Forest fire monitoring in Sirohi district, Rajasthan using remote sensing data

Forest is one of the most important renewable natural resources and plays a significant role in the human life and environment. In recent years, prolonged dry weather together with rapidly expanding exploitation of tropical forests and the demand for conversion of forest to other land uses have resulted in significant increase in forest fire size, frequency and related environmental impacts. Recurrent fires decrease the green cover by preventing regeneration and lead to the slow death of the forest[1]. The frequency of fires in Indian forests today is far greater than at any time in the past. Human influence has now become so pervasive that most fires are 'unnatural' like in arid and semi-arid regions of India. There is a need to focus on studies related to monitoring and management of forest fires of Indian forests.

In this regard, use of satellite remote sensing in view of its synoptic view and temporal frequency is realized as one of the potential tools in identification of burnt areas and potential fire zones. Few studies have been conducted in India to know burnt forest area assessment using high-resolution data from IRS satellites. Currently, several satellite-based sensors like LISS-III, AWiFS, MODIS, OCM, WIFS, AVHRR and MODIS provide synergistic data sets that have potential in forest detection and monitoring[2].

Reports from the Ministry of Environment and Forests in 1995 recorded that forest fires affect 37 million ha of forests annually, and about 55% of the country's forest areas are being subjected to forest fires each year[3]. The study in the Mudumalai Wildlife Sanctuary estimated an average fire-return interval of <7 years, which represents a three-fold increase in the frequency of fires in these forests over the last century alone[4]. Fire-return intervals are even shorter in Mendha, in Central India, where forests are burned annually to facilitate collection of two locally important non-timber forest products, *Madhuca indica* (Mahua) flowers and *Diospyros melanoxylon* (Tendu) leaves[5]. Forest fire risk zones were delineated by assigning subjective weights to the classes of all the layers according to their sensitivity to fire or their fire-inducing capability in Gorna Sub-watershed, Madhya Pradesh[6]. Results from the DMSP-OLS fire products (derived from February to May 2005) showed forest fires over Indian region[7]. The observations in the past 20 years show that the intensity and spread of forest fires in Asia were largely related to rise in temperature and decline in precipitation in combination with increasing intensity of land use changes[8]. The present day knowledge about the forest fire condition in India has been reviewed in ref. 9.

The main objectives of the present study are preparation of baseline information on vegetation types, forest burnt area mapping using multi-temporal satellite data and integrated analysis for identification of fire-prone areas in Sirohi district. The district is situated at the south-west part of Rajasthan between parallel of 24°20′N and 25°17′N lat. and 72°16′E and 73°10′E long. It has an area of 5136 sq. km. It is bounded on the west by Jalore district, on the north by Pali district, on the east by Udaipur district, and on the south by Banas Kantha district of Gujarat. The district had a population of 850,756 (2001 census), with a population density of 166 persons per sq. km. Sirohi district is much broken up by hills and rocky range. The period from mid-June to mid-September is the south–west monsoon season; mid-September to the end of November constitutes the post-monsoon season. The temperature in the winter varies from 23°C (max.) to 8°C (min). May and June are considered to be the hottest months. During these months the highest temperature is around 47°C. Humidity is generally high in the brief south-west monsoon season. During the rest of the year, the air is dry[10].

The Sirohi district falls in path/row 95/55 of IRS-P6 AWiFS reference map. IRS-P6 AWiFS data of October, 2005; January 2005, May 2005, May 2006 and May 2008 have been used in the study for the preparation of vegetation type map and forest burnt area mapping. Topographical maps of the Survey of India (SOI) in 1960 on 1 : 50,000 scale numbered 45D were used as ancillary data. The ortho-rectified satellite data of Landsat TM were downloaded from the Global Land Cover Facility (GLCF) website. The IRS AWiFS datasets was geometrically rectified to Landsat TM data. Each image was enhanced using linear contrast stretching and histogram equalization to improve the image quality and to identify ground control points (GCP). The datasets were brought into Universal Transverse Mercator (UTM) projection and WGS 84 datum. A nearest neighbour algorithm was used to perform the resampling procedure.

IRS P6 AWiFS has spatial resolution of 56 m. IRS P6 AWiFS sensor has four spectral channels, each one of which can be used for a different observational task during and after a fire event. Short-Wave IR, Near IR, Red spectral bands were assigned to respective Red, Green and Blue gun to highlight source point of active fire. More specifically, fire plumes and burnt areas can be better distinguished in the Short-Wave IR spectral channel (i.e. 1.55–1.70 μm), for detecting high temperature targets. Because 1.65 μm in the electromagnetic spectrum is very sensitive to flame and flaming energy and not very sensitive to smouldering and its energy, FCC with the SWIR, NIR, R combination highlights the active fire pixels. SWIR channel is considered more suitable for identifying hotspots, because the maximum Planck black body radiance shifts to shorter wavelengths as temperature increases. The usefulness of the SWIR channel has long been recognized and demonstrated for monitoring forest fires[11]. Repetitivity of sensor is only five days.

Digital image classification uses the spectral information represented by the digital numbers in one or more spectral bands and attempts to classify each individual pixel based on this spectral information. This type of classification is termed spectral pattern recognition. In the present study, unsupervised classification and visual image interpretation techniques were used to achieve the objectives. Unsupervised classification in essence reverses the supervised classification process. Spectral classes are grouped first, based solely on the numerical information in the data and are then matched to information classes based on field data. The ISODATA iterative clustering algorithm was utilized to identify clusters of forest burnt scar pixels.

Spatial maps are shown in Figures 1–3. The land use/cover was mapped into eight classes using visual image interpretation technique. Multi-season IRS P6 data (October 2005, January 2005, May 2005, May 2006, May 2008) was used in delineation of land use/cover classes. Area of each class has been calculated. In Sirohi district, vegetation cover occupies 25.4% of total geographical area. The area under forest cover is proportionately 21% of total geographical area. From land cover map, it may be seen that the forest cover accounted for about 1080 sq. km, whereas the scrublands cover 225.5 sq. km area (Table 1). The forest types found in the district are broad leaved forest, deciduous forest and thorn forest. The most abundant forest type was deciduous forest (Figure 2) which comprises 73.2% of the total forest area, followed by broad-leaved forest of 14.2%. Scrub/shrub land occupies significant area, which is about 4.4%.

Subtropical broad-leaved forest: Mt. Abu (1727 m) is the highest peak between western Himalayas and Nilgiris. The vegetation here falls into fairly distinct elevational zones. The vegetation above 1300 m gradually changes into subtropical broad-leaved hill forest. The predominant species are *Syzygium cumini*, *Mangifera indica*, *Crateva magna*, *Carvia callosa*, *Girardina zeylanica*, *Kydia calycina*, *Mallotus philippensis* and *Trema orientalis*. Total area covered by this forest is 153.8 sq. km (14.2% of total forest area). Image shows these areas as bright tone with rough texture in both seasons. Association feature includes interior terrain, riverine areas of moist tracts, characterized by interspersion of shadows and barren patches. Trans-seasonal feature would be persistence of foliage.

Deciduous forest: These forests depicted prominence of *Anogeissus pendula*, *Cassia fistula*, *Boswellia serrata*, *Diospyros melanoxylon*, *Lannea coromandelica* and *Buchanania lanzan*. The area coverage is about 791.2 sq. km (73.2% of total forest area). In green season satellite image deciduous forest looks dark red in tone with rough texture, but in dry season the areas take up greenish shade with no evidence of foliage. Background reflectance of dry/often

Table 1. Areal extent of land use/land cover of Sirohi district

Class	Area (sq. km)	Area (%)
Broad leaved forest	153.8	3.0
Deciduous forest	791.2	15.4
Thorn forest	135.5	2.6
Sub total	1080.5	21.0
Scrub	225.5	4.4
Agriculture	2265.2	44.1
Barren land/long fallow	1513.0	29.5
Water	4.3	0.1
Built up area	47.5	0.9
Grand total	5136.0	100.0

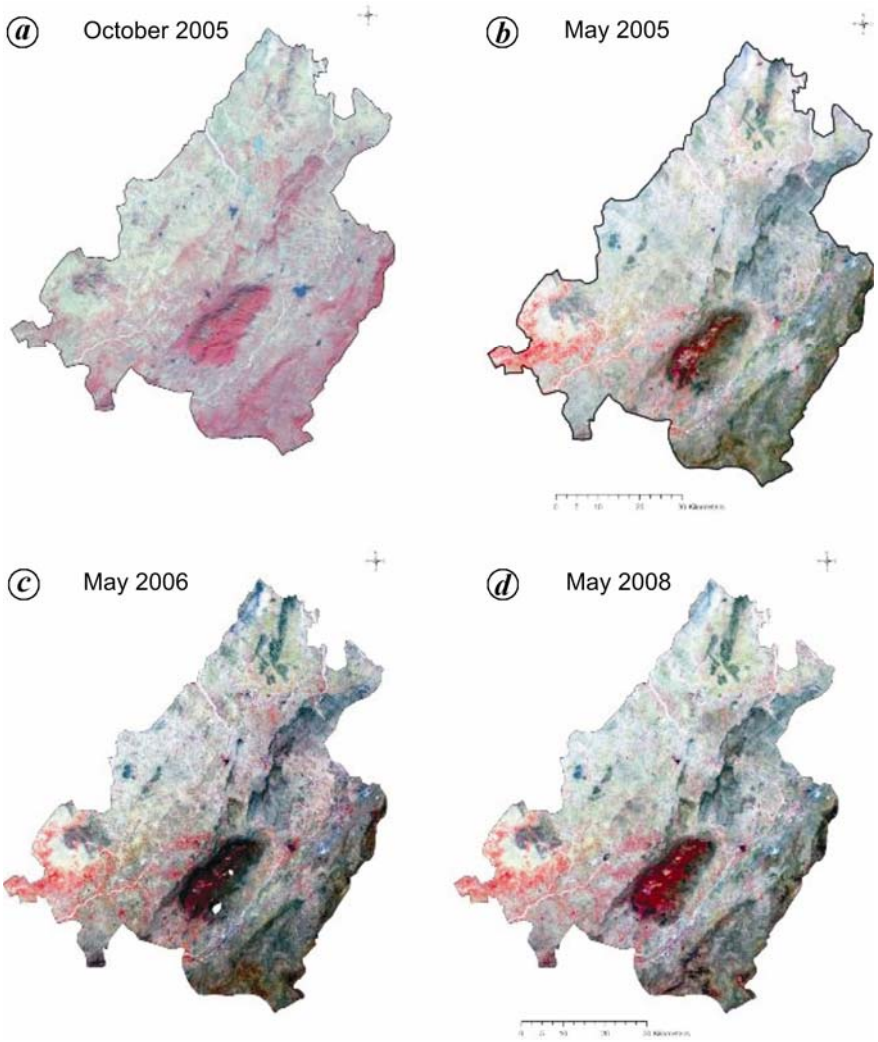

Figure 1. Spatial maps of Sirohi district. ***a***, False colour composite (FCC) images of IRS P6 AWiFS data. FCC of IRS P6 AWiFS data, (***b***) 2005, (***c***) 2006 and (***d***) 2008.

Table 2. Forest burnt area of Sirohi district

Forest type	Burnt area (ha)		
	2005	2006	2008
Broad leaved forest	1033.3	1590.8	1317.4
Deciduous forest	3899.6	3854.02	8913.8
Thorn forest	0.0	17.9	159.5
Scrub	68.1	332.1	1685.3
Total	5001.0	5794.8	12076.0

burnt undergrowth marks this system. Contiguity of these forests over large areas is common.

Thorn forest: It prevails mostly in north-western part of Sirohi district. This is characteristic of the dry areas with low rainfall and high temperatures. These forests consist of mostly small trees with short trunks and spreading crowns and the dense shrubby undergrowth. Common species in this type are *Acacia senegal*, *Albizia amara*, *Catunaregum spinosa*, *Canthium parviflorum*, *Mimosa hamata*, *Prosopis cineraria*, *Prosopis juliflora*, *Wrightia tinctoria*, *Flacourtia indica*, etc. On image it gives a rough texture with light to dark tone in green season image.

Scrub: Scrub is predominantly occupied by shrubs or poor tree growth. These systems are generally seen in the fringes of forests and hill tops, and nearby settlements. It is the third most dominant vegetation class covering an area of 225.5 sq. km. It is spread throughout the district.

Other nonvegetation classes: Most of the land use in Sirohi district is under agriculture (44.1% of area), as this is the main occupation of people. Wheat, rice, pulses and sarson are the principal crops. Barren lands (including long fallow areas) contribute significantly to the land cover with 29.5% of area, depicting the arid and semi-arid status. Urban/rural settlements represent an area of 47.5 sq. km.

The vegetation-type wise burnt-area data for the study area are given in Table 2. The data are based on the extent of burnt scars as existing on the date of satellite data used. The fire monitoring using burnt area provides the areas already burnt and helps to orient the effort towards unburnt areas.

The total area affected under forest fire has been estimated as 5001 ha in 2005, 5794.8 ha in 2006 and 12,076 ha in 2008 and proportionately covers 3.8%, 4.4% and 9.2% of total vegetation area respectively. The total burnt area of deciduous forest, broad-leaved forest and scrub are 3899.6, 1033.3 and 68.1 ha respectively during 2005. The dry deciduous forests contributed to the majority of the total burnt area.

Fire extent in the tropical deciduous vegetation was significantly higher than the subtropical broad-leaved type. Fuel loads from both grasses and leaf litter were also significantly higher in tropical

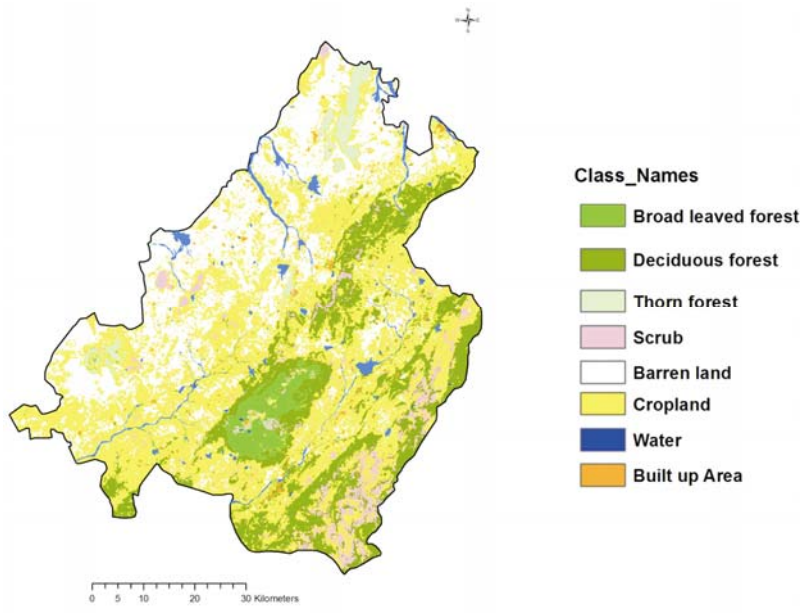

Figure 2. Classified land use/land cover map of Sirohi district.

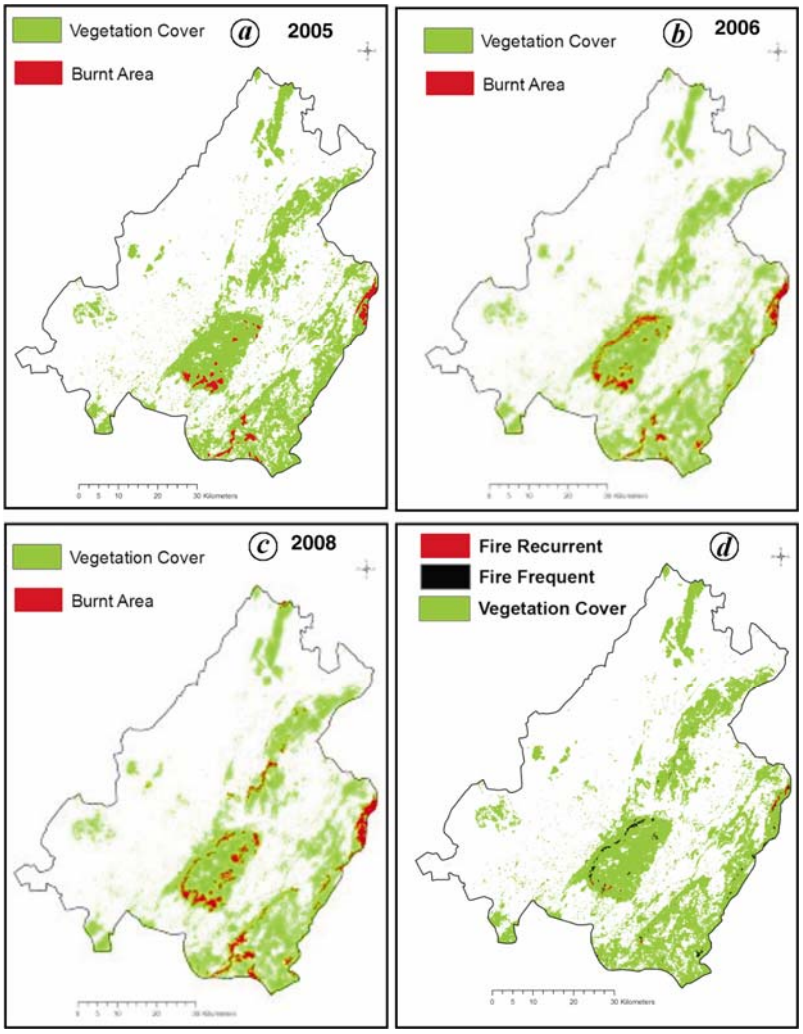

Figure 3. Spatial maps of Sirohi district. Forest burnt areas overlaid on vegetation cover in (***a***) 2005, (***b***) 2006 and (***c***) 2008; (***d***) Forest fire risk area map.

Table 3. Patch size distribution of forest burnt areas (2008)

Patch size (ha)	No. of burnt area patches	Burnt area (ha)	Area (%)
<25	173	1323.1	11.0
26–50	15	541.3	4.5
51–100	15	960.2	8.0
101–150	7	891.6	7.4
151–200	4	668.0	5.5
201–250	4	905.7	7.5
251–300	3	857.1	7.1
301–350	4	1286.1	10.6
351–400	1	384.8	3.2
>400	6	4258.7	35.3
Grand total	232	12076.4	100

deciduous vegetation. No fires were observed in thorn forests during 2005, but recorded in 2006 and 2008. The classified burnt area maps were overlaid on land use/cover map and 25 points were assigned randomly in each land cover class. The error matrix was generated to provide accuracy of burnt area in individual land cover classes. GPS-based forest fire locations were used in assessing the accuracy.

Accuracy assessment showed burnt area estimates with an accuracy ranging from 93% (broad-leaved forest) to 95% (deciduous forest) depending on the vegetation-cover type. The recurrent fire burnt area was estimated as 590 ha, which has witnessed fire in all the three years. Analysis shows that frequent fire burnt area of 2870 ha, which faced fire in two of the three years studied.

Sirohi district endured about 232 number of burnt area patches during 2008. Patch size analysis of forest burnt areas revealed that maximum number (173) of burnt area patches is under < 25 ha. Interestingly, the burnt area class of >400 ha shows 35.3% (4258.7 ha) of total burnt area followed by < 25 ha class with representation of 11% (1323.1 ha) of the area (Table 3).

The present study thus reports forest burnt area on particular vegetation types using IRS P6 AWiFS of 2005, 2006 and 2008. Burnt area statistics generated from satellite data provides useful information to forest managers in effective planning for ground control operation during the summer months.

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ACKNOWLEDGEMENTS. We are grateful to Dr V. Jayaraman, Director, NRSC and Dr P. S. Roy, Deputy Director, NRSC, Hyderabad for kind support and facilities. The present work is carried out under 'biodiversity characterisation at landscape level using remote sensing and GIS' sponsored by Department of Space and Department of Biotechnology, Govt of India.

Received 1 February 2009; revised accepted 22 September 2009

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