FOREST FIRES IN INDIA: REGIONAL AND TEMPORAL ANALYSES

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SRIVASTAVA P & GARG A. 2013. Forest fires in India: regional and temporal analyses. Forest fire threatens the wealth and biodiversity of the forest. Studies suggest that 90% of vegetation fires in India may be man-made and, annually, about 3.73 mil ha of forest area are affected, leading to a loss of USD104 million. The present study, using MODIS (Moderate Resolution Imaging Spectroradiometer) data from Web Fire Mapper on active fire location for 2001–2011, tried to relate vegetation fire incidences with causal factors and vulnerability of the forest types in India. There were four regional cluster variation based on types. Tropical dry deciduous forest contributed the highest number of fires with maximum numbers in 2004, 2009 and 2010. The main factor affecting the spread of forest fire was inflammable material, i.e. type and characteristics of vegetation. The study also analysed the vegetation component using landuse/land cover maps derived from satellite data and also anthropogenic factors such as livelihoods coupled with fire-favourable weather. The study highlighted the need for an integrated approach to forest fire management.

Keywords: Vegetation fires, vegetation type, causative factors, vulnerability

SRIVASTAVA P & GARG A. 2013. Kebakaran hutan di India: analisis serantau dan waktu. Kebakaran hutan mengancam kekayaan serta biodiversiti hutan. Kajian mencadangkan bahawa 90% kebakaran hutan di India mungkin diakibatkan oleh manusia. Setiap tahun hampir 3.73 juta ha kawasan hutan terbakar melibatkan kerugian sebanyak AS$104 juta. Kajian ini menggunakan data MODIS (Spektroradiometer Pengimejan Resolusi Sederhana) daripada Web Fire Mapper untuk lokasi kebakaran aktif bagi tahun 2001–2011 bagi mengaitkan kejadian kebakaran hutan dengan faktor penyebab serta kerentanan jenis hutan di India. Terdapat empat variasi kelompok serantau berdasarkan jenis tumbuhan. Hutan daun luruh kering tropika menyumbang bilangan kebakaran yang paling tinggi dengan bilangan maksimum pada tahun 2004, 2009 dan 2010. Faktor utama yang menyebabkan api merebak ialah bahan boleh bakar iaitu jenis serta ciri-ciri tumbuhan. Kajian ini juga meneliti komponen tumbuhan menggunakan peta tumbuhan penutup bumi/penggunaan tanah yang diperoleh daripada data satelit dan faktor antropogenik yang termasuk sumber mata pencarian serta cuaca yang menggalakkan kebakaran. Kajian ini menyerlahkan keperluan pendekatan bersepadu untuk pengurusan kebakaran hutan.

INTRODUCTION

Vegetation fires are part of the natural seasonal cycle of growth, decay and combustion, and are ignited by lightning strikes. However, humans have long played a significant role in modifying fire regimes by changing the season and frequency of burning and, consequently, vegetation composition and structure (Goldammer & Price 1998). During the 1990s in tropical humid areas, major fires have occurred in the Brazilian Amazon, Mexico and Indonesia (Kalimantan and Sumatra) and were particularly severe in 1997–1998 during the El Niño episode (FAO 1997, Nepstad et al. 1999). Fire is also a serious threat to native forests in many parts of tropical and non-tropical developing countries. In India, forest ecosystems are under severe threat due to recurrent fires apart from anthropogenic pressures which cause land degradation, soil erosion and reduced productivity.

Fire frequency is expected to increase with human-induced climate change, especially where precipitation remains the same or is reduced (Stocks et al. 1998). A general but moderate increase in precipitation, together with increased productivity, favours generation of more flammable fine fuels. Unsustainable development and forest management practices

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could also contribute to enhanced forest fires. Monitoring and management of forest fires are, therefore, very important in tropical countries such as India where 55% of the total forest cover is prone to fires annually, causing adverse ecological, economical and social impacts (Gubbi 2003). Studies of impacts of tropical wildfires on environment indicate high emissions of carbon, trace gases and aerosol particles. There is widespread concern about the loss of biodiversity, effects on atmospheric chemistry and increase in surface albedo and water runoff due to biomass burning. Thus, mapping the timing and the extent of fires is important as fire is a prominent change agent affecting ecosystem structure and the cycling of carbon and nutrients as well as is a globally-significant cause of greenhouse gas emission.

In India, about 55% of the forest area, which is predominantly covered by deciduous forests, is prone to fires every year causing loss of about USD104 million. Researchers regard the origin of forest fires in India as mostly anthropogenic (Roy 2003, Giriraj et al. 2010). This needs to be properly surveyed and inventoried especially since the number of incidences of forest fires is increasingly affecting the legally protected nature conservation areas. The present study analysed the impact of climate, types of vegetation and human interventions on the occurrence of forest fire in India.

MATERIALS AND METHODS

Data sources

We built up spatial datasets based on various sources from classified remote sensing datasets and literature surveys. Major spatial datasets which were used in the present study included land cover map, fire location information and meteorological data. For the present study we used global 2000 land cover maps (Agarwal et al. 2003) at a 1-km resolution and Defense Meteorological Satellites Program (DMSP) data. Daily historical data on the incidences of fires in India from 2001 till 2011 were obtained from the Fire Information for Resource Management System (FIRMS) (Anonymous 2011) and the Global Fire Information Management System (GFIMS) (FAO 2011). For state-wise analysis, administrative boundary was obtained from Survey of India. Meteorological data from 2001 till 2005 were a soil and water assessment tool model output obtained from the Integrated Natural Resources Management (personal communication) (Figure 1).

Satellite land cover map

Land cover map was needed to ascertain the vegetation types that were affected by fire. A total of 45 classes of land cover were identified based on the land cover classification scheme of FAO. For this study, only 23 forest classes were retained and the rest were sliced into non-forest category. These 23 forest classes were further integrated into 5 major forest type classes with spatial resolution of 1-km^2 pixel (Figure 2) to establish a correspondence with the classification system of Indian forest (Table 1) (Champion & Seth 1968, Agrawal et al. 2003).

These classes were further grouped under six broad categories based on the number of incidences of fire on the type of vegetation and vulnerability (Table 2). Tropical evergreen and semi-evergreen forests recorded high incidences of fires and form a major composition in the states in south India. All the classes with smaller number of fires have been merged into 'others' category.

Historical data on incidence of fire on vegetations

Monthly data on the number of occurrences of fires from 2001 till 2011 were derived from Web Fire Mapper (FIRMS and GFIMS), an open source internet-based mapping tool that gave locations of hotspots/fires. Each hotspot/active fire location represented the centre of about 1-km^2 pixel flagged as containing one or more actively burning hotspots/fires within that pixel. The hotspots/fires were detected using data from the MODIS (Moderate Resolution Imaging Spectroradiometer) instrument, on board NASA's Aqua (EOS AM) and Terra (EOS PM) satellites. In this research, active fire detection for MODIS was based on heritage algorithms developed for

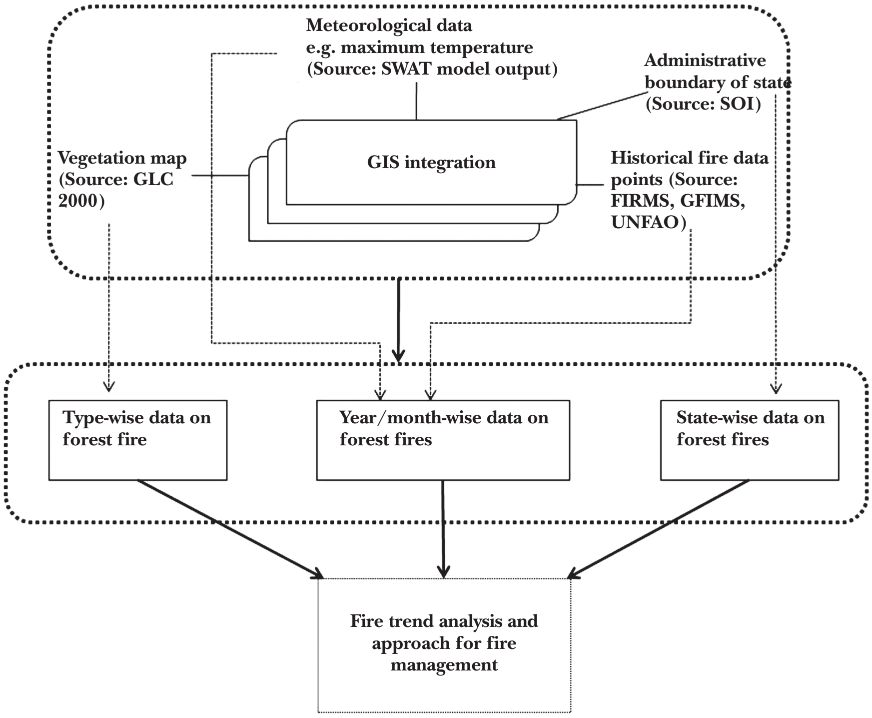

Figure 1 Methodological framework; SWAT = soil and water analysis tool, GIS = geographic information system, GLC 2000 = global land cover 2000, SOI = Survey of India, FIRMS = Fire Information for Resource Management System, GFIMS = Global Fire Information Management System, UNFAO = United Nations Food and Agriculture Organization

the AVHRR (Advanced Very High Resolution Radiometer) and TRMM VIRS (Tropical Rain Measuring Mission–Visible and Infrared Scanner) (Kaufman et al. 1990, Justice et al. 1996, Giglio et al. 1999, 2003). The algorithm used brightness temperatures derived from MODIS 4 and 11 μ channels, denoted by T4 and T11 respectively.

In the present study, only fire location points with brightness value of 320 K and confidence level more than 70% were retained. This was necessary as air temperature in India could reach up to 45–47 °C (318–320 K) during hot summer days in March till June (Saxena & Srivastava 2007). The fire season in India generally starts from the month of February and extends up till June. Forests are drained of moisture because of increasing temperature. Therefore, analysis on the occurrence of fire on vegetation was limited to these five months only. In the years 2001 and 2002 the detection of the fire spots was comparatively very low as the MODIS active fire products were designated a provisional maturity status only in November 2000 following adjustments to

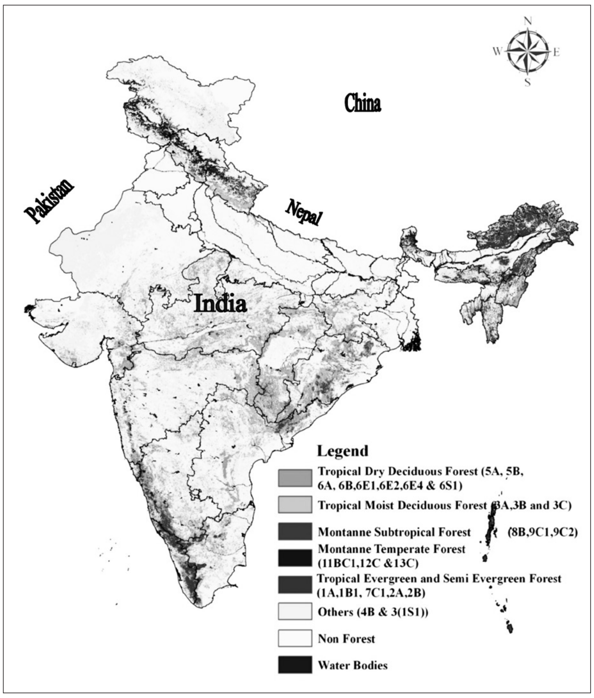

Figure 2 Vegetation map of India classified into five major classes according to the global land cover for 2000 (groups and subgroups of forest types are explained in Tables 2 and 3)

Table 1 Land cover classification scheme classes (LCCS) and their corresponding Champion and Seth (1968) scheme of classification

LCCS classification scheme	Champion and Seth (1968) classification scheme	
Tropical evergreen forest (broadleaved)	Tropical wet evergreen (southern and northern tropical wet evergreen) tropical dry evergreen	1A, 1B, 7C1
Tropical semi-evergreen forest	Southern tropical semi-evergreen and northern tropical semi-evergreen	2A, 2B
Moist deciduous forest (broadleaved climate: tropics–humid)	Andaman moist deciduous, south Indian moist deciduous and north Indian moist deciduous	3A, 3B, 3C
Dry deciduous forest, (broadleaved) climate: tropics–dry semi-arid	Southern tropical dry deciduous and northern tropical dry deciduous	5A, 5B
Subtropical evergreen forest (broadleaved)	Northern subtropical broadleaved wet hill forests	8B
Subtropical conifer (needleleaved forest, climate: subtropics)	Himalayan subtropical pine forests, Assam subtropical pine forests	$9C_1$, $9C_2$
Temperate evergreen forest (broadleaved evergreen forest, climate: temperate continental)	East Himalayan wet temperate forest	$11BC_1$
Temperate conifer (needleleaved evergreen forest, climate: temperate continental)	Himalayan moist temperate and Himalayan dry temperate	12C, 13C
Mangroves (broadleaved evergreen medium high forest on water logged soil, water quality: saline) and other coastal vegetation	Tidal swamp forests	4B
Northern tropical thorn forest (aphyllous woodland, climate: tropics–dry semi-arid)	Northern tropical thorn forest	6B
Southern tropical thorn forest (aphyllous woodland, climate: tropics–moist semi-arid)	Southern tropical thorn forest	6A
Tropical thorn scrub (aphyllous sparse medium high trees, climate: tropics)	*Euphorbia scrub, Acacia senegal* forest, Rann saline thorn forest, Salvadora scrub, desert dune scrub	$6E_1$, $6E_2$, $6E_3$, $6E_4$, $6S_1$
Savannah grassland (grassland with trees, climate tropics)	Low alluvial savannah	3_1S_1

the instrument. This provisional status meant that the product was usable, although it had known problems and validation was ongoing. Therefore, detection of forest fires in 2001 and 2002 was less as at that time level 2 products of MODIS MOD14 (Terra) and MYD14 (Aqua) were used and these were most basic. With the introduction of level 3, the detection of active fire location became more accurate.

Overlaying of fire points on the land cover map

Initially 23 classes of the vegetation map derived from global land cover 2000 maps of LCCS were converted from the raster format to vector. The point layer of annual number of incidences of forest fires was overlaid on the vegetation map (Figure 3) and the attribute

Table 2 Broad categories of vegetation types used in the study of incidences of fires in India from 2001 till 2011

Vegetation type	Classifier
Tropical evergreen and semi-evergreen forest	1A, 1B, 7C1, 2A, 2B
Tropical moist deciduous forest	3A, 3B, 3C
Tropical dry deciduous forest	5A, 5B, 6A, 6B, $6E_1$, $6E_2$, $6S_1$
Montane subtropical forest	8B, $9C_1$, $9C_2$
Montane temperate forest	$11BC_1$, 12C, 13C
Others	4B, 3_1S_1

information of point and polygon were joined using attribute table function in ArcGIS 10× to obtain the number of incidences of fires on the vegetation and finally, to analyse the vulnerability of the forests. The resultant layer was further integrated with administrative boundary of the state to obtain total count of forest fires in each state. The total count of fires for the years 2001 till 2011 were analysed statistically for their dependence on temperature and precipitation.

Statistical analysis

Statistical test was performed to ascertain the effects and causes on the incidences of forest fires. A regression analysis was done to ascertain the relation between temperature, precipitation and the incidences of forest fires. Normal distribution and Spearman rank

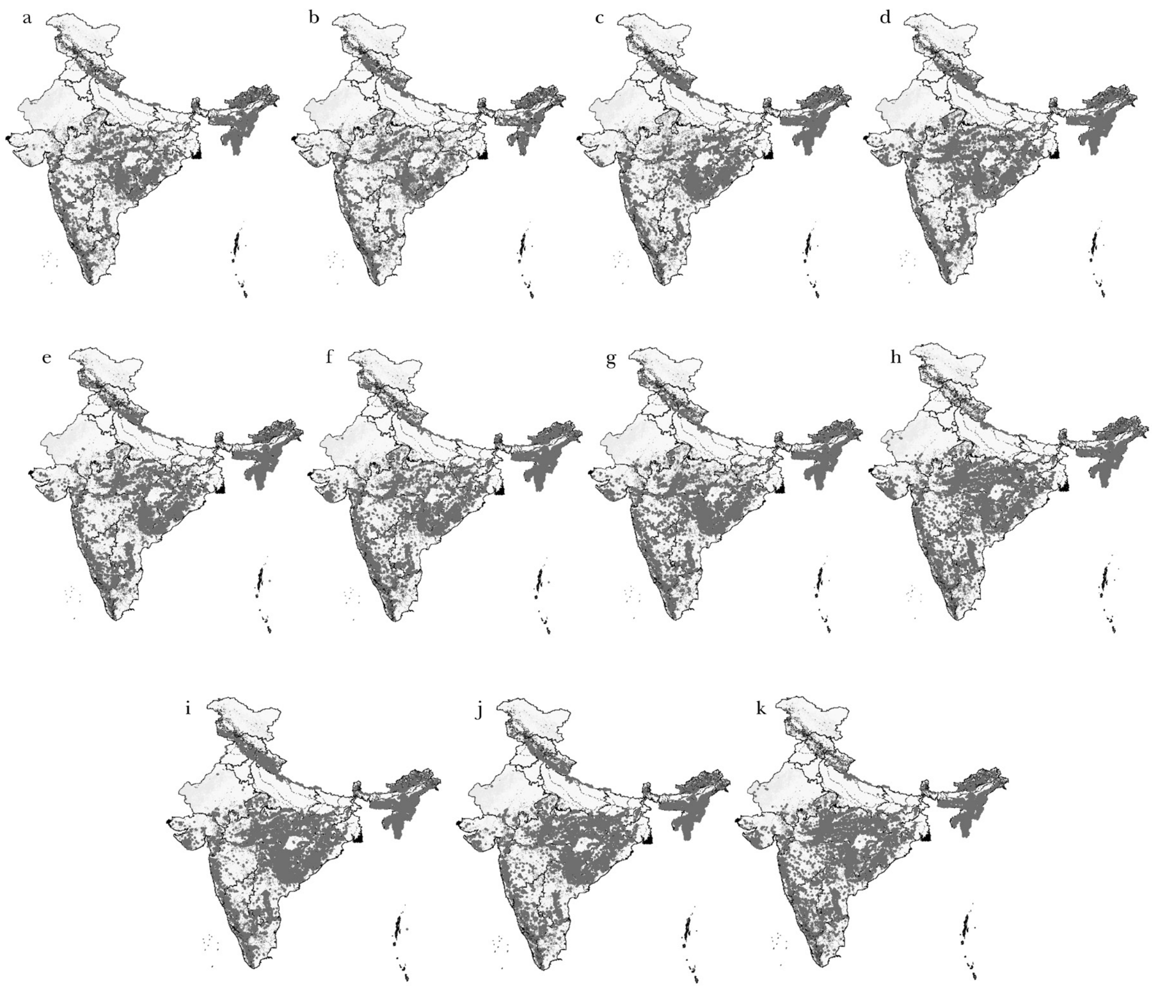

Figure 3 Spread of fire points over major vegetation in India: (a) 2001, (b) 2002, (c) 2003, (d) 2004, (e) 2005, (f) 2006, (g) 2007, (h) 2008, (i) 2009, (j) 2010 and (k) 2011

correlation analysis were performed for the vulnerability assessment and tribal influence on forest fires.

RESULTS

Temporal analysis on the incidence/ occurrence of fires

Fire incidences were highest in the months of March and April and gradually subsided with the onset of the monsoon (Table 3). In March 2004 there was an abnormally high incidence of fires compared with 2005.

Over the years the number of incidences of fires had increased with an average number of 17,196 (Table 3). After removing the values of years 2001 and 2002, it can be inferred from the negative skewness in the months of March and April (Table 3) that the number of incidences of forest fires has increased exponentially. High deviation from the mean in the yearly and monthly data exhibited inconsistency in the pattern of total number of fire incidences. In 2009 there was drastic increase in the number of forest fires which was directly linked to the increase in temperature (Figure 4a) (India Meteorological Department 2009). The annual mean temperature for 2009 was 25.6 °C, 0.9 higher than the long-term annual average of 24.6 °C. Interestingly, it was one of the 12 hottest years in 108 years since 1901 when the meteorological department started maintaining temperature records; 8 have been in the past decade.

There was an abnormal increase in the mean values of fire points in 2004 and 2009 (Table 3). This might be directly attributed to high temperatures and also longer spells of sustained heat, even if temperatures were not so high, that reduced moisture content in the available fuel material. High deviation from mean over the years represents more instability in the occurrence of fires. There was positive correlation between incidences of fire with temperature but negative with precipitation (equation 1).

$$y = -63879 + 2362x_1 - 168x_2 \quad (1)$$

where y = forest fire count, x_1 = temperature and x_2 = precipitation.

The p value in the analysis of variance table (0.000) showed that the model estimated by the regression procedure was significant at α level of 0.05. The p values for the estimated coefficients of temperature and precipitation were 0.000 and 0.031 respectively, indicating that temperature was significantly correlated with the incidences of forest fires. However,

Table 3 Monthly total incidences of forest fires in India

Year	Monthly total of the number of incidence of fire on vegetation						Mean ± SD
	Feb	March	April	May	June	Total	
2001	701	1923	908	262	2	3796	759 ± 742
2002	273	805	766	336	16	2196	440 ± 339
2003	934	7938	6008	1527	330	16,737	3347 ± 3410
2004	1723	16,697	2797	904	58	22,179	4436 ± 6942
2005	2396	6374	6876	1194	325	17,165	3433 ± 3010
2006	2712	12,835	3394	703	46	19,690	3938 ± 5162
2007	1361	12,338	5822	1008	232	20,761	4152 ± 5070
2008	1085	6427	7883	2354	68	17,817	3563 ± 3420
2009	4333	15,513	6584	1234	374	28,038	5608 ± 6066
2010	1300	15,384	5456	712	100	22,952	4590 ± 6393
2011	991	10,890	4445	1426	76	17,828	3566 ± 4410
Mean ± SD	1619 ± 1147	9739 ± 5456	4631 ± 2391	1060 ± 593	148 ± 139		
ɤ(2003–2001)	1.555	-0.211	-0.388	1.355	0.463		

Source: Analysis of the data obtained from FIRMS and GFIMS; ɤ = skewness; SD = standard deviation precipitation alone was insignificant for forest fires. The r^2 at 96.2% and adjusted r^2 at 94.6% indicated that the model fitted the data well. The regression fit line, with temperature as dependent variable and number of incidences of fires as independent variable, showed very significant result with r^2 = 91.2%. Precipitation alone showed insignificant results with r^2 = 35.7% (Figure 5).

Vulnerability of vegetation type

Forests in the youngest mountain ranges are the most vulnerable to fire. The forests of Western Himalayas are more prone to forest fires compared with those in Eastern Himalayas. This is because of the higher rain density in the latter. The tropical dry deciduous forest which formed the highest composition of forest area was the most vulnerable to fire (Table 4). This forest type experienced higher number incidences of fire in 2004, 2009 and 2010. Tropical evergreen and semi-evergreen as well as tropical moist forest type showed lesser deviation from the mean values.

Forest in this study exhibited strong positive correlations with temperature Maximum vulnerability was observed in tropical dry deciduous forest (ρ = 0.788) followed by tropical evergreen and semi-evergreen forest

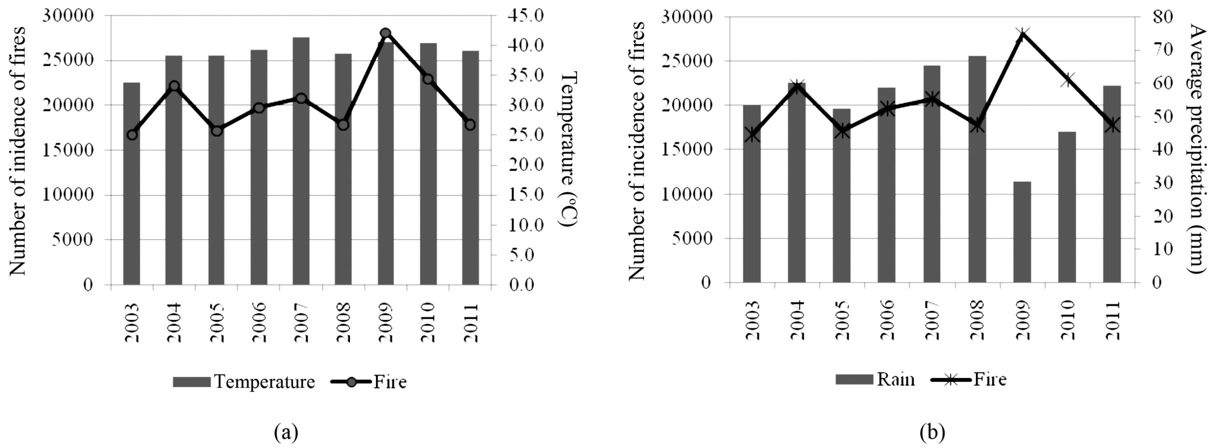

Figure 4 (a) Temperature versus fire counts and (b) precipitation versus fires counts

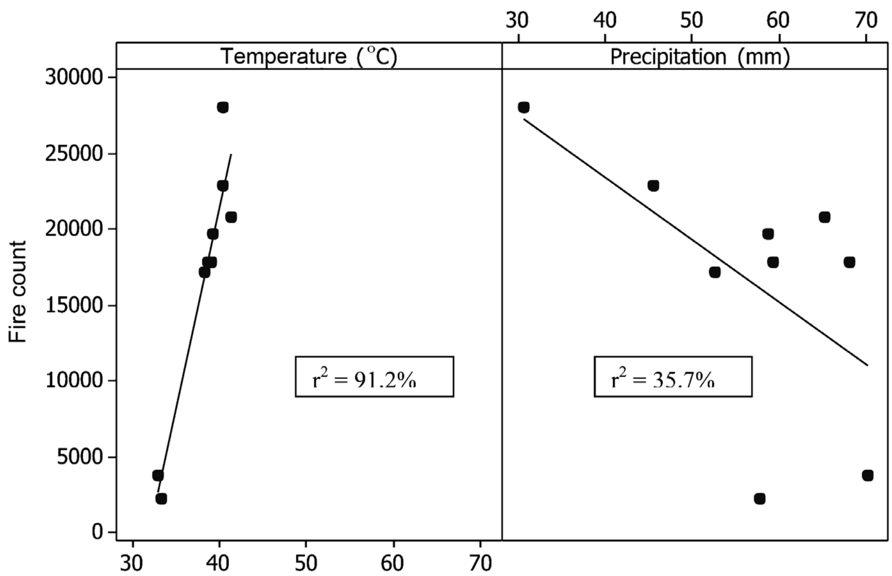

Figure 5 Scatter plot of fire counts versus (a) temperature (°C) and (b) precipitation (mm)

Table 4 Total number of annual incidences of fires in major forests from 2001 till 2011 in India

Vegetation type	Number of forest fires											Mean number of forest fires ± SD
	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	
Tropical evergreen and semi-evergreen forest	776	396	4602	5771	4447	5978	5941	3899	7189	5757	3523	4389 ± 2158
Tropical moist deciduous forest	1166	694	5327	5581	4833	4428	5770	4635	7175	6168	4450	4566 ± 1977
Tropical dry deciduous forest	1800	1049	6494	10408	7601	8968	8732	8882	12984	10648	9576	7922 ± 3626
Montane subtropical forest	26	33	180	181	137	158	123	144	297	184	96	142 ± 75
Montane temperate forest	9	8	65	82	44	51	62	60	204	84	31	64 ± 53
Others	19	16	69	156	103	107	133	197	189	111	152	114 ± 61
Total	3796	2196	16,737	22,179	17,165	19,690	20,761	17,817	28,038	22,952	17,828	

Source: FIRMS, GFIMS and Agarwal et al. (2003)

(ρ = 0.695) and tropical moist deciduous forest (ρ = 0.673) (Table 5). Precipitation exhibited inverse correlation with the number of incidences of forest fires. The negative and very low value correlation of tropical dry deciduous forest (ρ = -0.355) suggested higher dryness in the available inflammable material on the ground. These results are consistent with the hypothesis that temperature and precipitation variables can be used for the assessment of vulnerability of characteristic forest types.

Factors contributing to incidences of fire

From the analysis of 11 years (2001–2011), it was deduced that maximum fire detection was in the north-eastern states. This may be attributed to shifting cultivation which is prominent in the hill forests. The incidences of vegetation fire across the states were higher in March and April compared with other months (Figure 6). Forest is cleared

Table 5 Spearman's rank correlation for different forest types

Variable	Temperature	Precipitation
	ρ	ρ
Tropical evergreen and semi-evergreen forest	0.695	-0.355
Tropical moist deciduous forest	0.673	-0.464
Tropical dry deciduous forest	0.788	-0.355
Montane subtropical forest	0.497	-0.600
Montane temperate forest	0.564	-0.436
Others	0.645	0.073

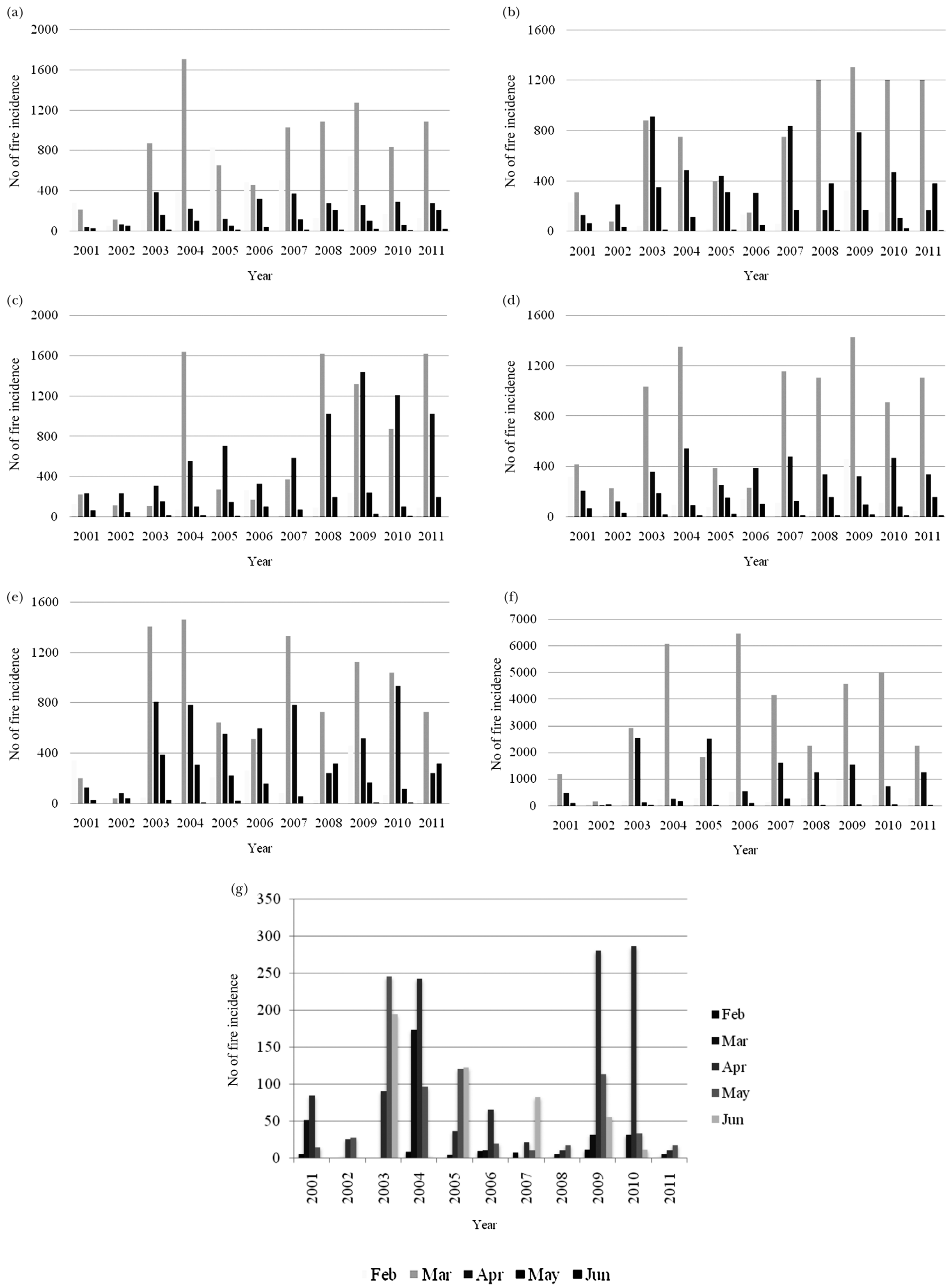

Figure 6 Distribution of fire across some major states over 11 years: (a) Andhra Pradesh, (b) Chhatisgarh, (c) Madhya Pradesh, (d) Maharashtra, (e) Orissa, (f) north-eastern states and (g) Uttarakhand

for agricultural activities and burning starts in March and April. During the summer months of March and April, parts of central India and Western Ghats were predominantly covered with deciduous forests (Figure 2) and became dry. Falling leaves aided ignition of fire. The incidences of fire in Andhra Pradesh, Chhattisgarh, Madhya Pradesh and the north-eastern states reached regular seasonal maximum in March and April (Figure 6). Human ignition easily triggered fire in these forests with rising summer temperatures and dry weather conditions. Western Ghats and Eastern Ghats (Maharashtra, Karnataka, Kerala and Tamil Nadu) have a unique vegetation formation with considerable seasonality in the distribution of precipitation. December till June is a long dry period that causes accumulation of flammable fuels in the form of litter and dry grass.

In May, incidences of forest fire in the southern and north-eastern states almost subsided despite high air temperature condition (Figure 6). On the other hand, the West Himalayan forests (Uttarakhand State), primarily composed of *Pinus roxburghii,* experienced heavy fire episodes every year in May and June. High summer temperatures in this region occur in mid-April till May and the forests become more susceptible to human-induced fires.

Role of village and tribal community in the incidences of fire on vegetation

The Spearman's rank correlation analysis for the influence of tribal population on the number of incidences of fires on different forest types showed a very strong statistical correlation coefficient ($\rho = 0.864$ at $\alpha = 0.01$ level and $p < 0.0001$) (results not shown). The incidences of fires were mostly concentrated in tribal districts only and were positively correlated with the total counts of forest fires (Figure 7). However, this did not dispute the dependency of the tribes and forest-dwelling communities on the forest which was obvious from the number of claims in states such as Chhattisgarh, Madhya Pradesh and Orissa (Figure 8). Chhattisgarh and Orissa had the highest number of claims (Figure 8) and number of incidences of fires (Figures 6b and 6e). Although the claims shows the rights of the forest-dependent people, the mode of extraction involves use of fires for forest produce in any form either as fuelwood, fodder or any other forest produce.

CONCLUSIONS

The present analysis demonstrates the threatened forest types and regions by fires in India. Our results showed that incidences of fires were higher in March and April compared with May and June as temperature during these months increased drastically and long spell of dryness led to low moisture in the flammable material. Although the number of incidences of fires varied across different forest types (most vulnerable being tropical dry deciduous forests), all types of forest ecosystems in India burned frequently. Maximum number of fires has been reported in north-eastern states followed by Chhatisgarh, Orissa, Madhya Pradesh, Maharashtra and Andhra Pradesh. These states (north-eastern states, Chhatisgarh, Orissa, Madhya Pradesh, Maharashtra and Andhra Pradesh) account for maximum tribal community/forest dwelling people and they live in the vicinity of forests. The incidences of fires and the management of forest fires seem to be closely correlated with the level of dependency that a community living in close proximity to the forest has over the forest.

The study emphasised the need for impending use of remote sensing data in understanding the spatial and temporal variability on occurrences of fire in different vegetation types. Forestry practices have been developed for a large number of forest types and species in India through well-prepared working plans. Manual fire prevention and control have always constituted an important component in these plans. However, these fire control systems are at times difficult to implement due to lack of manpower, resource constraints and time-effective control mechanisms. These requirements can be met if satellite- and ground-based data are used. Results of this study can be helpful in introducing an early warning system for prevention and management of forest fires that can become an integral part of fire mitigation projects in tropical countries.

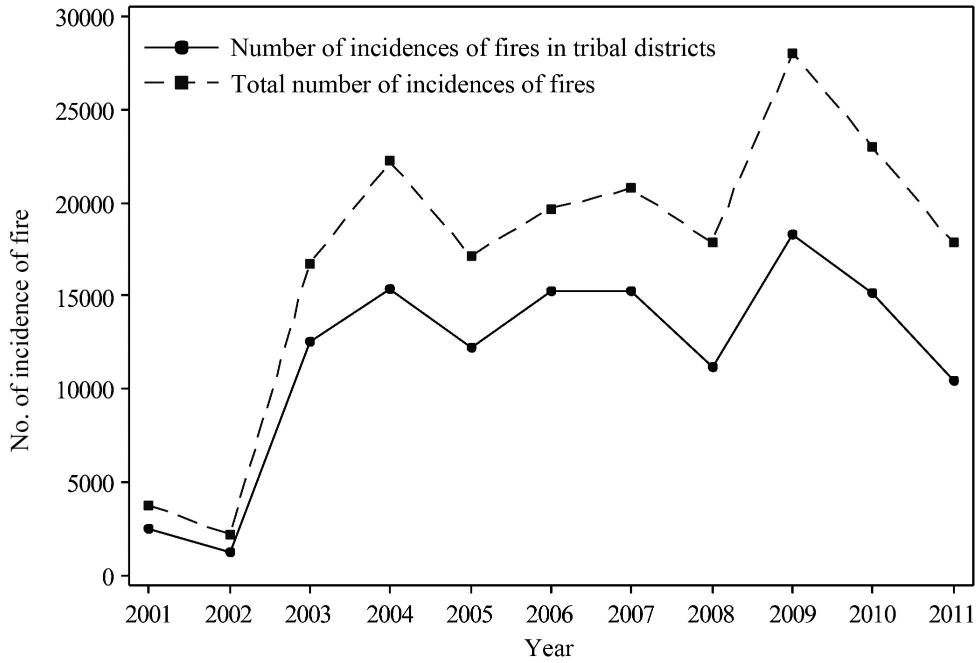

Figure 7 Graph showing pattern comparison of total number of fires and the number of fires in the tribal districts

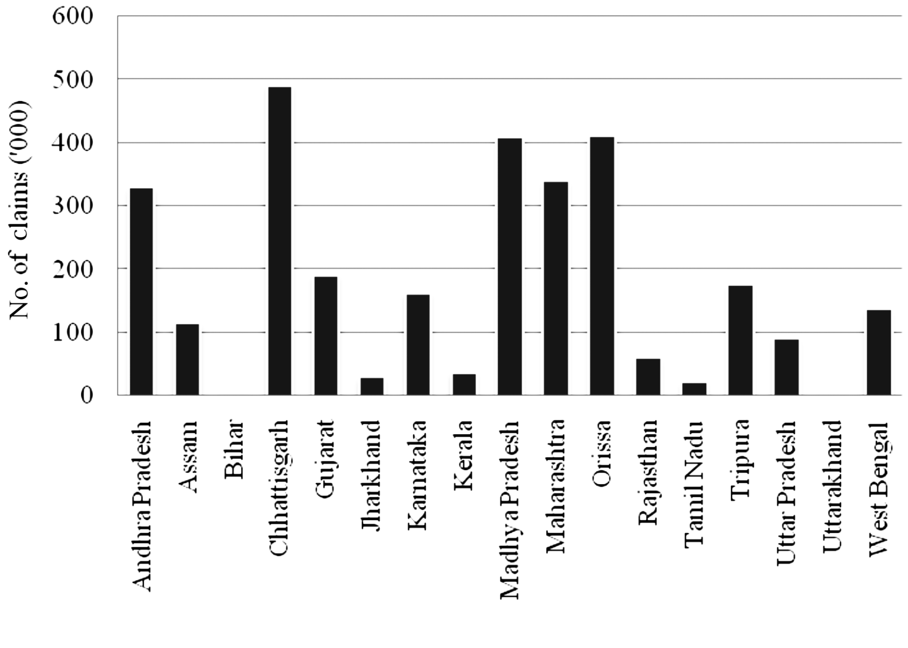

Figure 8 Graph showing number of claims made by indigenous community/forest-dependent community (source: http://www.indiastat.com)

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