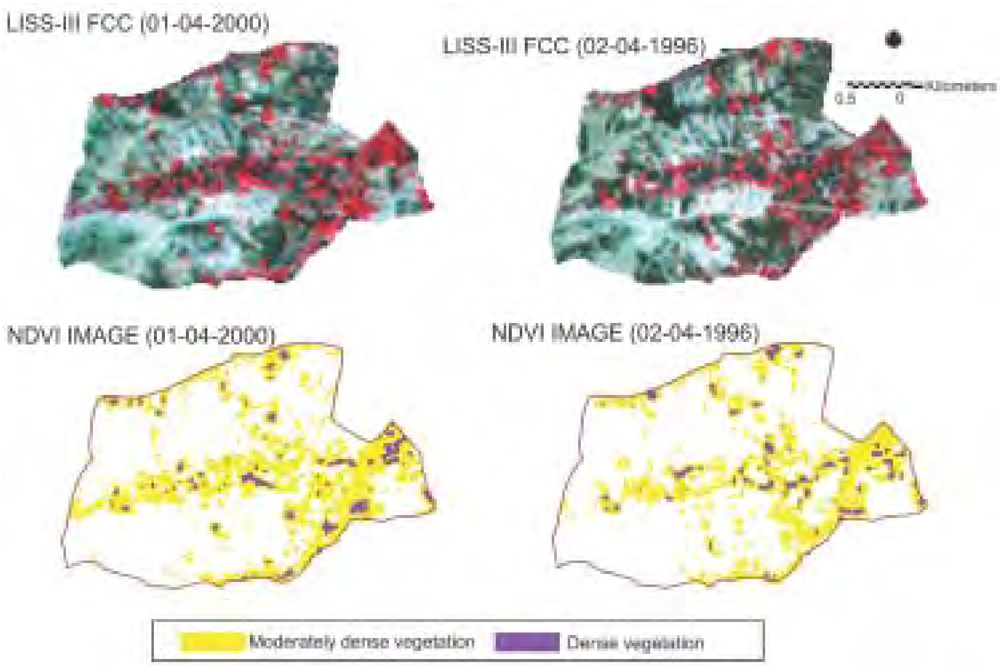

Figure 3. Satellite and NDVI images of Adarsha watershed, Kothapply, India.

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