ORIGINAL ARTICLE

Fire risk assessment along the climate, vegetation type variability over the part of Asian region: a geospatial approach

Firoz Ahmad[1] · **Md Meraj Uddin[2]** · **Laxmi Goparaju[1]**

Abstract

In the present study, we evaluated the long term MODIS fire counts with the grid spacing $1° \times 1°$ over the part of continent of Asia. The grid show high percent of fire events was assigned to high risk grid. The study further evaluated three selected 2×2 window representing the risk grid. We have analyzed the fire events along various vegetation types as well as country boundary. The climate data set is further analyzed and statistical analysis was performed to understand the relationship with fire events. The first selected 2×2 window grid roughly represents over region of Punjab and Haryana state of India show 83% of total fire in the month of October and November due to agricultural residues burning. The result of the analysis of vegetation types with fire events manifest the vegetation types dominated by shifting cultivation which occupies the geographical area of 8% whereas they retain fire percent equivalent of 30% of total fire events. Country based fire events analysis shows that Burma fire events per unit geographical area were found roughly 3.5 times higher when compared with India. The analysis of fire events and climate data from February to July in grids over a part of the Asian region (central part of India) exhibit the 50% fire events was in the month of March with maximum temperature (°C), precipitation (mm) and solar radiation (KJ/m^2/day) with range of (26.7–35.9), (6–26) and (22680–24366) respectively. The evaluation of Crammer's V coefficient (CVC) values of precipitation, mean maximum temperature and solar radiation are found in decreasing order and in the range of 0.77–0.31. The highest CVC value of precipitation (0.77) shows that among all other climatic parameters the precipitation has very strong relationship to fire events. Remote sensing data (fire and climate) when coupled with various analyses in GIS domain reflect better understanding of their relationship which will greatly help in management/planning/making strategy on fire prevention/control.

Keywords Fire risk analysis · Grid · Vegetation types · Climatic data · RCP-4.5 · Cramer's V coefficient · Asia

Introduction

Fire is a key element which contributes to carbon cycle, greenhouse gases and aerosol emissions in the atmosphere (Andreae and Merlet 2001; van der Werf et al. 2010). Biomass burning has a very critical relevance to global vegetation dynamics (Kloster et al. 2012; Thonicke et al. 2010), increasingly influencing human lives and property (Bowman et al. 2009). Fire frequency, intensity, size, pattern, season, and severity are important contributors in many ecosystems (Bowman et al. 2009; Bond and Keeley 2005; Gill 1975) leading to many spatial and temporal changes (Goldammer and Price 1998; Pew and Larsen 2001; Fearnside 2005). Climate of a region is a vital parameter in maneuvering the fire regimes (Harrison et al. 2010) and decides the vegetation patterns and has a significant role in distribution, structure, composition and ecology of forests (Kirschbaum et al. 1996). Fire activity in forest is strongly guided by fuel accumulation (Finney 2001), local climate/weather parameter (Flannigan et al. 2000), source of ignition agents (Malamud et al. 2005) and human activity (Rollins et al. 2001; Yang et al. 2007) whereas the dry climate increases the risk of forest fire (Flannigan and Harrington 1988), fuel moisture by and largely determines whether fuels can sustain/withhold ignition (Blackmarr 1972) and therefore it determines its spread (Wotton et al. 2010). Weather condition severity during the

✉ Firoz Ahmad
adfiroz@yahoo.com

1   Vindhyan Ecology and Natural History Foundation, Vindhya Bachao Secretariat, 36/30, Shivpuri Colony, Station Road, Mirzapur, Uttar Pradesh 231001, India

2   University Department of Mathematics, MCA, Ranchi University, Ranchi, Jharkhand, India

summer season determines all of the necessary parameters to start the spread of fire and making fuel available with the percent of moisture content of the forest (Swetnam and Betancourt 1998; Littell et al. 2009). A long period without rain and drought dries out the vegetation, making it easier to burn and thus becomes a better fuel source for fire (Pausas and Fernández-Muñoz 2012). Studies in the past reveal that the climate of a region has an influence on fire activity (Krawchuk and Moritz 2011; Westerling et al. 2003). Seasonal trends in maximum temperature, precipitation, and drought severity (Wells et al. 2004) are vital factors in determining the wildfire frequency and the extent of damage. The fire not only destroys the existing vegetation and reduces the forest cover (Roy 2003) but leads to change in forest structure and composition (Lavoie and Sirois 1998; Brassard et al. 2008; Fleming et al. 2014), loss of economically important timber species (Rodriguez y Silva et al. 2012), destroys the wildlife habitat (Engstrom 2010) and adversely impacts on small mammal population (Sollmann et al. 2015), degrade soil and water (Ferreira et al. 2008) of an ecosystem, destroy/ reduces biodiversity (Tropical 2001) of forest, and enhance the source of air and haze pollution (Srivastava and Singh 2003; Vadrevu et al. 2011) in the existing atmosphere, leads to change the vegetation succession and modifies the nutrient and global carbon cycles (Kutiel and Inbar 1993; Capitanio and Carcaillet 2008) and regulates the climate change (Ramanathan et al. 2005; Crutzen and Andreae 1990). Fire on forests has severe implications for the people/communities/tribes that are the inhabitants of forest and are largely dependent on forest resources for their livelihoods (Aggarwal et al. 2009).

There are several studies that have been carried out adequately in the developed countries for fire risk analysis/ prediction utilizing fire events and climatic datasets. The advent of Remote sensing satellites with improved sensors became a boon in recent years and can be adequately used to monitor the fire patterns (Ager et al. 2017; Ahmad 2017; Ahmad and Goparaju 2017b; Dwyer et al. 1998, 2000) and have increased our understanding/ knowledge of biomass burning (Kaufman et al. 1992), land-use/land-cover change (Eva and Lambin 2000) at landscape level, and fire risk and hazard assessment (Chuvieco and Congalton 1989). Satellite fire data offers clear advantage over the traditional fire data sources which were time consuming, expensive and difficult, especially in remote/inaccessible/hilly areas. Satellite based fire monitoring thus to offer a reliable source of fire occurrence data that largely overcomes some of the limitations of traditional fire records (Csiszar et al. 2005; Eva and Lambin 1998; Flannigan and Vonder Haar 1986; Korontzi et al. 2006). Wotton et al. (2010) made a study in Canada for fire prediction utilizing fire events and its climate/weather parameter. The study advocates that an increase in fire occurrence/events of 25% by 2030 and 75%

by the end of the twenty-first century are due to the impact of climate change. Tian et al. (2012) studied the climate change and forest fire events in China. He simulates the temperature and precipitation for their study in the baseline period. Spatial distribution of the temperature and precipitation was largely consistent with the observed values. Result manifests that the climate change would increase the potential burned areas in future. Pinol et al. (1998) studied in Europe between the period 1941–1994. They analyzed that fire hazard is an increasing trend during this period and further concluded that climate warming and its severity leads to increase in the number of wildfires over this area. Tapper et al. (1993) study utilized climatic datasets such as temperature, relative humidity, wind speed and preceding year rainfall when combined with fuel characteristics/features and its availability for modeling of fire risk or danger indices over the study area. These indices were further modified based on local weather database and observe fire events. Krusel et al. (1993) studied wildfire activity in southern Australia which suggested that the mean maximum daily temperature and maximum relative humidity are the significant parameters which are used to depict high fire activity. The study of Antonovsky et al. (1989) showed that the fire events are strongly correlated with mean air temperature, total rainfall and the maximum period between two successive rains over the fire season. Reddy et al. (2017) analyzed the spatial and temporal patterns of fire events and CO_2 emissions using Resourcesat-2 AWiFS data for the whole India. The total burnt area (km^2) in 2014 were found 48765.45, 6540.97 and 1821.33 in the forest, scrub and grasslands respectively whereas total CO_2 emissions evaluated from the existing fires was to be 98.11 Tg. Giriraj et al. (2010) have evaluated fire for whole India utilized 9 years night-time Advanced Along Track Scanning Radiometer (A) ATSR satellite data to find out high fire prone zones. The study revealed that the Central Highlands, Eastern Highlands, Central Plateau and Chhota Nagpur of Deccan peninsula of India were the most affected by fires and have approximately 36% of the total fire events between the periods 1997–2005. Vadrevu et al. (2008) carried study of forest fire events over India utilizing Along Track Scanning Radiometer (ATSR) satellite datasets. They analyzed spatial patterns of fire across diversified geographical, vegetation and topographic gradients. Study revealed that the maximum numbers of fires events are found in low and medium elevation gradient and in very low to low-slope gradient types. Vadrevu et al. (2013) studied the vegetation fire using MODIS active fire satellite datasets in India. They analyzed various fire regimes (fire frequency, seasonality, intensity and the type of vegetation burnt) over the various geographical diverse regions of India. Ahmad and Goparaju (2017a) have studied decadal fire events across the Jharkhand state of India and delineated fire hotspot districts. Ahmad et al. (2017) studied the trends of various

spatial and temporal perspectives of forest fires events in the Jharkhand state of India. Furthermore they also evaluated forest fire events with respect to meteorological/climate parameter utilizing Cramer's V coefficient (CVC). The study highlights that rainfall has the highest association/relationship with forest fire events. Ahmad et al. (2018) evaluated the forest fire in Arunachal Pradesh of India and recommended for policy intervention towards its conservation/management/ fire prevention and control in forest.

The present study focuses on the part of Asian region which is also affected largely because of fires. A large part is dominated by deciduous forests which makes it more vulnerable. An increasing trend in fire frequency is observed in the world and the Asian region is not an exception. (http://www.dw.com/en/how-climate-change-is-increasing-forest-fires-around-the-world/a-19465490).

The relationship between climate change and fire events and its prediction have been studied by various researchers in the developed countries (Pinol et al. 1998; Tian et al. 2012; Wotton et al. 2010). However this is a conspicuous research interstice over the Asian region.

The prediction regarding climate change shows that more climate anomalies such as mean annual temperature will increase (Lal et al. 1995) and drought will be more frequent over the Asian region (Ramanathan et al. 2005) in future. The precipitation over the Asia has decreased (Goswami et al. 2006; Dash et al. 2007) and will show abrupt behavior in future due to change in the rainfall pattern.

In light of this, the following study has utilized the climatic data, vegetation type's map and the 16 years MODIS fire data over the part of Asian region and analyzed its spatial pattern/distribution/relationship in the GIS domain.

The objectives are as follows:

1. Fire risk evaluation over the 1° × 1° grid over the part of Asian region.
2. Fire events analysis over the various vegetation types.
3. Fire events analysis was done within the country boundary.
4. Climate and fire events data evaluation.
5. Statistical analysis the Cramer V coefficient (CVC) was performed to evaluate the fire events and its relationship with climate datasets.

Materials and methods

The study area was taken as the Asian subcontinent including countries India, Pakistan, Bangladesh, Bhutan, Nepal, Srilanka, Burma and Thailand. In the present study we have used various dataset from diversified source are given in the Table 1.

We have used MODIS data based fire counts for the year 1-11-2000 to 31-12-2016 was in the point shape file available as download by NASA Fire Information for Resource Management System (FIRMS) (https://firms.modaps.eosdis.nasa.gov). Quality of data was evaluated based on specific software by the MODIS land quality assessment group to ensure its high standard (Roy et al. 2002). The fire point data in the form of vector shape file was utilized for determining fire risk and evaluated further to find its trend and relationship.

The SPOT4 satellite based vegetation cover (VEGA 2000 dataset) was used in this study, derived from 'Vegetation instrument' which has 1 km spatial resolution. The legend (http://forobs.jrc.ec.europa.eu/products/glc2000/legend.php) used in this classification was defined by FAO Land Cover Classification System (LCCS) with the help of the regional partner based on regional expertise knowledge. South central Asian regional datasets (http://forobs.jrc.ec.europa.eu/products/glc2000/products.php) covering the south Asia region (Roy et al. 2003) was utilized for our study. The fire events in each vegetation type were evaluated. In this study we have only analyzed those vegetation types having forest fire events greater than 1% of the total fire events.

Climate data (maximum temperature, precipitation and solar radiation) an average monthly was utilized here which retain the spatial resolution one kilometer were downloaded from the WorldClim-Global Climate Data website (http://worldclim.org/version2) widely used for GIS modeling (Fick and Hijmans 2017). Climate data were collected (1970–2000) based on utilizing 9000 to 60,000 weather stations which were further interpolated using thin-plate splines with covariates including elevation, distance to the coast and three satellite-derived covariates: maximum and minimum land surface temperature as well as cloud cover, acquired by the MODIS satellite platform. Satellite data improved the prediction accuracy to a large extent in that area where the station density was low whereas global cross-validation correlations were found ≥ 0.99 for temperature and humidity, 0.86 for precipitation and 0.76 for wind speed (Fick and Hijmans 2017). The 6 months climate data (maximum temperature, precipitation and solar radiation) monthly average from February to July was in GeoTiff format were utilized and brought into map and further analyzed.

We have also downloaded the temperature and precipitation anomalies prediction data (RCP-4.5 scenario) for the year 2030 over the Asia (NCAR GIS Program 2012). The data was in point a Gaussian grid with longitudes are equally spaced at 1.25°, while the latitudes vary in spacing slightly around 0.94° (https://gisclimatechange.ucar.edu/gis-data-ar5). The temperature and rainfall surface were generated from the point vector file using the kriging interpolation technique.

Administrative boundary of country over Asia was downloaded. We have created a grid vector polygon file with spacing 1° × 1° over the study area. Fire data vector file was utilized for determining grid wise fire frequency based on evaluation of each grid using ArcGIS software. In this study fire risk percent is determined by identifying the grid having highest number of fire events and was assigned fire risk percent as 100%. In all other grids fire risk was relatively calculated based on fire events and further percent was assigned. In this evaluation we have only considered the grid risk fire percent greater than 1% for better visualization and clear understanding of overall scenario over Asia. We have selected three different fire events grids windows (2×2) in Asian region to characterize fire risk analysis and for discussion. First two (2×2) grids were selected in India and 3rd (2×2) grids was in Burma.

Cramer's V coefficient (CVC), as suggested by Liebetrau (1983) for statistical analysis was executed to see the relationship of the driving factor i.e. climate data (maximum temperature, precipitation and solar radiation) with fire events in few fire risk grids. Cramer's V is a statistic used to measure the strength of association between two nominal variables, and the values derived from 0 to 1. Values close to 0 indicate a weak association between the variables and values close to 1 indicate a strong association between the variables.

Result and discussion

Fire risk evaluation

The understanding of the spatial pattern of fire is important (Konoshima et al. 2010; Taylor and Skinner 2003) as it helps in its prevention, control and management. The produced map of fire risk grid with an interval of 1°×1° over the part of Asia based on long term fire events is given for better visualization and clear understanding of overall scenario (Fig. 1).

The red grids are high fire risk grids (100%) whereas green grids show the least fire risk grid (1%) as shown in the map. The similar spatial pattern of fire was also observed in this region by Vadrevu et al. (2013).

Punjab and Haryana states (first four grids) of India (north western side of study area) show high fire which was further analyzed. The month wise forest fire trend was analyzed which is given in Fig. 2.

The total number of fire in the four grids was 229,139 over span of 16 years. 83% of total fire is consolidated in this region over the month of October and November. In the states, Punjab and Haryana of India, farmers burn agricultural residues during the month of October and November to control pests and weeds, improve and enhance soil

Fig. 1 Fire risk grid over Asia based on long term fire events
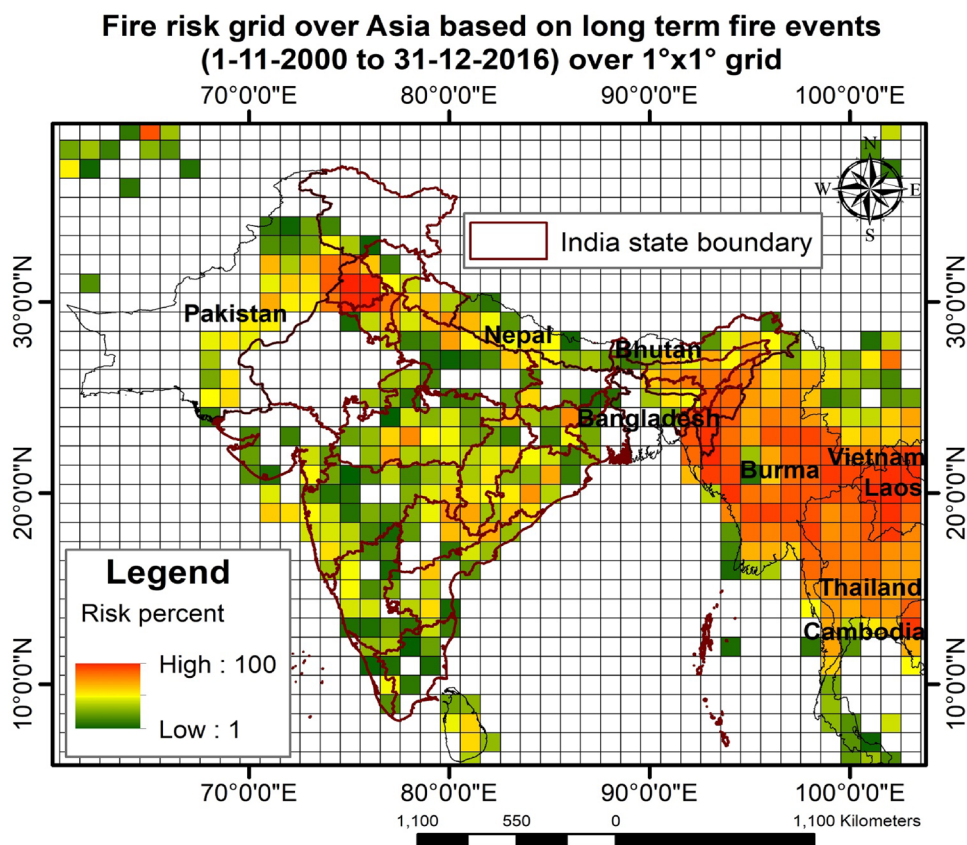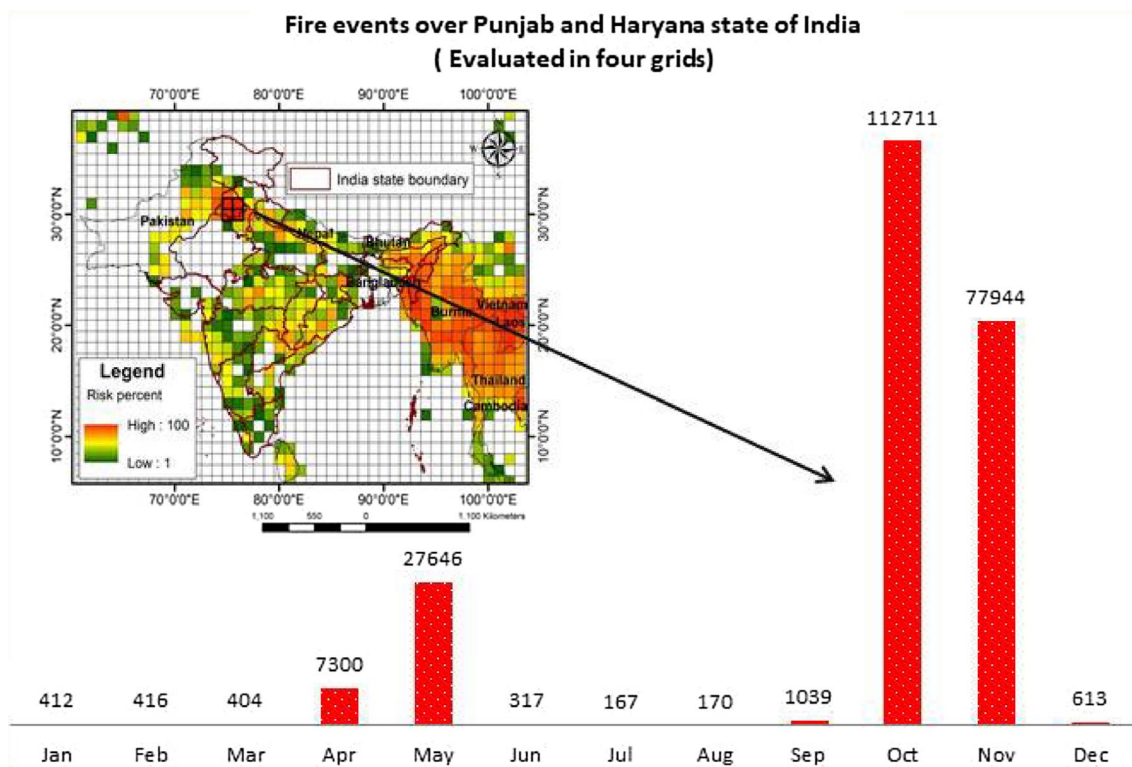
Fig. 2 Fire events month wise over Punjab and Haryana state of India

fertility through ash and to promote planting of new crops (Gadde et al. 2009; Taylor 2010; Vadrevu et al. 2011; Kharol et al. 2012; Sahu and Sheel 2014).

We have also analyzed the fire events month wise over the part of Chhattisgarh, Telangana, Maharashtra and Odisha state of India (2nd four grids) to understand the fire trend (Fig. 3).

The total number of fires in the four grids was 29,834 over span of 16 years. 82% of total fire is consolidated in this region over the month of February, March and April. We have also partially validated the existing MODIS fire points with Forest survey of India (FSI) downloaded fire points and found large agreement with our existing result within the forest. We have analyzed the fire events over these four grids based on vegetation cover derived from VEGA 2000 dataset. The result shows that 67% of the fire events occurred in two classes "Tropical mixed deciduous and dry deciduous forests" (54.7%) and "deciduous thorny scrubland" (12.3%). The 23% of the fire events occupied by class "Cropland, irrigated, inundated or flooded". These forest areas face tremendous pressure due to fires during summer season mostly due to severity of the climate. Similar finding has been observed by Ahmad et al. (2017, 2018).

We have analyzed the fire events month wise over eastern part of the Burma because it falls in potentially high fire risk area (3rd four grids) to understand the fire trend (Fig. 4).

The total number of fires in the four grids was 108,347 over span of 16 years. 98% of total fire is consolidated in this region over the month of February, March and April. The accidental and intentional land-use fires are very frequent in Southeast Asian countries (such as India, Burma, Bangladesh and Thailand) during the summer season (https://earthobservatory.nasa.gov/NaturalHazards/view.php?id=18070).

We have evaluated the vegetation in these four grids based on the vegetation cover map and also compared with forest fire events over the same area. The results show that the class "Tropical mixed deciduous and dry deciduous forests" occupy 38% of area and retain 42% of forest fire events. Similarly the class "Evergreen shrubland and regrowth/Abandoned shifting cultivation/ Extensive shifting cultivation" have 20% area and contain 28% of fire events, the class "Deciduous shrubland/Mosiacs of deciduous shrub cover and cropping" occupy 15% area and retain only 1.5% of forest events, the class "Forest Mosaics and degraded/ fragmented forests" have 12% of area and sustain 13% of fire events and finally "Mosiac of cropping, regrowth or other natural vegetation/Intensive Shifting cultivation" occupy 8% of area and have consist 13% of fire events. From this result we can conclude that in Burma deciduous forest are prone to fire which retain the highest fire frequency whereas the practice of shifting cultivation in this region is also a major contributor that leads to the fire events. The conflicts
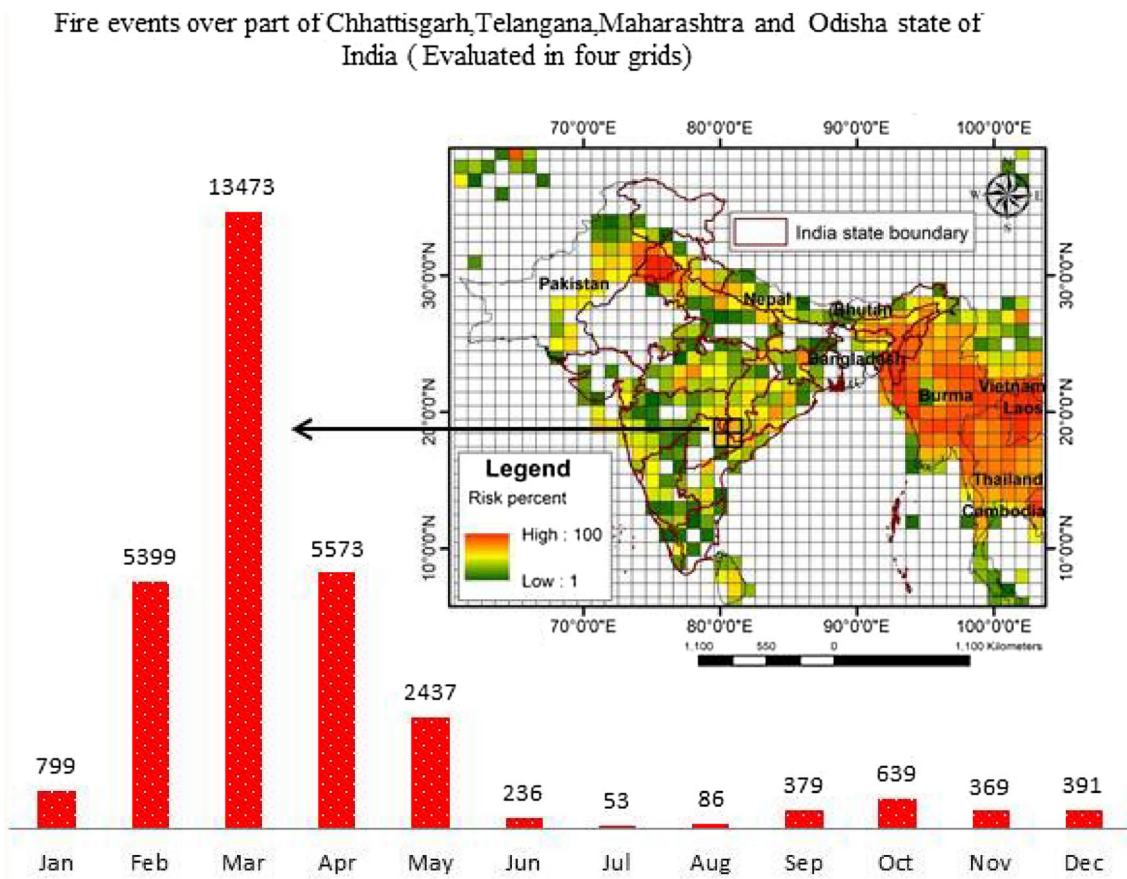
Fig. 3 Fire events month wise over part of Chhattisgarh, Telangana, Maharashtra and Odisha state of India
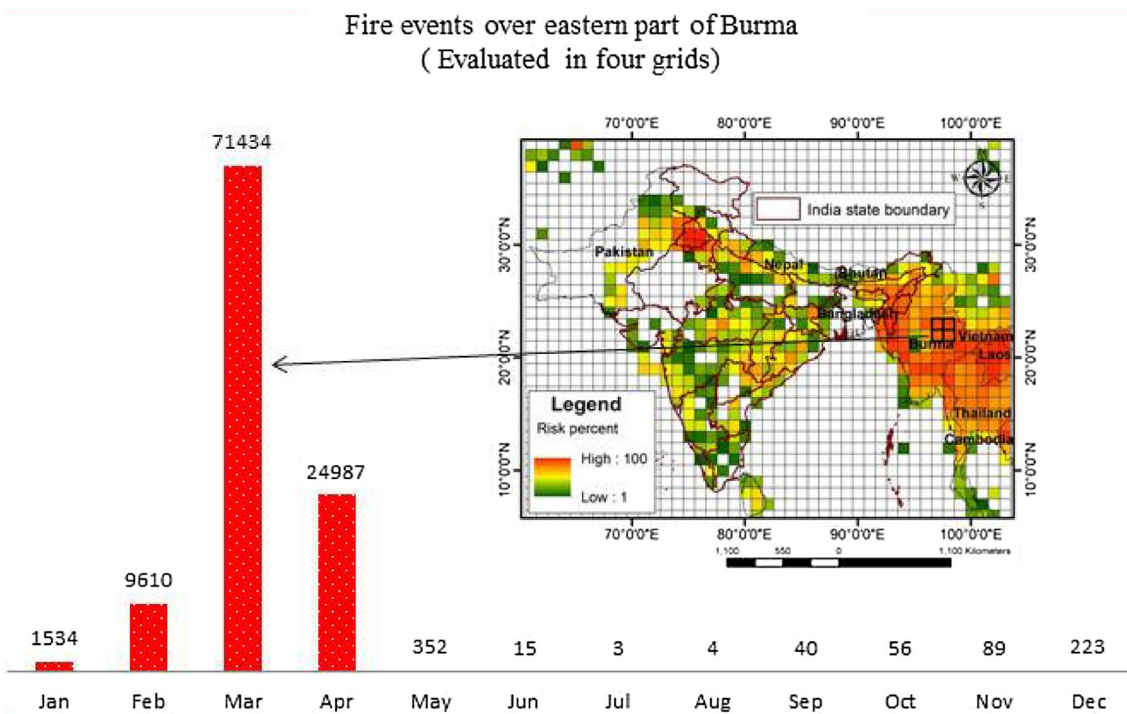

Fig. 4 Fire events month wise over Burma

between government and ethnic armed groups is also one of the reason in reducing/ mitigating the practice of shifting cultivation in Burma (Heinimann et al. 2017).

Fire events analysis over the various vegetation types

In this study we have evaluated fire events in each vegetation types (Fig. 5). The area and fire percent of various vegetation types over the part of Asian region are given in the Fig. 6 for general understanding and discussion. The two vegetation type classes where the Shifting cultivation is widely practiced are "Evergreen shrubland and regrowth/Abandoned shifting cultivation/ Extensive shifting cultivation" and "Mosiac of cropping, regrowth or other natural vegetation/ Intensive Shifting cultivation" occupy the geographical area roughly 8% whereas they retain fire percent equivalent to 30% which is a serious concern for Asian countries policy makers. Similarly the class "Tropical mixed deciduous and dry deciduous forests" as well as "Deciduous shrubland/ Mosiacs of deciduous shrubcover and cropping" occupies 13.5% of geographical area mostly dominated by Sal (*Shorea robusta*) with Mahua (*Madhuca longifolia*), Bidi leaf (*Diospyros melonoxylon*) tree species retain fire percent equivalent to 25%. The vegetation type "Cropland, irrigated, inundated or flooded" however occupy 35% geographical area mostly dominated in plain with high soil fertility status widely practiced for growing agriculture crop (paddy, wheat and pulse etc.) exhibit 20.5% fire events mostly due to agriculture residues burning by farmers. Similar observations have been analyzed by Vijayakumar et al. (2016), Rajput et al. (2013) and Sharma et al. (2011).

Fire events analysis over the country boundary

We have also analyzed the fire events based on Asian countries political boundary that including India, Pakistan, Bangladesh, Bhutan, Nepal, Srilanka, Burma and Thailand for general fire scenario and better understanding (Fig. 7). Burma and Thailand shows high fire events when compared with their geographical area. Burma fire events per unit geographical area were found roughly 3.5 times higher when compared with India. In Burma the practice of shifting cultivation is common (Heinimann et al. 2017) whereas the existing Forest Law 1992 (http://www.forestlegality.org/risk-tool/country/myanmar) which describes for prevention and control of fire was never strictly implemented due to political instability.

Climate and fire events data evaluation

The present comprehension of climate and fire interactions/ relationship is limited (Alonso-Canas and Chuvieco 2015).

There is also increasing research manifestation on their mutual impact (Kloster et al. 2012; Pechony and Shindell 2010) on ecosystem.

Here we have utilized the climate data over the part of Asian region during the fire season. The six months climate data (maximum temperature, precipitation and solar radiation) monthly average from February to July were used and brought in ArcGIS software for producing maps (Figs. 8, 9, 10) and further analysis was carried out. The average maximum temperature (°C) was found in the range of (− 44.7 to 34.3), (− 43.5 to 37.4), (− 40.5 to 40.8), (− 33.6 to 44.6), (− 25.1 to 46.3) and (− 17.7 to 47.9) in the month of February, March, April, May, June and July respectively. The high maximum temperature was found in the plains of all central part of Asia from February to April. The maximum temperature gradually shows the shifting towards North West part of the study area from May onwards because of weather phenomenon built-up in Bay of Bengal which leads to rainfall and moves towards north western part. The negative values of maximum temperature are found over very high altitude of northern Himalaya mostly shown in green color in Fig. 8.

Similarly, the average of highest precipitation (mm) over the part of Asian region was found to be 212, 315, 634, 910, 1827 and 2982 in the month of February, March, April, May, June and July respectively. The precipitation was concentrated in the hills of all Himalayan regions from February to April over the north and north western part. The north eastern region and Kerala state of India, Bangladesh, Burma and Thailand starts receiving adequate precipitation in the month of May (Fig. 9). The precipitation moves further towards North West part of Asia from May onwards. Some central-eastern part of India also, receives pre monsoon rain during this month. Most parts of the Asian countries receive good precipitation except Pakistan and southern and western parts of India such as in the states of Rajasthan and Tamil Nadu.

The solar radiation shows very interesting pattern in month of February, March and April which exhibit high concentration in the central and southern part of India, south eastern part of Pakistan, southern part of Burma and western part of Thailand (Fig. 10). In the month of April, high concentration is visible only in the central part of India and south eastern part of Pakistan. The high concentration in the month of June and July move further towards north eastern part of Asia over Pakistan and western parts of India.

Statistical analysis and evaluation

In this study, we have generated the statistics and evaluated month wise (from February to July) in grids (Fig. 3) over a part of the Asian region (central part of India) mostly dominated by deciduous forest is given in Table 1. The average month wise (from February to July) mean maximum temperature (°C), precipitation (mm) and solar radiation (KJ/m²/
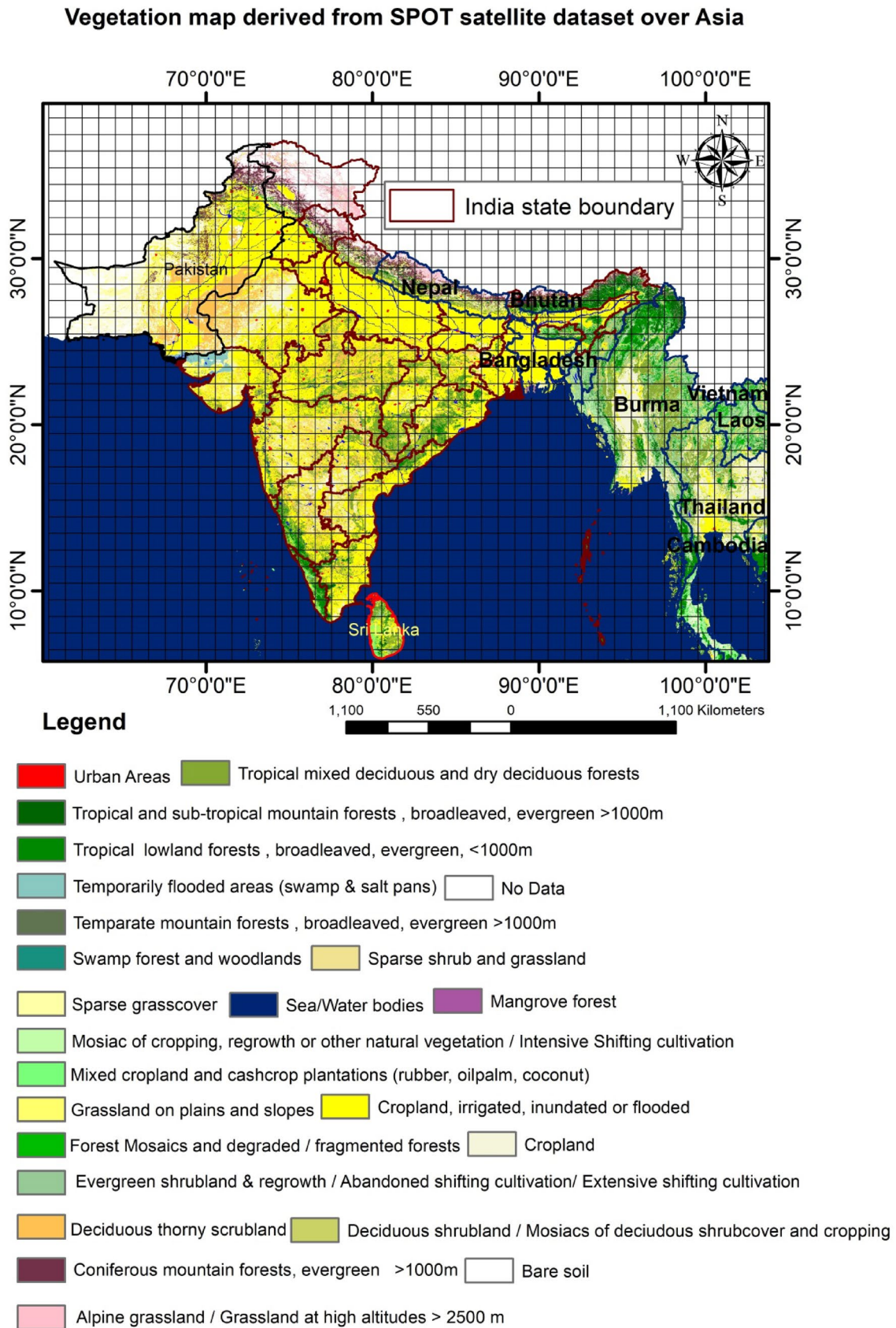
Vegetation map derived from SPOT satellite dataset over Asia

Legend

- Urban Areas
- Tropical mixed deciduous and dry deciduous forests
- Tropical and sub-tropical mountain forests , broadleaved, evergreen >1000m
- Tropical lowland forests , broadleaved, evergreen, <1000m
- Temporarily flooded areas (swamp & salt pans)
- No Data
- Temparate mountain forests , broadleaved, evergreen >1000m
- Swamp forest and woodlands
- Sparse shrub and grassland
- Sparse grasscover
- Sea/Water bodies
- Mangrove forest
- Mosiac of cropping, regrowth or other natural vegetation / Intensive Shifting cultivation
- Mixed cropland and cashcrop plantations (rubber, oilpalm, coconut)
- Grassland on plains and slopes
- Cropland, irrigated, inundated or flooded
- Forest Mosaics and degraded / fragmented forests
- Cropland
- Evergreen shrubland & regrowth / Abandoned shifting cultivation/ Extensive shifting cultivation
- Deciduous thorny scrubland
- Deciduous shrubland / Mosiacs of deciudous shrubcover and cropping
- Coniferous mountain forests, evergreen >1000m
- Bare soil
- Alpine grassland / Grassland at high altitudes > 2500 m

Fig. 5 Vegetation map over part of Asian region

Fig. 6 Vegetation types showing area and forest fire percent over the part of Asian region
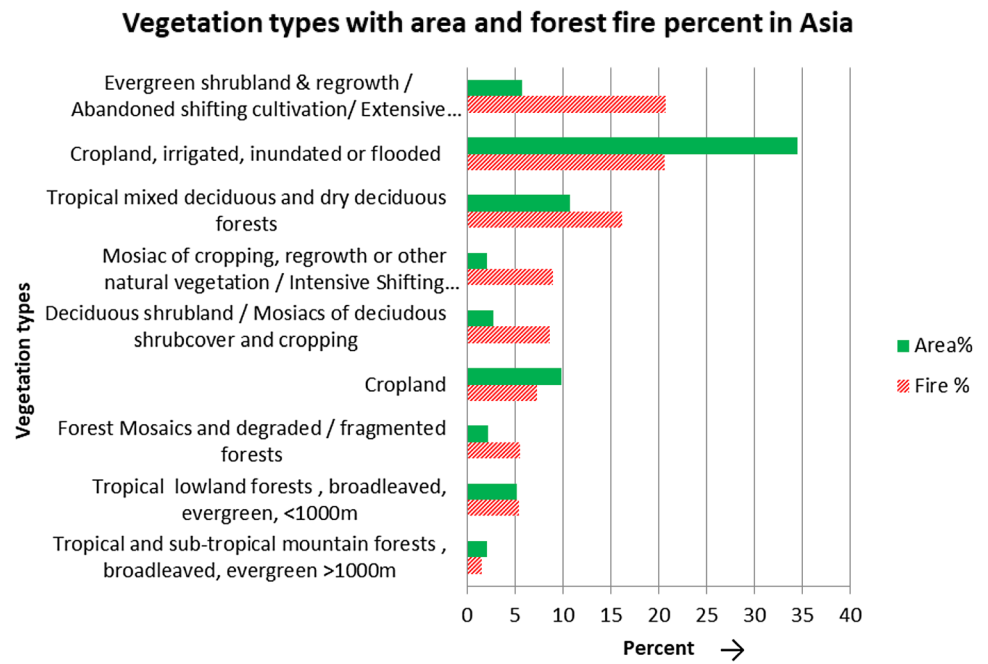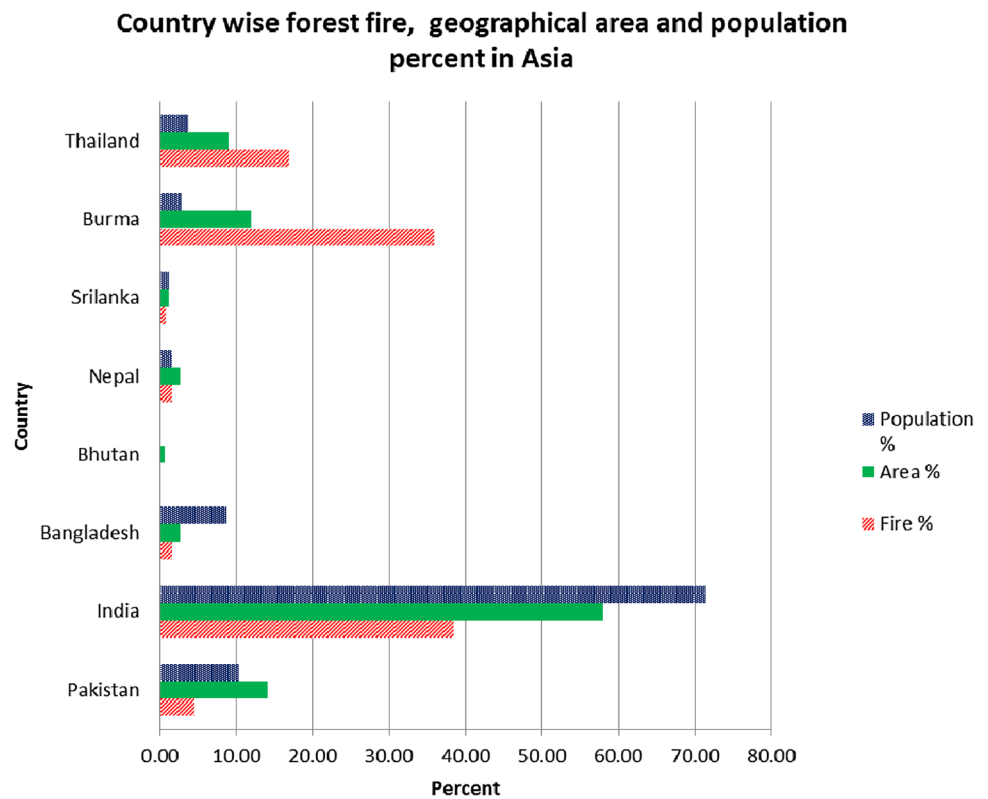

Fig. 7 Country wise forest fire percent over the part of Asian region

day) were found in the range of (30.1–39), (5.5–361.7) and (20,837.7–25,292) respectively. The maximum temperature shows continuously increasing trend from February to May whereas it decreases afterwards up to the month of July. The increase of maximum temperature in month March was found equivalent to 3.8 °C with preceding month (February) was highest among all months (Table 2). The precipitation from February to May is below 28.3 mm whereas these areas receive good rainfall in the month of June equivalent to 165.4 mm due to pre monsoon shower whereas these
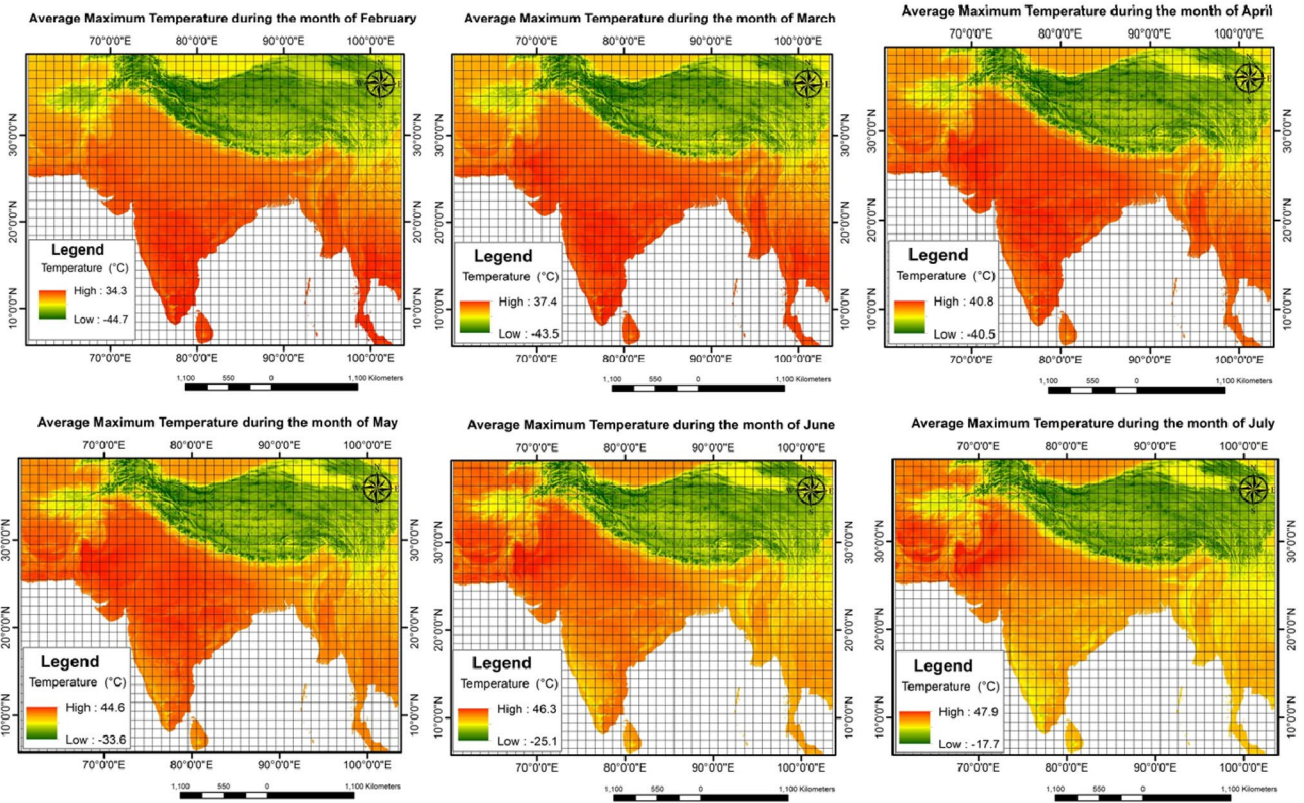
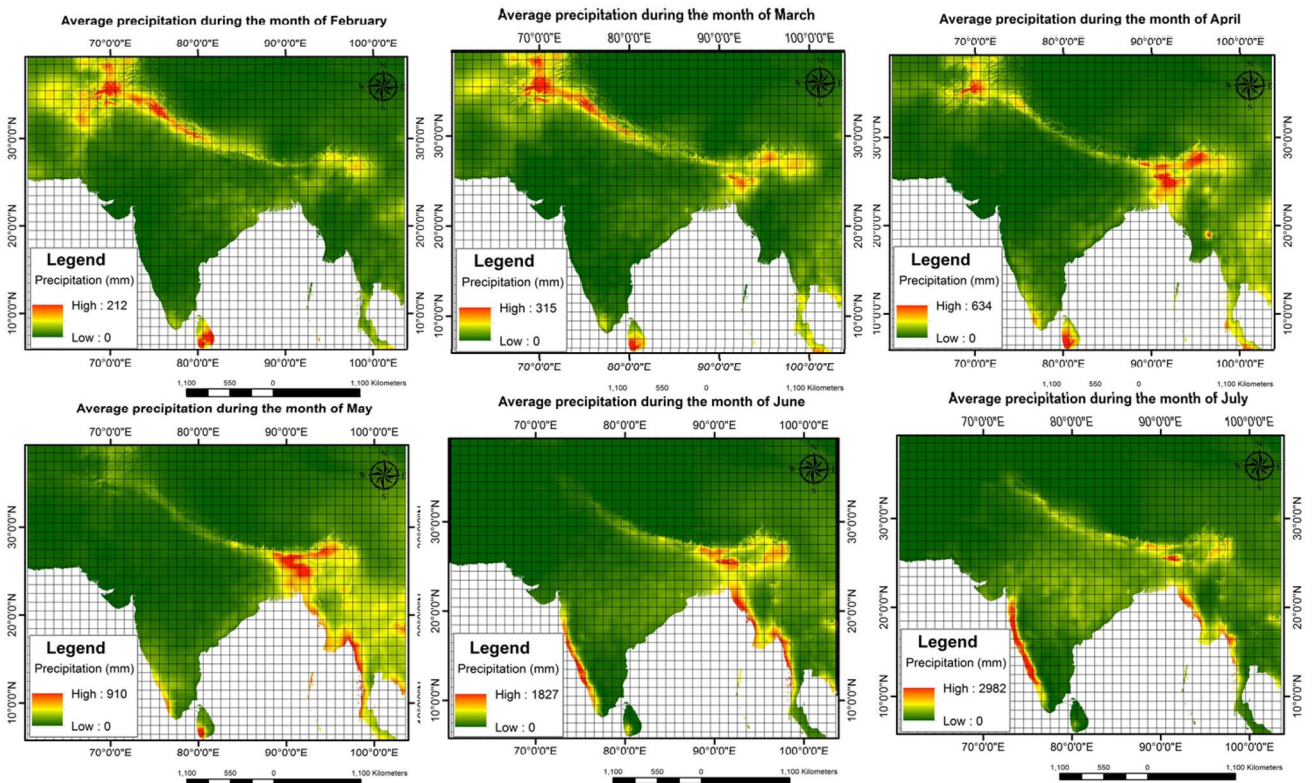**Fig. 8** Month wise average Maximum Temperature from February to July

Fig. 9 Month wise average precipitation from February to July
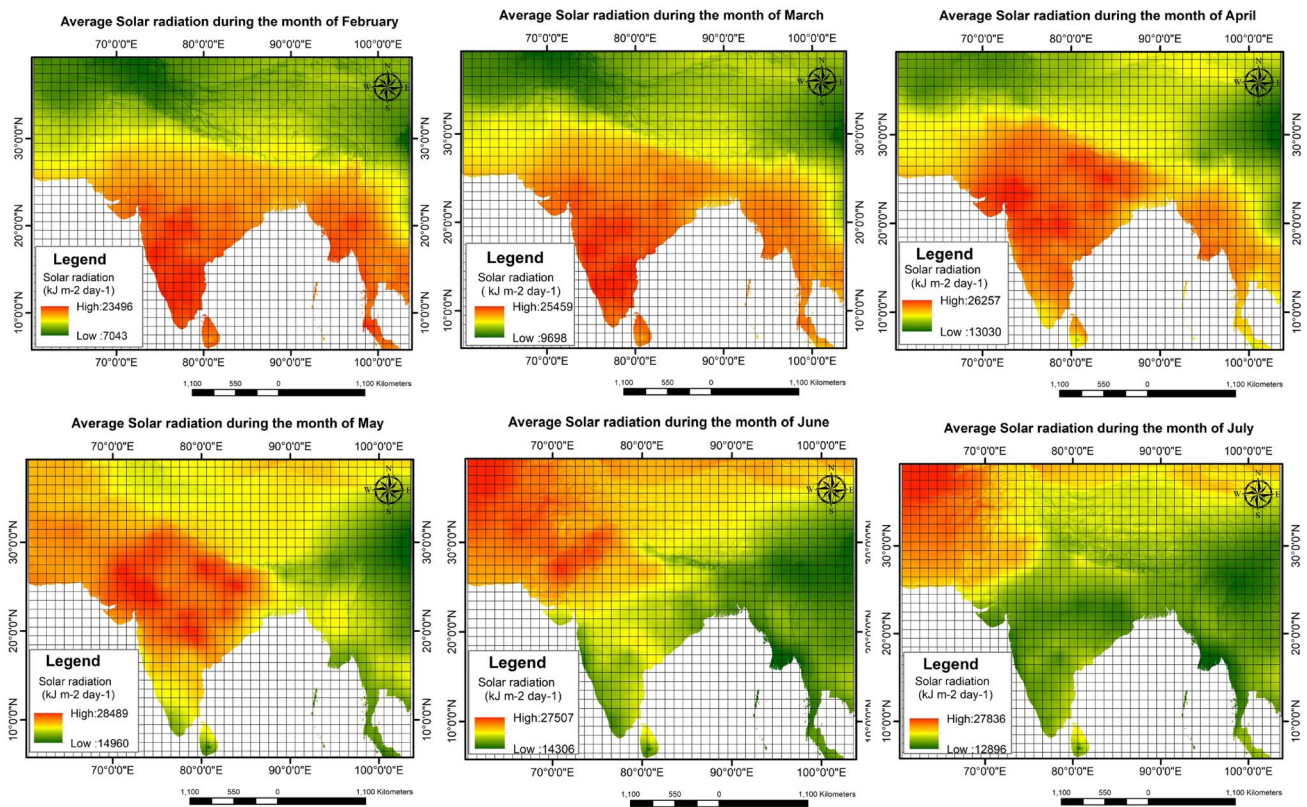
Fig. 10 Month wise average solar radiation from February to July

Table 1 Various data and their sources used in this study

Data used	Source/references
MODIS data based fire counts with spatial resolution one km from the year 1-11-2000 to 31-12-2016	https://firms.modaps.eosdis.nasa.gov
SPOT4 satellite based vegetation cover (VEGA 2000 dataset) with spatial resolution 1 km	http://forobs.jrc.ec.europa.eu/products/glc2000/products.php (Roy et al. 2003)
Climate data (maximum temperature, precipitation and solar radiation) average of 31 years (1970–2000) with spatial resolution 1 km	WorldClim-Global Climate Data website (http://worldclim.org/version2)
Future (2030) climate change temperature and precipitation anomalies data (RCP-4.5) in the form of grid with spacing at 1.25°	NCAR GIS Program. 2012

areas receive adequate rainfall in month of July equivalent to 361.7 mm. The solar radiation shows continuously increasing trend from February to May whereas it shows a decreasing trend afterwards. Crammer's V coefficient based analysis was performed to find out the relationship between mean maximum temperature, precipitation and solar radiation with forest fire frequency. Here CVC value of solar radiation, maximum temperature and precipitation are in increasing order and in the range of 0.31–0.77 given in the Table 3. Wang et al. (2016) also advocated that the value greater than 0.3 of CVC shows strong relationships with driving factor for their study. The result of CVC value of precipitation was

found highest which shows that it has a very strong association/relationship with fire events whereas mean maximum temperature and solar radiation occupy 2nd and 3rd position respectively. Similar finding has been manifested by Ahmad et al. (2017, 2018) in their study.

Climate change anomalies and forest fire events characterization

Increase in human population and their activities have altered the Earth's climate at both global and regional scales. In recent years the potential impacts of climatic change and

Table 2 Fire events and climatic parameter statistics month wise from February to June

	Fire events	Statistics	Maximum Temperature (°C)	Precipitation (mm)	Solar radiation (KJ/m²/day)
February	5399	Range	23.1–32.2	3–11	19,897–21,583
		Mean	30.1	5.5	20837.7
		SD	1.4	1.4	210.3
March	13,473	Range	26.7–35.9	6–26	22,680–24,366
		Mean	33.9	13.4	23565.1
		SD	1.3	5.7	200.1
April	5573	Range	29.4–39.5	11–48	23,838–25,581
		Mean	37.1	25.2	24547.8
		SD	1.3	6.8	307.5
May	2437	Range	30–41.9	10–62	24,206–26,906
		Mean	39.1	28.3	25,292
		SD	1.7	8.9	629.8
June	236	Range	27.3–38.8	122–200	20,083–21,833
		Mean	36	165.4	21035.1
		SD	1.6	15.4	260.9
July	53	Range	26.3–26.3	209–541	16,630–18,628
		Mean	33.2	361.7	17448.7
		SD	1.4	76.2	365.4

Table 3 Crammer's V coefficient (CVC) values of forest fire driving factors

Meteorological variable (driving factors)	Forest fire frequency Crammer's V coefficient (CVC)
Maximum temperature	0.36
Solar radiation	0.31
Rainfall	0.77

variability have received a lot of attention from the researchers. Climate is an important driver which decides the fire intensity, extent and behavior (Flannigan et al. 2000; Fried et al. 2004) whereas climate change is a predominant factor attributing to forest fire events (Stephens 2005; Westerling et al. 2006). Studies by Pinol et al. (1998), Tian et al. (2012) and Wotton et al. (2010) suggested that the forest fire events will increase in future due to climate change in Europe, China and Canada respectively. A recent study by Ahmad et al. (2017, 2018) in the states of Jharkhand and Arunachal Pradesh respectively reveals the weather and climate parameter has strong association with forest fire events. A study conducted by NASA reveals that the global temperature increases by approximately 1 °C in the year 2016 whereas it shows the continuous increasing trend after year 1978 (https://climate.nasa.gov). Temperature also acts as significant factor in maneuvering the climate and leads to influence the forest fire regime in many ways (Wells et al. 2004). "A warmer world will have drier fuels meaning it's easier for fires to start and spread" said Mike Flannigan, Director of

the Western Partnership for Wildland Fire Science at the University of Alberta in Canada. A warmer climate leads to higher rates of evaporation. These processes, in association with a shifting pattern of precipitation, will affect the spatial and temporal distribution of soil moisture, relative humidity and increase the frequency of droughts. Drought severity plays a major role in wildfire frequency and extent of damage (Wells et al. 2004). Furthermore, drought will lead to severity of weather during forest fire season (Flannigan et al. 2005) will increase the forest fire burnt area. The future climate change, though, will have its impact globally and will be felt severely in developing countries in the Asian region. Weather events associated with El-Nino were reported in Asian region to be more frequent and severe in the past 20 years (Aldhous 2004). Furthermore, longer heat wave duration has been noticed in many countries of Asia, as indicated by strong warming trends and several cases of intense heatwaves (Lal 2003; Zhai and Pan 2003). Study conducted by Vorobyov (2004) on the impacts of climate change on fires show that for an average temperature increase of 1 °C, the duration of wild fire season increase by 30% in North Asia.

We have produced maps of the annual temperature and precipitation anomalies using the RCP 4.5 simulation model (Clarke et al. 2007; Moss et al. 2008) for the year 2030 (Figs. 11, 12) respectively. The temperature increase in the year 2030 was observed over the whole of Asia with the range of 0.58–1.32 °C. The maximum temperature increase was witnessed in India especially in northern and north eastern part of India whereas medium increase was observed

Fig. 11 Temperature anomalies

Prediction of temperature anomalies for the year 2030
(RCP- 4.5 scenario)
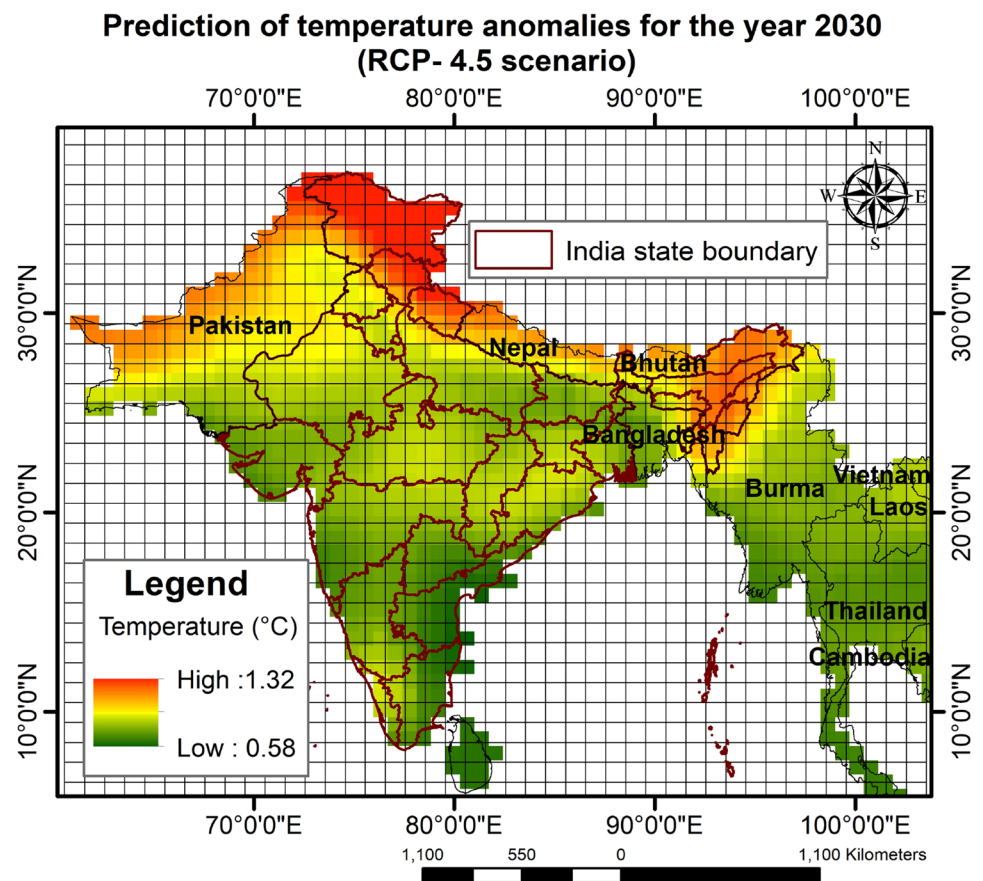
in north western part of Pakistan and central part of India. Similarly rainfall variation as a deficit in the year 2030 was observed largely in India (north western part, north eastern part and coastal part of Orissa and Kerala state). The precipitation anomalies range over the Asia was found from − (decrease) 44.2 to + (increase) 119.1 millimeter. The severity of temperature and deficit in precipitation in these areas will certainly adversely affect the forest due to forest fire severity especially the Himalayan flora and its biodiversity in future. Finally based on the climate data prediction map for the year 2030 we can conclude the climate change impact should be significant over Asia whereas it more crucial for India.

Sinha Ray and De (2003)'s study in India on climate change reveals that there will be occurrence of extreme events in the future. Lal et al. (1995) study analyzed and predicted the increase in temperature for the year 2040. Study revealed an increase of 0.7–1.0 °C annual mean maximum and minimum surface air temperatures in comparison to the 1980s. Some studies also suggest that the frequent intense rainfall pattern such as number of rainy days and annual precipitation in Asia have decreased (Lal 2003; Goswami et al. 2006; Dash et al. 2007). This will lead to increase in forest fire events in Asia in future is a major policy concern towards its prevention and control.

The study conducted by Jhajharia et al. (2009) in the North East region of India suggest that two parameters, viz. sunshine duration (solar radiation) and wind speed, strongly influenced leads to changes in evaporation at various sites. A study in the North East region of India reveals all four temperature variables viz. maximum, minimum, and mean temperatures and temperature range had rising trend (Jain et al. 2012) will further enhance fire frequency and occurrence in this forest fire hotspot area. Dry deciduous forests of India are more vulnerable to forest fire (FAO 2001).The area of central part of India largely occupied by deciduous trees and seems to be forest fire hotspot during the summer season is also experienced decreasing trends of rainfall and in number of rainy days (Kumar and Jain 2010) is a major future challenge. A study conducted by Chaturvedi et al. (2011) on impact of climate change over India based on assessment on climate projections of the Regional Climate Model of the Hadley Centre (HadRM3) and the dynamic global vegetation model IBIS for A2 and B2 scenarios reveals that many forest dominant states of central part of India are projected to undergo change up to 73%, 67% and 62% of forested grids respectively.

Fig. 12 Precipitation anomalies

Prediction of precipitation anomalies for the year 2030
(RCP- 4.5 scenario)
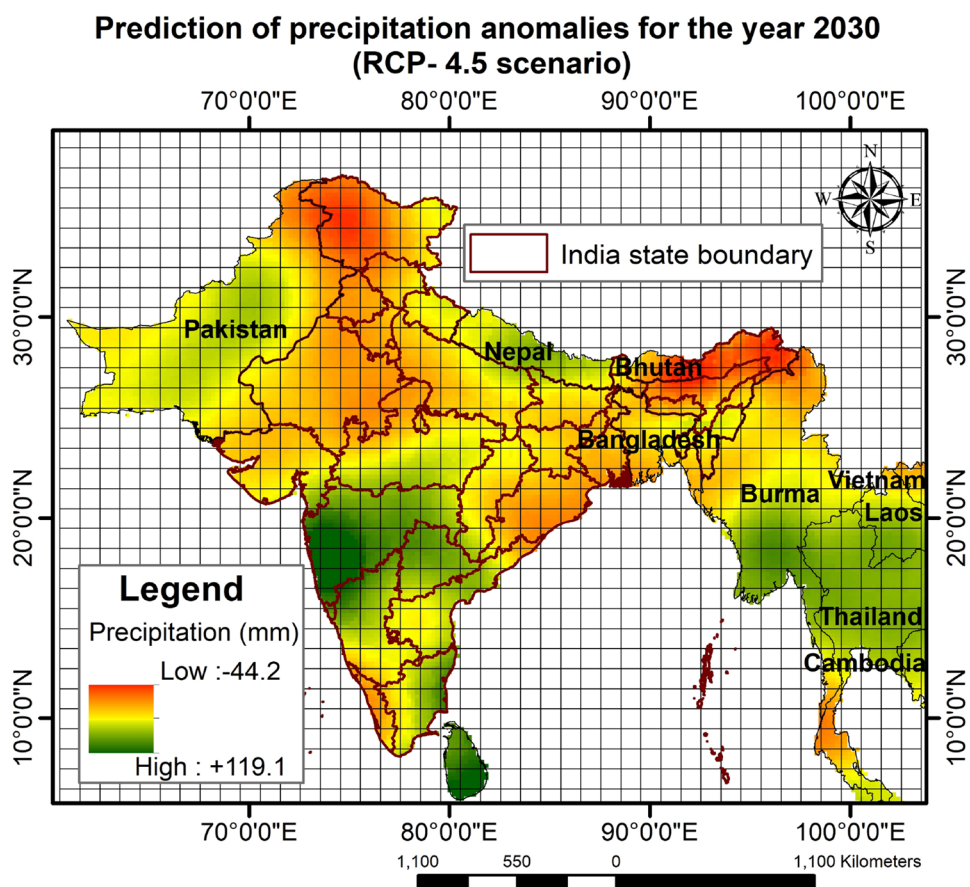
Conclusion

The above study exhibited the capability of geospatial technology in assessing the long term fire counts with the grid spacing of $1° \times 1°$ over the part of Asian region and evaluated their pattern and relationship along with vegetation types, country boundary and climate datasets in GIS domain.

The highlight of the research showed that over the first window (four grids) in the month of October and November the notably high fire events were observed in the states of Punjab and Haryana of India. Similarly in the second window (four grids) the vegetation type most affected is "Tropical mixed deciduous and dry deciduous forests" as this is more prone to fire due to adverse climate condition. The overall evaluation of forest fire events over the study area with respect to various vegetation types reflected a significant high forest fire event in the categories representing shifting cultivation. Countries like Burma and Thailand exhibited high fire events in comparison to their geographical areas. Statistical analysis revealed significant relationship between fire and climate parameters of which rainfall shows the highest correlation. The major factor found responsible for fire events were the practice of shifting cultivation, residue burning and extreme weather/climate events. Adequate policies and law are required to regulate these activities. There is a need of weather forecasting stations and fire alarm system in each country of the Asian region especially during the summer season which would help in taking adequate preventive measures in the forest to control the extent of damage from fire. Educating and involving the local/tribal/inhabitants about fire, its damage and about the protection would enable them to safeguard the forest more meaningfully.

More studies are required to address the issue of climate change anomalies and forest fire events characterization which is a potential research gap in the Asian region. Long term strategies should be formulated to reduce the climate change impact on forests.

Compliance with ethical standards

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