# Assessment of increasing threat of forest fires in Rajasthan, India using multi-temporal remote sensing data (2005–2010)

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**Rajasthan is the largest state of India experiencing recurrent forest fires. The present study determines forest burnt areas through remote sensing-based time series analysis. IRS P6 AWiFS satellite data covering March, April and May of six years (2005–2010) were used to cover all forest-fire events. The total forest burnt area was assessed as 53,023.5 ha in 2005; 44,681.5 ha in 2006; 57,689 ha in 2007; 89,655.2 ha in 2008; 199,837 ha in 2009 and 144,816 ha in 2010. Forest fires were observed only in the southern Aravallis. Of the total forest cover in southern Aravallis, burnt area proportionately represents 6.8% in 2005, 5.6% in 2006, 7.3% in 2007, 11.1% in 2008, 23.0% in 2009 and 17.6% in 2010. Forest fires were severe during 2009, which was the warmest year since 1901. Small sized (< 25 ha) forest burnt area patches contributed to 44% of the total count during 2010. Among the vegetation types, fire prevalence in the dry deciduous forest was higher and it always contributed to > 90% of the burnt area. GIS analysis demonstrated highest burnt area in occasional category (70%) followed by frequent fire area (24%). The abundance of fires in edge forests in relation to interior forests clearly indicates significant anthropogenic influence on the forest edges. The fires in Rajasthan are mainly attributed to ethnic culture, collection of non-timber forest produce and grazing pressure. The study provides critical spatial information of increased forest fire threat in Rajasthan. Long-term planning for forest fire management is necessary for effective conservation of biodiversity and bioresources.**

**Keywords:** Burnt area, forest fire, remote sensing, threat.

TROPICAL forests which are the most species-rich habitats on earth, are experiencing the highest rate of species extinction[1]. Qualitative ecological changes involve degradation of the structure, function or composition of the forest ecosystem[2]. Among the global ecological issues, forest fires emerge as a major problem in the tropics. Globally, more than 350 m ha of forests was burned in 2000, equal to 6% of the world's geographical area[3]. Observations during the past 20 years indicate that increasing intensity and spread of forest fires were largely related to rise in temperature and land-use changes[4]. India has a geographical area of 328 m ha, of which 69 m ha area is under forest cover[5]. The Indian forests are broadly classified into 16 types[6]. Of these, the tropical moist and dry deciduous forests account for 64% of the total forest area[7]. In India, large areas of tropical deciduous forests are under intense pressure due to recurrent fires. Forest burnt area size and spread has a critical impact on the climate as well biodiversity.

The global forest burnt area assessment made by the European Space Agency in 2000 using coarse resolution (1.1 sq. km) SPOT 4-VEGETATION (SPOT-VGT) reported forest burnt area as 9% (47,134 sq. km) of the total forest area of India[8]. The global assessments do not reflect the realistic small-scale burning. Detailed information concerning the location and extent of the burned area is important in assessing economic losses and ecological effects, monitoring vegetation change and modelling atmospheric and climatic impacts of biomass burning[9]. There are no comprehensive data on different dimensions of fire, such as area burned, loss of environmental and economic values, and regeneration status in India[10].

With the current trend of increasing rate of forest fires, there is an urgent need to generate a spatial database for planning, decision-making and further objective-oriented requirements. Remote sensing technology can contribute to a variety of natural resources applications. Technological advancement of satellite remote sensing can contribute to a better cost-effective and time-effective solution for specifying the location of the fire, intensity of fire events and the extent of the burned area, and is thus useful for biodiversity conservation[11]. Further, remote sensing data when combined with GIS and statistical models, allow us to predict 'where and when' forest fires will most likely occur[12]. Currently, several satellite-based sensors like AWiFS, LISS-III, MODIS, ETM$^+$, SPOT, AATSR, AVHRR and MODIS provide synergistic datasets that have potential in forest detection and damage assessment[13,14]. Fire occurrence data using the AATSR satellite show maximum fires during March and April in tropical parts of India[15]. There has been a three-fold increase in the frequency of fires in India over the last century[16].

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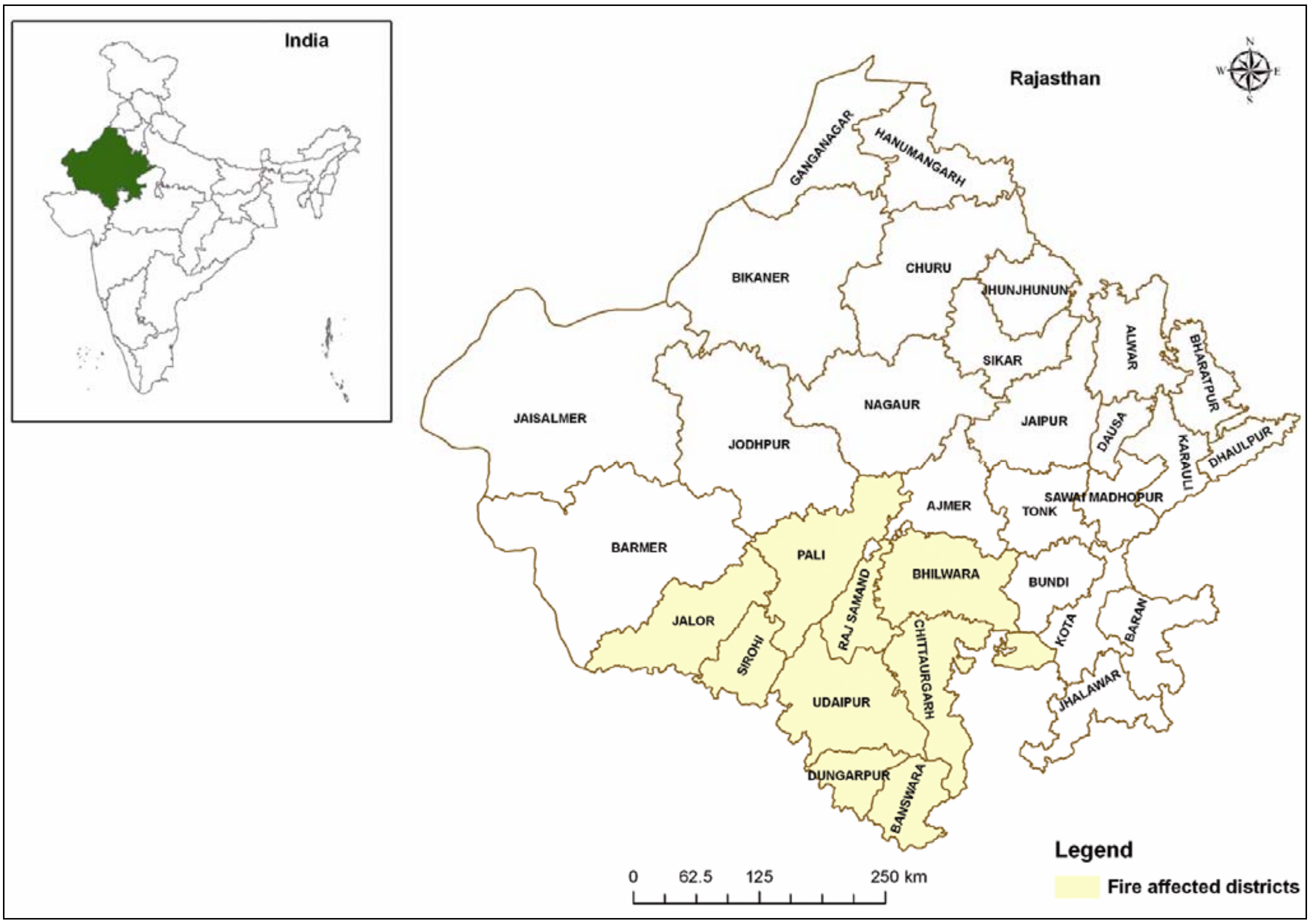


**Figure 1.** Map of the study area showing Rajasthan and the fire-affected districts (2005–2010).

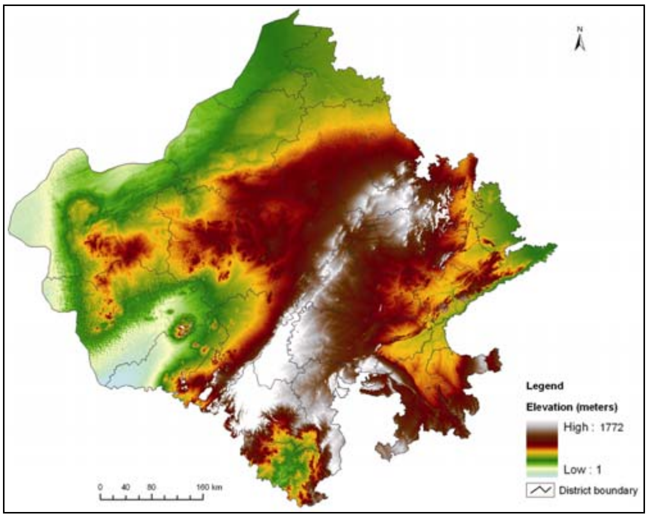


**Figure 2.** Topography map of Rajasthan.

In view of the scanty research work on forest fires in India, the present study was focused on the assessment covering a number of fires, burnt area size, annual area burned, fire recurrence and distribution through multi-temporal IRS P6 AWiFS data for the past six years (2005–2010) in Rajasthan.

## Study area

Rajasthan is the largest state in India, occupying an area of about 342,239 sq. km and covers 10.41% of the geographical area of the country. It lies between 23°30′N and 30°12′N lat. and 69°30′E and 78°17′E long. Rajasthan is bordered by Pakistan in the west and northwest, the Indian states of Punjab, Uttar Pradesh and Haryana lie to its north and northeast, Madhya Pradesh to the southeast and Gujarat to the southwest (Figure 1). As shown in Figure 1, Rajasthan is divided into 33 districts.

The state has three major physiographic regions, viz. the western desert (Thar Desert), the Aravalli hills and the eastern plateau. The elevation of Rajasthan ranges between 50 and 1772 m (Figure 2)[17]. The most striking geographical feature is the Aravallis – one of the world's oldest mountain ranges. The Aravalli range intersects the state diagonally end to end northeast to southwest into three-fifth northwestern desertic zone and two-fifth eastern semi-arid region. The elevation of the Aravalli range

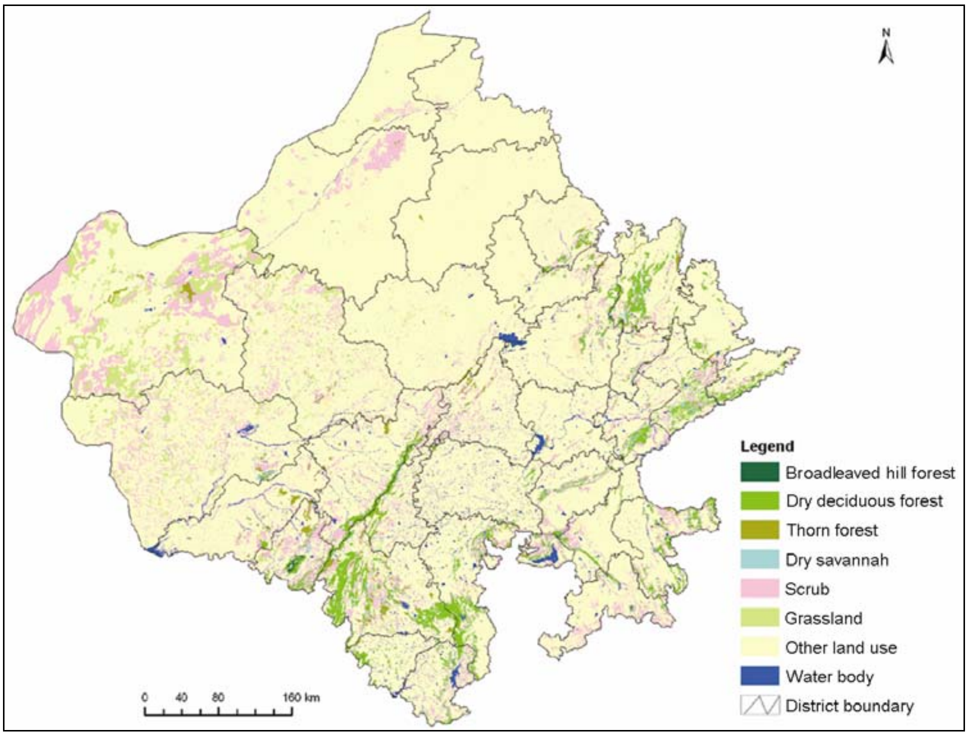


**Figure 3.** Vegetation type map of Rajasthan.

gradually decreases in the northeast direction, as it is 1772 m at Mt Abu, 1100 m at Bijapur, 913 m at Harshanath and 792 m at Khetri; the elevation further decreases to 335 m at Delhi beyond the boundaries of the state in northeast direction. The total forest area of Rajasthan is 16,036 sq. km, which occupies 4.69% of the total geographical area[5]. Of the three main forest types, dry deciduous forest covers the highest area of 12,850.2 sq. km (79.6%), followed by thorn forest 2536.5 sq. km (15.7%), dry savannah 593.5 sq. km (3.7%) and broad-leaved hill forest 153.8 sq. km (1%) (Figure 3)[18].

The population of the Rajasthan is 68.6 million (ref. 19). The state experiences varied climatic conditions ranging from extreme aridity in the northwestern parts (Jaisalmer) to sub-humid conditions in the southern parts (Jhalawar, Banswara and Mt Abu). However, most of the state (94%) falls under arid and semi-arid conditions with low and erratic rainfall patterns. Pre-monsoon season, the hottest period, extends from April to June with temperatures ranging from 32°C to 45°C. The winter season is from January to March and temperature may drop to 0°C in some cities, such as Churu.

## Materials and methods

### *Satellite data*

IRS-P6 AWiFS data with 56 m spatial resolution were used in the study. All the data were acquired from the NRSC Data Centre, ensuring least cloud coverage. IRS P6 AWiFS satellite sensor has four spectral channels, each of which can be used for a different observational task during and after a fire event. Short-wave IR, near IR and red spectral bands were assigned to the red, green and blue gun respectively to highlight the source point of active fire[20].

All the IRS P6 AWiFS images are geometrically co-registered, with sub-pixel accuracy in relation to the orthorectified Landsat TM data as the master image using ERDAS IMAGINE 9.2.

Multi-temporal IRS P6 AWIFS satellite data (path 93–95 and row 54–56) covering March, April and May of 2005–10 were used to cover all forest fire events (Figure 4). State and district boundaries were used from the archive database of the National Remote Sensing Centre, Hyderabad.

The methodology adopted to map forest burnt areas was a digital supervised method. Field data were collected from 600 ground control points which witnessed fire during 2010 using GPS. Appropriate signatures/training sets generated from 320 ground control points were collected. The remaining 280 points were used for accuracy assessment. For the 2005–2009 period, training sites of forest burnt areas were generated based on standard spectral signature set evaluation and transformed divergence index. The 2010 forest burnt area map was also used as reference. Satellite image datasets were classified into burnt and unburnt areas based on maximum likelihood classifier technique. In the first step all the non-

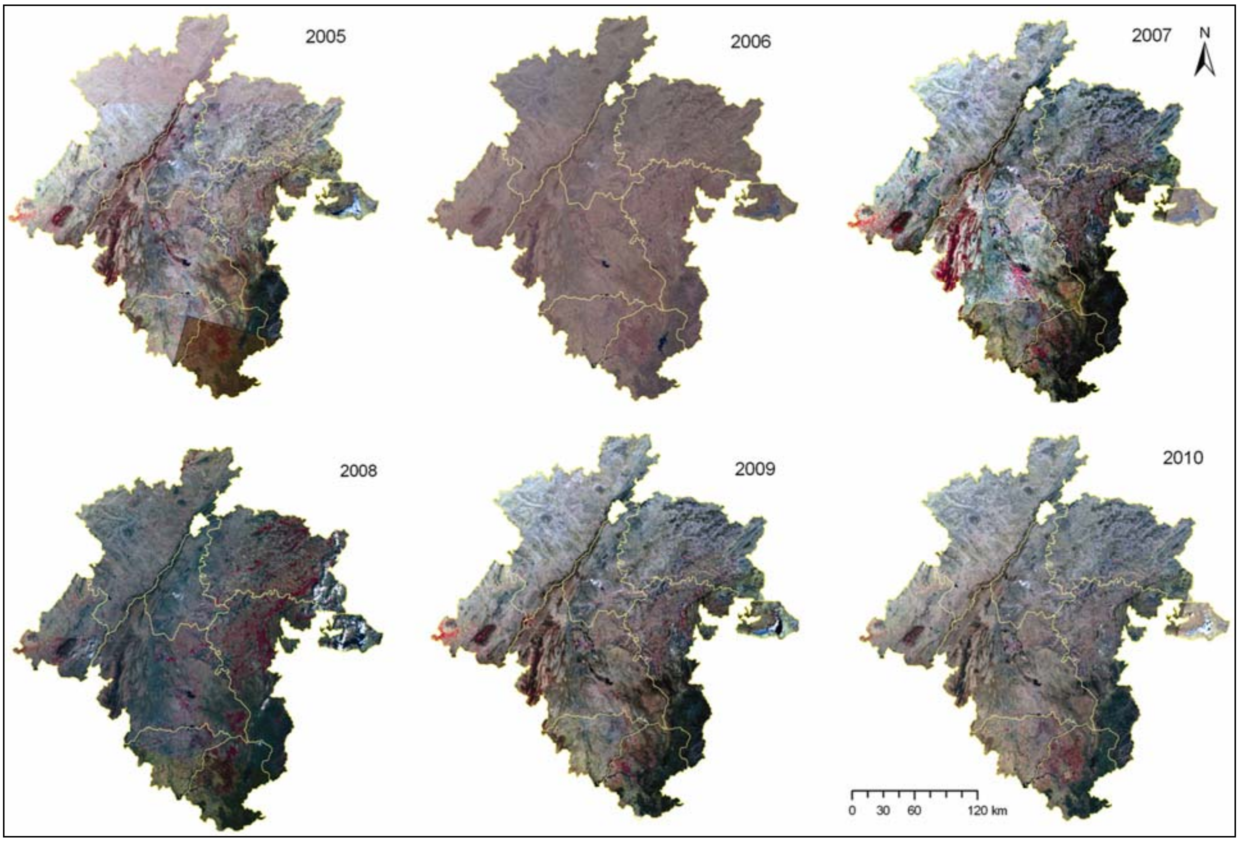


**Figure 4.** IRS P6 AWiFS images of fire-affected districts in Rajasthan: April 2005–2010.

vegetation classes, viz. agriculture, settlement, barren and water body were masked out using spatial data of vegetation type and land-use data available at the NRSC[18]. The January image data which do not show any burnt area were used as reference. Post-classification smoothening was carried out with a $3 \times 3$ matrix. Edges were sharpened with a $3 \times 3$ matrix to build the boundary of the burnt area. Burnt pixels were overlaid on different vegetation types to assess the area under forest fire and also were converted to vector data for GIS analysis.

Vegetation type map of Rajasthan generated as part of the DOS–DBT project was used to understand the spatial distribution of forest burnt areas and for integrated GIS analysis[18]. Finally, the multi-year satellite data were analysed to prepare forest fire maps for the past six years in Rajasthan. Area burned in the different years was used to examine the differences in fire occurrence across the different vegetation types. The area statistics reported for each year is based on the extent of burnt scars as existing in March, April and May of the satellite data used. In view of this, areas burnt in March were also included under the burnt scars of data for April and so on.

## Results

It was determined through remote sensing based-time series analysis that there have been significant forest fires throughout the study period from 2005 to 2010. The total burnt area was assessed as 53,023.5 ha in 2005, 44,681.5 ha in 2006, 57,689 ha in 2007, 89,655.2 ha in 2008, 199,837 ha in 2009 and 144,816 ha in 2010 (Table 1). Of the total forest cover of, 1,613,362 ha in Rajasthan, 2.7% (minimum in 2006) to 10.9% (maximum in 2009) was affected by fire. The fires were distributed only in the forests, scrublands and grasslands of the southern Aravallis. Of the total forest cover in southern Aravallis, burnt area represents 6.8% in 2005, 5.6% in 2006, 7.3% in 2007, 11.1% in 2008, 23.0% in 2009 and 17.6% in 2010. No fires were observed in the northern Aravallis and east of Aravallis during 2005–2010.

### *Vegetation type wise analysis*

The forest burnt area results also follow a similar area coverage pattern, but the area burnt within the forest type differs. Of the total forest cover within broadleaved forest, 13.8% of the area was affected by fire in 2010. While dry deciduous forest cover of 9.6% was under fire-affected area in 2010. Scrub and grasslands are other vegetation types considered in the study. Of the six vegetation types, dry deciduous forest shows significantly high burnt area, followed by thorn forest, broadleaved forest, dry savannah, scrub and grasslands. The total burnt area of dry deciduous forest, thorn forest, broad-

**Table 1.** Areal extent of forest burnt scar area (ha) during 2005–2010

| Class | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|---|---|
| Forest | | | | | | |
| Broadleaved | 455.7 | 1259.4 | 46.5 | 896.3 | 3762.1 | 2,125.6 |
| Dry deciduous | 51,352.2 | 40,915.6 | 54,264.4 | 81,102.9 | 161,135.3 | 123,316.5 |
| Thorn | 435.2 | 940.2 | 1,514.9 | 2,488.4 | 9,399.6 | 7,857.4 |
| Dry savannah | 124.6 | 87.7 | 179.6 | 651.2 | 1,484.6 | 1,129.8 |
| Sub total | 52,367.7 | 43,202.9 | 56,005.4 | 85,138.7 | 175,781.7 | 134,429.2 |
| Scrub | 622.3 | 1,258.8 | 1,556.2 | 3,900.0 | 21,496.5 | 8,982.0 |
| Grassland | 33.5 | 219.7 | 127.5 | 616.5 | 2,559.1 | 1,404.7 |
| Sub total | 655.8 | 1478.6 | 1,683.7 | 4516.5 | 24,055.5 | 10,386.8 |
| Grand total | 53,023.5 | 44,681.5 | 57,689.1 | 89,655.2 | 199,837.3 | 144,816.0 |

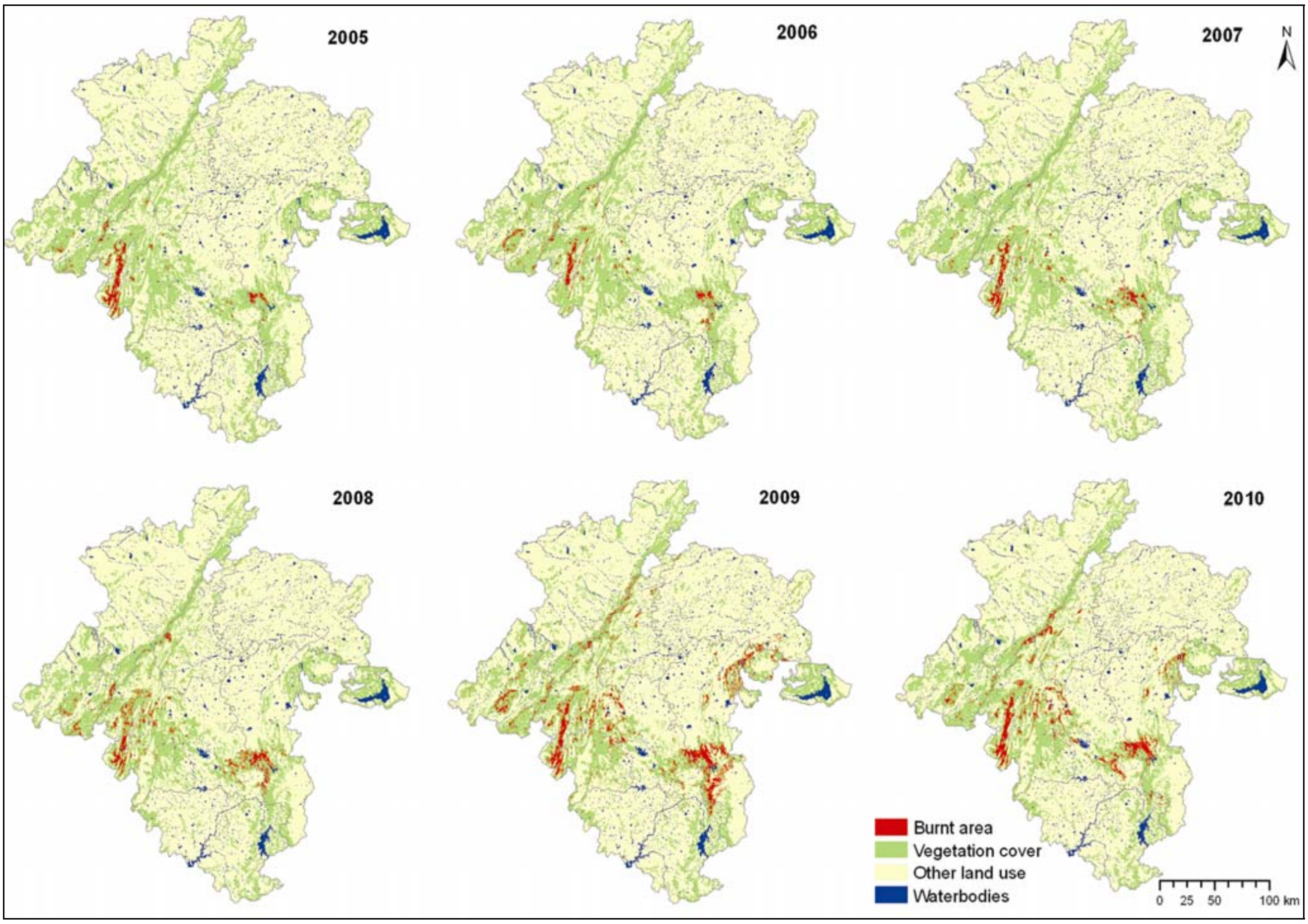


**Figure 5.** Spatial forest burnt area map 2005–2010.

leaved forest, dry savannah, scrub and grasslands was 123,316.5 ha, 7857.4 ha, 2125.6 ha, 1129.8 ha, 8982 ha and 1404.7 ha respectively during 2010.

## *Spatial coverage under districts*

Of the 33 districts in Rajasthan, forest fires were observed only in Udaipur, Sirohi, Chittaurgarh, Rajsamand, Banswara, Dungarpur, Bhilwara and Pali districts (Figure 4).

These eight districts represent forest cover of about 7650 sq. km which occupies 47.7% of the total forest area in Rajasthan[5]. Udaipur has the highest forest cover of 3115 sq. km, followed by Chittaurgarh (1689 sq. km), Sirohi (917 sq. km), Pali (658 sq. km), Rajsamand (422 sq. km), Banswara (375 sq. km), Dungarpur (252 sq. km) and Bhilwara (222 sq. km).

Forest fires were consistently recorded in Udaipur, Chittaurgarh and Sirohi districts. Fires were frequent in

**Table 2.** Burnt area (ha) with reference to district forest cover

| District | 2005 Burnt area | 2005 Percentage of area | 2006 Burnt area | 2006 Percentage of area | 2007 Burnt area | 2007 Percentage of area | 2008 Burnt area | 2008 Percentage of area | 2009 Burnt area | 2009 Percentage of area | 2010 Burnt area | 2010 Percentage of area |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Udaipur | 40,990.0 | 13.2 | 28,432.9 | 9.1 | 47,925.2 | 15.4 | 57,416.9 | 18.4 | 86,419.1 | 27.7 | 87,879.7 | 28.2 |
| Sirohi | 5001.0 | 5.5 | 5,794.8 | 6.3 | 2,773.7 | 3.0 | 12,076.0 | 13.2 | 16,136.0 | 17.6 | 8,115.2 | 8.8 |
| Rajsamand | 70.3 | 0.2 | 0.0 | 0 | 63.8 | 0 | 3,117.7 | 7.4 | 9,232.8 | 21.9 | 10,144.9 | 24.0 |
| Chittaurgarh | 6,306.3 | 3.7 | 8,975.2 | 5.3 | 5,242.5 | 3 | 11,758.0 | 7.0 | 53,407.3 | 31.6 | 24,991.3 | 14.8 |
| Banswara | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2,538.5 | 6.8 | 796.0 | 2.1 |
| Pali | 0 | 0 | 0 | 0 | 0 | 0 | 770 | 1.2 | 3,600.0 | 5.5 | 2,094.8 | 3.2 |
| Dungarpur | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 399.7 | 1.6 | 227.3 | 0.9 |
| Bhilwara | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4,048.2 | 18.2 | 180.0 | 0.8 |
| Total | 52,367.7 | 6.8 | 43,202.9 | 5.6 | 56,005.2 | 7.3 | 85,138.7 | 11.1 | 175,781.7 | 23.0 | 134,429.2 | 17.6 |

**Table 3.** Areal extent of fire progression and patch size distribution of forest burnt area: 2005–2007

| Patch size (ha) | 2005 No. of patches | 2005 Area (ha) | 2006 No. of patches | 2006 Area (ha) | 2007 No. of patches | 2007 Area (ha) |
|---|---|---|---|---|---|---|
| < 25 | 164 | 631.5 | 336 | 3,311.7 | 282 | 2,585.2 |
| 26–50 | 35 | 1,272.3 | 70 | 2,468.7 | 74 | 2,786.9 |
| 51–100 | 30 | 2,050.6 | 50 | 3,568.8 | 59 | 4,279.0 |
| 101–200 | 14 | 2,058.9 | 26 | 3,638.6 | 40 | 5,741.5 |
| 201–500 | 19 | 6,382.8 | 22 | 6,244.8 | 17 | 5,159.6 |
| > 500 | 13 | 40,627.3 | 13 | 25,448.8 | 14 | 39,630.1 |
| Total | 275 | 53,023.4 | 517 | 44,681.5 | 486 | 60,182.3 |

Rajsamand and sporadic in Banswara, Dungarpur, Bhilwara and Pali districts. Of the total forest burnt area at the state level, Udaipur district contributed to the highest burnt area, estimated as 49.2% in 2009 and 65.4% in 2010 (Figure 5). Chittaurgarh, Sirohi and Rajsamand districts occupied second, third and fourth place respectively. Bhilwara, Pali, Banswara and Dungarpur have less than 10% of total forest burnt area. The forest burnt area covered only 6.8% of the forest cover of the eight districts in 2005; it showed a slight drop in 2006 of 5.6% and is increasing every year (Table 2). The fire in 2009 was rigorous, occupying 23% of the forest cover in the southern Aravallis. The forest cover burnt in Udaipur was least (28,432.9 ha) in 2006 and very high (87,879.7 ha) in 2010. The forest cover burned in Chittaurgarh was least (5242.5 ha) in 2007 and very high (53,407.3 ha) in 2009.

## *Trends in burnt area patch size*

The spatial analysis suggests that 2009 was a very severe fire year and affected vegetation cover of about 199,985.8 ha. Maximum size of contiguous vegetation burnt areas was also very high in 2009 and was estimated as 50 in number (58.3% of the total burnt area). Rajasthan was affected with 1362 burnt area scar patches during 2010. Patch size analysis of forest burnt areas revealed that maximum number (942) of burnt area patches was under < 25 ha. Interestingly, the burnt area class of > 500 ha showed 99,405.7 ha of total burnt area followed by the < 25 ha class with 9501.5 ha of area (Tables 3 and 4). Patches of < 25 ha contribute 44% followed by 20.8% (25–50 ha), 15.3% (51–100 ha), 8.9% (101–200 ha), 5.6% (200–500 ha) and 5.3% (>500 ha). But if we consider area, greater proportion is seen in the > 500 ha patches contributing 68.6% followed by 8.6% in the 201–500 ha patches, 6.7% in the 101–200 ha patches, 6.6 in the < 25 ha patches, 5.7% in the 51–100 ha patches and 3.8% in the 26–50 ha patches.

The burnt area patches in 2005 were 275, which increased to 517 in 2006. The burnt area also increased from 53,023.4 ha in 2005 to 60,182.3 ha in 2007. The burnt area patches in 2008 were 559 and 1657 in 2009. However, the burnt area patches were less in 2010 – estimated to be 1362. The burnt area also increased from 89,655.2 ha in 2008 to 144,816 ha in 2010. Overall analysis indicates that majority of burnt area locations were under the < 25 ha area class. Burnt area patches of size > 500 ha were found to be less, but contributed to a very high area under forest fire.

## *Fire recurrence*

During the last six years (2005–2010) forest burnt area of 8566.3 ha was estimated as regular annual fire area and

**Table 4.** Areal extent of fire progression and patch size distribution of forest burnt area: 2008–2010

| | 2008 | | 2009 | | 2010 | |
|---|---|---|---|---|---|---|
| Patch size (ha) | No. of patches | Area (ha) | No. of patches | Area (ha) | No. of patches | Area (ha) |
| < 25 | 192 | 2,073.0 | 1,008 | 24,982.7 | 942 | 9,501.5 |
| 26–50 | 126 | 4,653.2 | 256 | 8,703.8 | 156 | 5,553.7 |
| 51–100 | 105 | 7,544.2 | 153 | 11,009.4 | 115 | 8,198.8 |
| 101–200 | 64 | 9,129.5 | 116 | 16,084.3 | 67 | 9,637.6 |
| 201–500 | 41 | 13,041.8 | 74 | 22,691.1 | 42 | 12,518.7 |
| > 500 | 31 | 53,213.5 | 50 | 116,514.5 | 40 | 99,405.7 |
| Total | 559 | 89,655.2 | 1,657 | 199,985.8 | 1,362 | 144,816.0 |

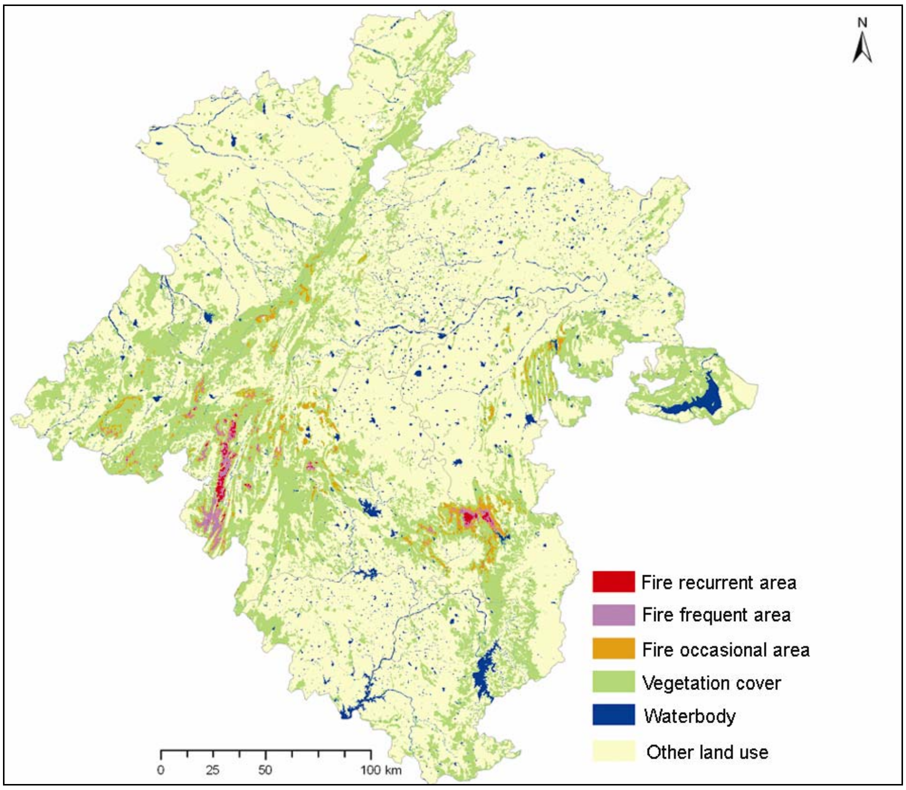


**Figure 6.** Forest fire recurrence map (2005–2010).

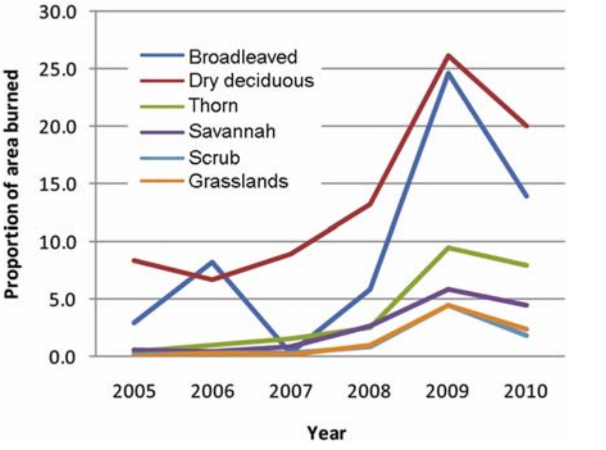


**Figure 7.** Temporal variability in the area burned under each vegetation type in the southern Aravallis of Rajasthan.

referred to as recurrent forest fires. The areas that faced continuous fires were identified as vulnerable and demarcated as high-risk areas. The areas affected 4–5 times in six years (34,438.2 ha; Table 5) were identified as frequent burnt areas (medium risk). The forests affected by fire during 2–3 years were demarcated as occasional fire areas (low risk) occupies (100,442.6 ha; Figure 6). Average estimate based on six years data revealed that every year nearly 91,154 ha (5.6%) of forest was affected by fire at the state level. The analysis for fires in Rajasthan indicates average annual forest burnt area for dry deciduous forests was 85,347.3 ha, followed by thorn forests (3772.6 ha) and broad-leaved hill forests (1424.3 ha) (Figure 7). Analysis showed that around 1–2% area of scrub and grasslands was burnt during each year.

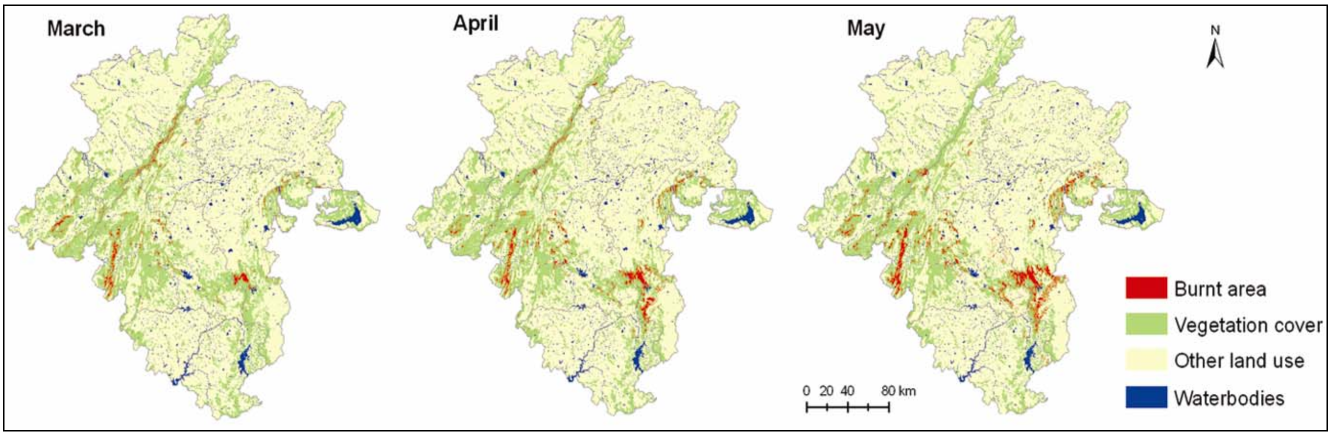


**Figure 8.** Forest burnt area progression map for 2009.

**Table 5.** Areal extent of forest fire return in Rajasthan (2005–2010)

| Fire occurrence | Area (ha) | Percentage of area |
|---|---|---|
| Fire recurrent area | 8,566.3 | 6 |
| Fire frequent area | 34,438.2 | 24 |
| Fire occasional area | 100,442.6 | 70 |
| | 143,447.1 | 100 |

## Discussion

The spatial data on vegetation-type maps are the prime input for identification forest fire risk areas. The analysis showed that the occurrence and extent of high forest fires during each year in broadleaved hill forest of Mt. Abu at Sirohi posed significant threat to this unique ecological system. There were no forest fires observed in the northern, central and southeast Aravallis (Sariska Tiger Reserve, Alwar District; Ranthambore Tiger Reserve, Sawai Madhopur District; Bharatpur, Dhaulpur, Ajmer, Bundi, Tonk, Kota, Bhilwara and Jhalawar districts) based on IRS P6 AWiFS satellite data of 2005–2010.

Forest fires were prominent in Udaipur, Sirohi and Chittaurgarh districts. Recurrent forest fires in the southern Aravallis revealed significant threat to biodiversity. Multi-temporal satellite data covering the whole dry season were used for all forest fire events. The normal fire season extends from March to May in Rajasthan. The progression of forest burnt area in March, April and May of 2009 is presented in Figure 8. Of the six natural vegetation types, dry deciduous forests are highly prone to fire, followed by broadleaved hill forest, thorn forest, dry savannah, scrub and grasslands. Significant differences existed between the tropical dry deciduous forests and all other vegetation types. Fire spread in the dry deciduous vegetation was significantly higher and it always contributed to > 90% of the burnt area among the vegetation types. The burnt area also increased from 2005 to 2009 in the dry deciduous and thorn forests. The year 2009 was the warmest year since 1901 showing large-scale fires as reported by the India Meteorological Department[21]. Thus it is clear that rising temperature and low rainfall affect the intensity of fires. Less fire was observed in the grasslands of Rajasthan in 2005, but it has gradually increased to 1404.7 ha in 2010.

There has been abrupt increase in the burnt area from 1995 till the present (Figure 9). FSI reported 31,600 ha of forest burnt area during 1995 using IRS 1B LISS II data. This is 2% of the total forest cover at the state level[22]. The forest burnt area for Sirohi district has been estimated as 12,076 ha in 2008 and proportionately covers 9.2% of the total forest area[23]. Whereas interpretation from satellite data of 2009 and 2010 depicts 17.6% and 8.8% forest burnt area cover in Sirohi district. The forest burnt area of Karnataka and Andhra Pradesh was high in comparison to Rajasthan, and occupied 693,800 ha and 636,900 ha respectively[12], in 2000. The forest burnt area in Kerala was reported[24] as 30,946 ha in 2004, which is less compared to Rajasthan, since the former mostly experiences tropical humid climate.

Based on the analysis carried out, it has been observed that forest fires were concentrated mostly at the edges of the forests up to 500 m. The interior forests contributed to a lesser area under forest fire (Figure 10). Thus, it is clear that anthropogenic interference plays a vital role in fire occurrence. A forest burnt area map showing the fire recurrence areas has been demarcated.

It was found that ethnic belief of tribes to worship the God is mainly responsible for recurrent fires. The occasional and frequent fire areas are the result of accidental fires or for collection of non-timber forest produce and grazing. Accuracy analysis was performed on the classified forest burnt area maps. The reference values are based on 280 GPS-based ground control points for the 2010. The error matrix was generated to provide accuracy of burnt area in individual vegetation type classes (Table 6). Besides the overall accuracy, accuracy of individual

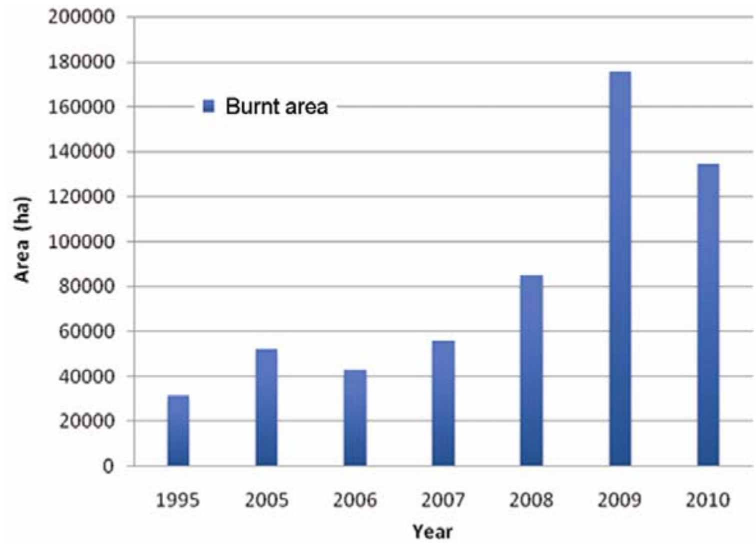


**Figure 9.** Increasing fire occurrences in Rajasthan from 1995 (FSI) to 2010 (the present study).

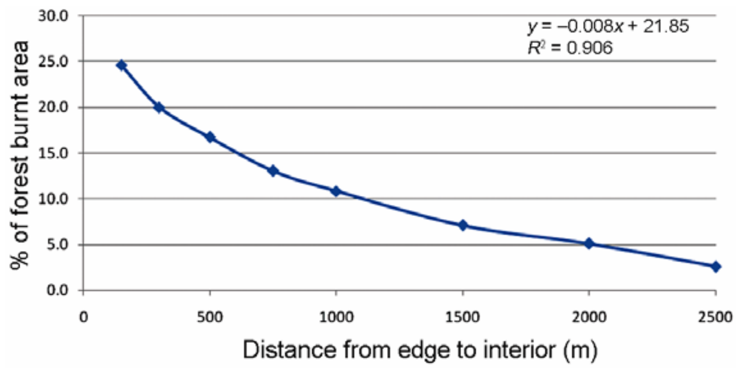


**Figure 10.** Pattern of forest fires from forest edge to interior.

**Table 6.** Accuracy assessment of forest burnt areas across the vegetation types

| Class | Producers accuracy | Users accuracy |
|---|---|---|
| Broadleaved hill forest | 90.4 | 92.2 |
| Dry deciduous forest | 92.5 | 91.4 |
| Thorn | 90.3 | 87.5 |
| Dry savannah | 91.4 | 88.9 |
| Scrub | 83.3 | 89.3 |
| Grasslands | 90.6 | 92.3 |

classes has also been determined by calculating producers' accuracy and users' accuracy. The producers accuracy is derived by dividing the number of correct sample points in one class by the total number of points as derived from reference data. The producers' accuracy measures how well a certain area has been classified. It includes the error of omission, which refers to the proportion of observed features on the ground that are not classified in the map. Greater the error of omission, lower is the producers' accuracy. Similarly, users' accuracy can be obtained by dividing the correct classified units in a class by the total number of units that were classified in that class. The greater the error of omission, lower would be the users' accuracy. The overall classification accuracy achieved was 90.6%. The kappa statistics was 0.88. The classified burnt area maps were overlaid on vegetation type map and 50 points were assigned to each vegetation cover class using stratified random method for the period of 2005–2009. Accuracy assessment of 2005–2009 datasets showed burnt area estimates with an accuracy ranging from 83% to 92% depending on the vegetation cover type.

## Conclusions

The present study assessed and monitored forest burnt areas based on the observation of multi-temporal IRS P6 AWiFS datasets from 2005 to 2010. Multi-temporal satellite data covering the whole dry season were used for forest fire events. Observations during the past six years showed the increasing intensity and spread of forest fires in Rajasthan, and consequently severe conservation threat to vegetation classes of southern Aravallis, especially Udaipur, Chittaurgarh, Sirohi and Rajsamand districts. Long-term planning for forest fire management is necessary for effective conservation of biodiversity and biological resources through environmental education, possible resettlement of the villages from inside the forest to the edges with all means for livelihood and strict implementation of the Indian Forest Conservation Act (1980).


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