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Evaluation of long term forest fires in India with respect to state administrative boundary, forest category of LULC and future climate change scenario: A Geospatial Perspective

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Abstract. Analysing the forest fires events in climate change scenario is essential for protecting the forest from further degradation. Geospatial technology is one of the advanced tools that has enormous capacity to evaluate the number of data sets simultaneously and to analyse the hidden relationships and trends. This study has evaluated the long term forest fire events with respect to India's state boundary, its seasonal monthly trend, all forest categories of LULC and future climate anomalies datasets over the Indian region. Furthermore, the spatial analysis revealed the trend and their relationship.

The state wise evaluation of forest fire events reflects that the state of Mizoram has the highest forest fire frequency percentage (11.33%) followed by Chhattisgarh (9.39%), Orissa (9.18%), Madhya Pradesh (8.56%), Assam (8.45%), Maharashtra (7.35%), Manipur (6.94%), Andhra Pradesh (5.49%), Meghalaya (4.86%) and Telangana (4.23%) when compared to the total country's forest fire counts. The various LULC categories which represent the forest show some notable forest fire trends. The category 'Deciduous Broadleaf Forest' retain the highest fire frequency equivalent to 38.1% followed by 'Mixed Forest' (25.6%), 'Evergreen Broadleaf Forest' (16.5%), 'Deciduous Needle leaf Forest' (11.5%), 'Shrub land' (5.5%), 'Evergreen Needle leaf Forest' (1.5%) and 'Plantations' (1.2%). Monthly seasonal variation of forest fire events reveal the highest forest fire frequency percentage in the month of 'March' (55.4%) followed by 'April' (28.2%), 'February' (8.1%), 'May' (6.7%), 'June' (0.9%) and 'January' (0.7%). The evaluation of future climate data for the year 2030 shows significant increase in forest fire seasonal temperature and abrupt annual rainfall pattern; therefore, future forest fires will be more intensified in large parts of India, whereas it will be more crucial for some of the states such as Orissa, Chhattisgarh, Mizoram, Assam and in the lower Sivalik range of Himalaya. The deciduous forests will further degrade in future.

The highlight/results of this study have very high importance because such spatial relationship among the various datasets is analysed at the country level in view of the future climate scenario. Such analysis gives insight to the policymakers to make sustainable future plans for prioritization of the various state forests suffering from forest fire keeping in mind the future climate change scenario.

Keywords: Forest fire, LULC, RCP-6, climate anomalies, geospatial technology, India

1. Introduction

The advancement and continuous improvement in Remote sensing satellites with refinement in sensors technology and online free dataset in recent years have become a boon for the researchers/scientist around the globe. They can be adequately utilized to monitor the fire patterns (Dwyer et al. 2000; Ager et al. 2017; Ahmad, Goparaju 2017b) and enhance our comprehension of land-use/land-cover change (Eva, Lambin 2000) and fire risk assessment (Chuvieco, Congalton 1989). Satellite fire data monitoring have the clear advantage over the traditional fire records due to its reliability, cost effectiveness, fast evaluation process and significant accuracy (Csiszar et al. 2005).

Fire regimes are significant contributors in many ecosystems (Gill 1975; Bond, Keeley 2005; Bowman et al. 2009) leading to change in spatial and temporal pattern (Goldammer, Price 1998; Pew, Larsen 2001; Fearnside 2005). Land Use/Land Cover (LULC) and its various forest categories play an important role on fire risk (Cumming 2001; Nunes et al. 2005; Bajocco, Ricotta 2008; Carmo et al. 2011), as its various categories vary significantly in terms of fuel load

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and inherent moisture content or horizontal and vertical fuel continuity (Saura-Mas et al. 2010). Thus, analysing the Land Use/Land Cover and its trend of change of various classes gives better comprehension and it is well recognized in the scientific/research community, which support the decision makers in improving management and resource allocation (Townshend et al. 2012; Vogelmann et al. 2012; Niraula et al. 2013).

Climate change impact the local weather events, which enhance the summer temperature and rainfall pattern significantly. Therefore, it is considered a vital parameter in manoeuvring the fire regimes (Harrison et al. 2010). Fire regime leads to change in distribution, structure, composition and ecology of forests (Kirschbaum et al. 1996). The seasonal monthly variation of weather condition and its severity determines the necessary phenomenon to start fire and to spread it by making fuel available to the forest floor with the percent of moisture content (Swetnam, Betancourt 1998; Littell et al. 2009).

In India, rainfall, temperature and its spatial distribution pattern is an important factor for Indian economy and livelihood (Bothale, Katpatal 2014) and controls the distributions of plant species and vegetation (Sykes 2009). Extreme natural calamities such as droughts, forest fire, floods, heat waves and cyclones (Goswami et al. 2006) badly impact the poor people leading to food insecurity, loss of livelihood and poverty (Birthal et al. 2014). The future climate change will increase the severity of weather such as increase in summer temperature and evapotranspiration; reduction in soil moisture will impact the ecological process such seed germination, natural regeneration, plant growth and decomposition (Ravindranath, Sukumar 1998) and will increase the dying back phenomenon, which was observed significantly in sal (*Shorea robusta*) dominated deciduous forest (Maithani et al. 1986). The forest fires have been analysed using the geospatial technology at the country level in India (Vadrevu et al. 2008, 2013; Giriraj et al. 2010; Reddy et al. 2017); whereas, at state level (Ahmad, Goparaju 2017a), forest fires and the summer weather parameters have been evaluated in Jharkhand and Arunachal Pradesh by Ahmad et al. 2017 and Ahmad et al. 2018 respectively. The result shows their mutual association/relationship. In one of the recent studies conducted by Chakraborty et al. (2018) reveals a negative trend of forest seasonal greenness over the different forest types of India. The results highlight that negative changes were found to be the highest in the deciduous forest.

The objective of the present study is to evaluate the long term forest fire spatial patterns with respect to the Indian state boundary and fire season. Furthermore, it was evaluated with respect to a few categories of Land Use and Land Cover (LULC) classes, which represent the forest of India to understand their mutual relationship and trend. The future season temperature (from February to June) and annual precipitation prediction for the year 2030 were further analysed for better understanidng and knowledge of future forest fire scenarios.

2. Materials and Methods

2.1 The Study area

The study area was the country India, which retains 6º 44' N to 35º 30' N latitude and 68º 07' E to 97º 25' E longitude. The total forest cover in India is 21.34% of the total geographical area (FSI, 2015). Forests of the India are facing deterioration due to various reasons, one of them is forest fire. Most of the forest fires are anthropogenic in nature due to negligence. Most of the forest fire in the North Eastern states of India is due to the 'shifting cultivation' practices by the tribal ethnic groups (due to poor socio-economic condition) for the purpose of their livelihood. The forest fires in central part of India such as Chhattisgarh, Jharkhand, Orissa, Telangana, Andhra Pradesh, Madhya Pradesh and Maharashtra are due to the reason of negligence in the process of minor forest produce collection such as mahua (*Madhuca indica*) flower, sal (*Shorea robusta*) seed collection and tendu (*Diospyros melanoxylon*) leaves. Most of these activities are executed in the summer season from February onwards. Furthermore, a large part of India is occupied by deciduous forest, which shed their leaves just before the summer season (in the month of February) and the dead leaves and litter on forest floor increase the chance of fire due to the enhanced ground fuel load. The extreme weather events during the summer season are largely accountable for aggravating the forest fire frequency, intensity, size and pattern.

2.2 Data acquisition and processing

In the first step, we have downloaded the country as well as the state boundaries from DIVA GIS as vector file. We have used the long term forest fire data (1/1/2008 to 26/6/2016), which was downloaded from the Forest Survey of India (FSI) website. FSI has been evaluating the fire incidences (from the year 2005 onwards) regularly across the Indian boundary using inputs provided from MODIS satellite system by collaboration with NASA and Geography Department of University of Maryland (http://nidm.gov.in/pdf/pubs/forest%20fire.pdf). The MODIS based active forest fire points are masked by the latest forest cover boundary, which removes the non-forest fire points. The downloaded fire point data were in EXCEL file format, which was converted to a point shape file (Ahmad et al. 2017). In this study, we have produced the map showing the long-term forest fires points overlaid by the Indian state boundary (Figure 1) for further study.

In this study, we have utilized the Land Use and Land Cover (LULC) data (2005) having a 100-meter resolution for India (Roy et al. 2015). The LULC data were procured from the satellite Landsat 5 and Resourcesat having the sensor Enhanced Thematic Mapper Plus (ETM+) and Linear Imaging Self-Scanning Sensor (LISS)–III respectively. The data were classified according to the International Geosphere-

-Biosphere Programme (IGBP) classification legend. This whole programme was supported by the NASA and Landsat (USGS). The quality of classified images was evaluated based on 12,606 field verified points (Roy et al. 2012). Most of the LULC class categories exhibit accuracies more than 90%, whereas overall mapping accuracy and Kappa accuracy were 94.46% and 0.9445 respectively for the year 2005 LULC map (Roy et al. 2015). We have created the LULC map of India showing all Land use type, which is given in the Figure 2.

We have also downloaded the fire temperature and the rainfall anomalies (climate change scenario) data for the year 2030 over India using the RCP-6 scenario model (NCAR GIS Program. 2012). The climate change scenarios have been designed for the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report. The approach defines the Representative Concentration Pathways (RCP), which provide the concentrations of atmospheric greenhouse gas (GHG) and the trajectory that is taken over time to reach those concentrations (Inman 2011). The data downloaded was in point grid, where each grid point constitutes a one-dimensional latitude and longitude. In the CCSM4 model output, the longitudes are equally spaced at 1.25º, while the latitudes vary in spacing slightly around 0.94º (https://gisclimatechange.ucar.edu/gis-data-ar5). The temperature and rainfall surface were produced from the point vector file using the kriging interpolation technique. The produced temperature anomalies map showing the prediction for the year 2030 in the month of February, March, April, May and June are given in Figure 3, Figure 4, Figure 5, Figure 6 and Figure 7, respectively. Similarly, the Figure 8 shows the annual precipitation anomalies for the year 2030. These maps were further evaluated to understand the future forest fire scenario.

We have used the Erdas Imagine and ARC/GIS Software adequately to execute and analyse the data for achieving overall objectives.

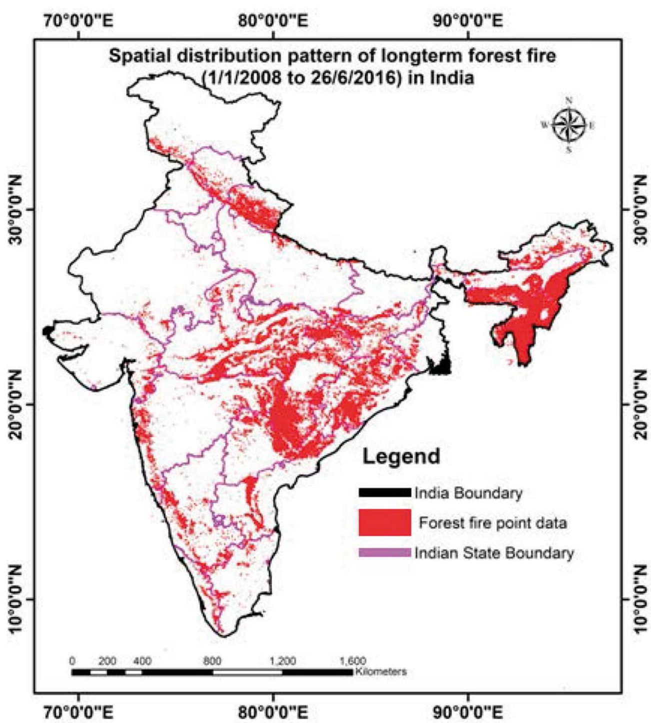

Figure 1. Long-term forest fires events in India

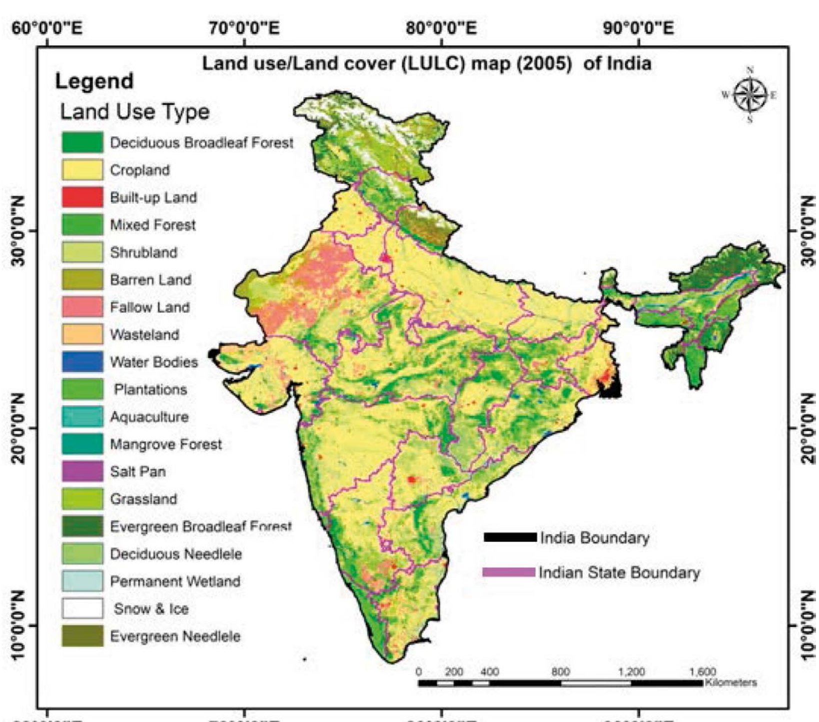

Figure 2. Land Use and Land Cover (LULC) map of India for the year 2005

Note: The Figure 2 in the full color version has been placed in the electronic version of the article. (Article available online: www.lesne-prace-badawcze.pl)

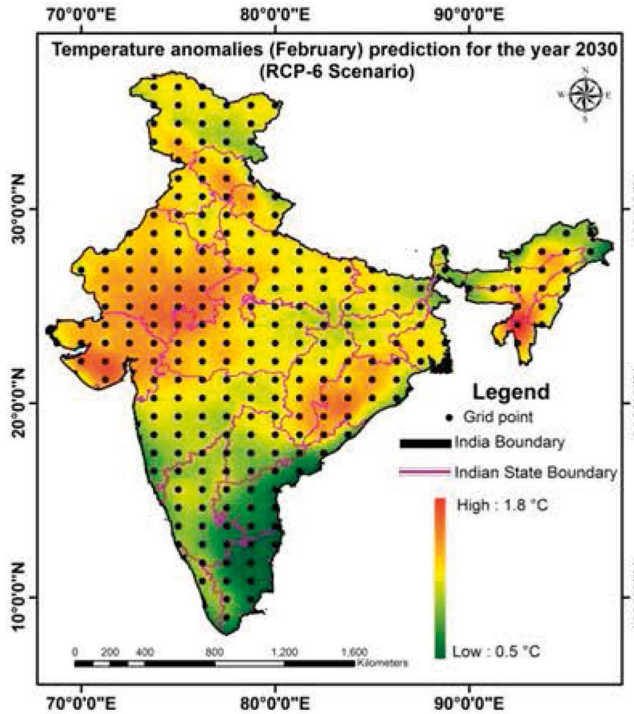

Figure 3. Temperature anomaly (February)

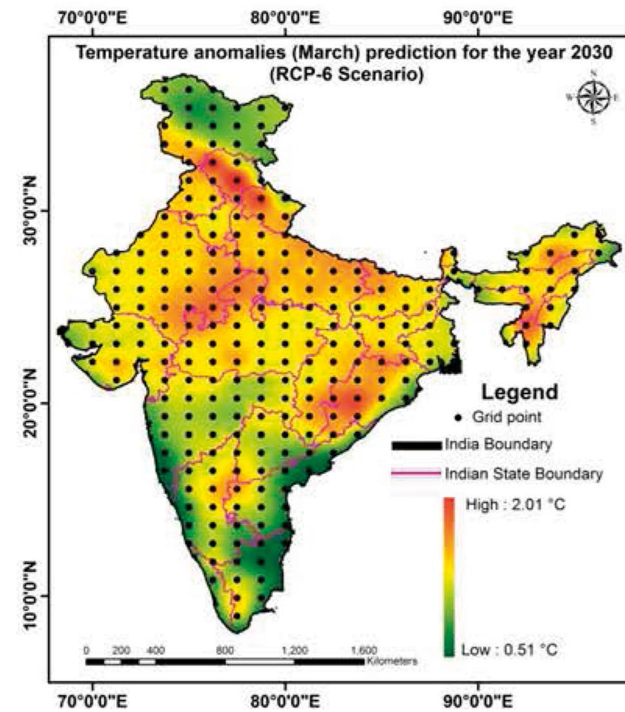

Figure 4. Temperature anomaly (March)

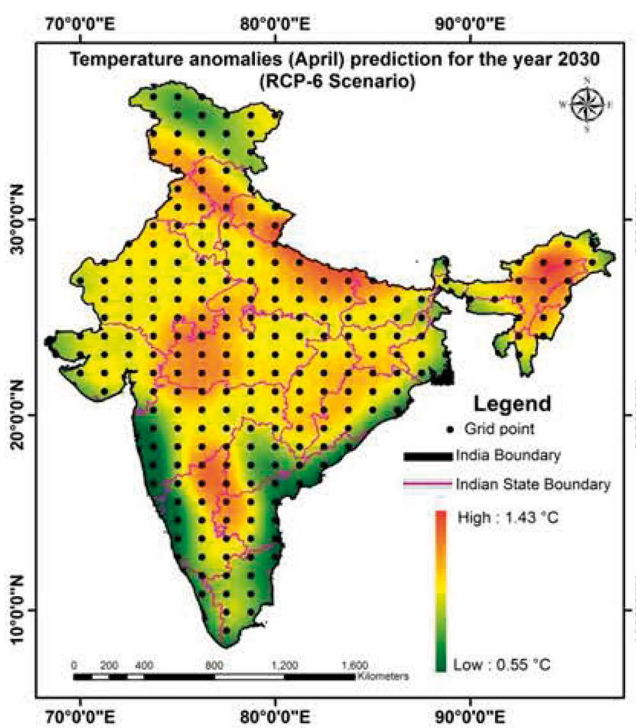

Figure 5. Temperature anomaly (April)

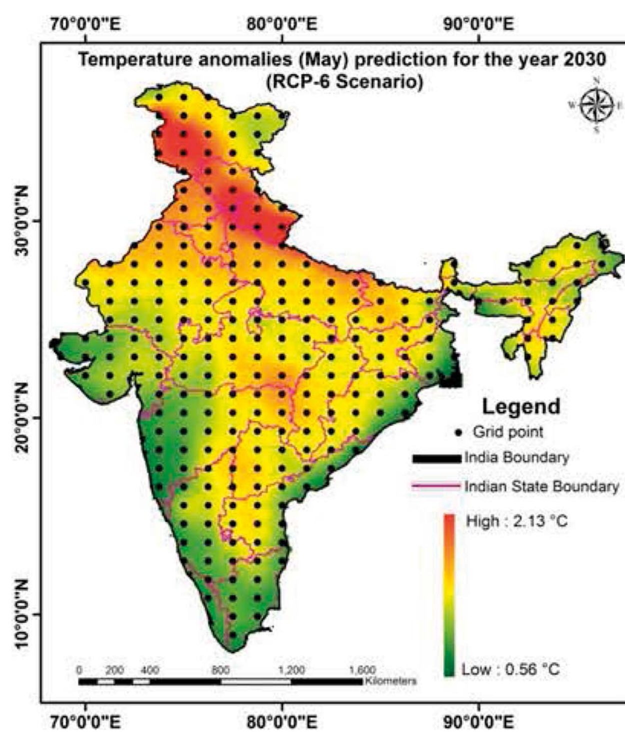

Figure 6. Temperature anomaly (May)

3. Results and Discussion

The long term forest fire data (1/1/2008 to 26/6/2016) evaluation over the Indian terrestrial region shows some interesting trends and results. In this analysis, we have evaluated the state wise forest fire counts, which were later converted into forest fire percent considering the total India's fire events as 100%. In this study, we have mentioned only the highest ten forest fire states of India. The total forest fires observed between these periods were 195714. The highest forest fire percent was found in

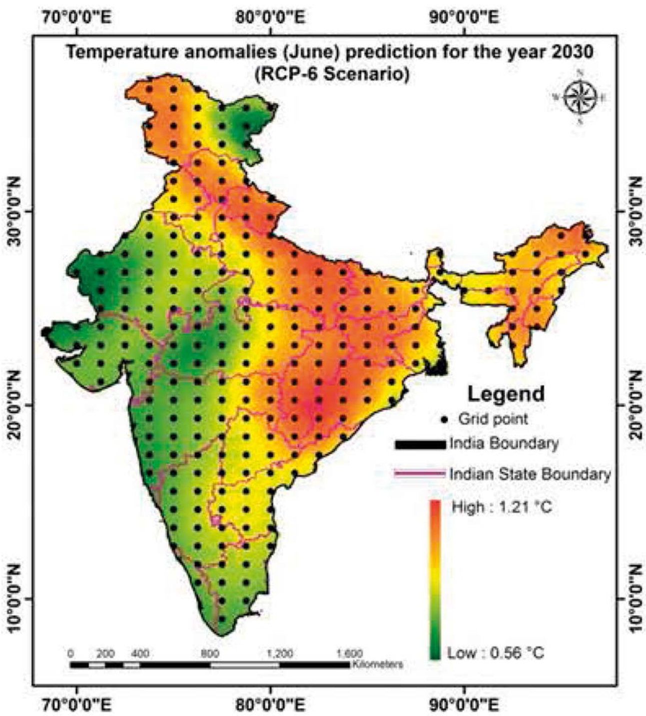

Figure 7. Temperature anomaly (June)

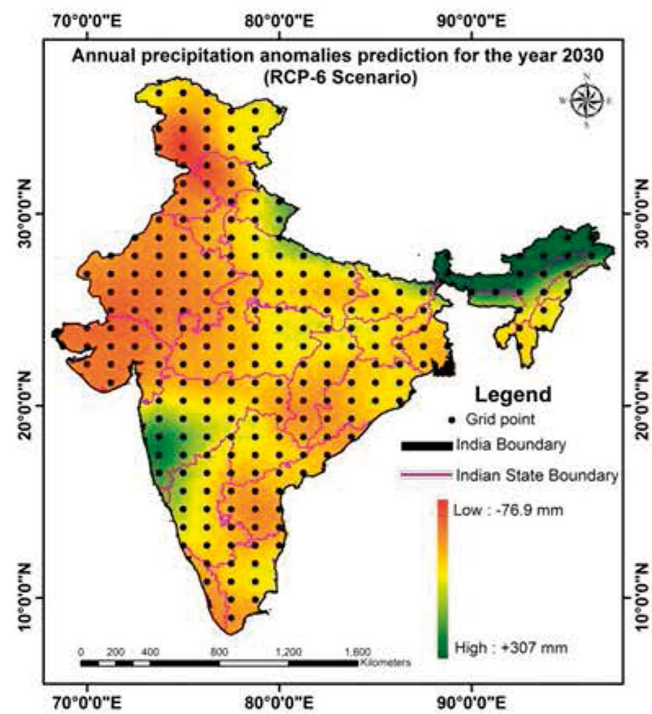

Figure 8. Annual precipitation anomaly

the state of Mizoram (11.33) followed by Chhattisgarh (9.39), Orissa (9.18), Madhya Pradesh (8.56), Assam (8.45), Maharashtra (7.35), Manipur (6.94), Andhra Pradesh (5.49), Meghalaya (4.86) and Telangana (4.23). Four of the ten highest forest fire percent states fall in the North East region of India, which retain roughly 36% of the total forest fire events of India is serious concern. The rest six highest forest fire states are in the central part of India, which is dominated by deciduous forest and to retain roughly 44% of total forest fire events of India. Similar observation of long term negative change in term of seasonal greenness in Indian deciduous forest was found the highest by the study of Chakraborty et al. (2018).

The Land Use/Land Cover area statistics are given below in Table 1. The 27.75% of the geographical area of country in the year 2005 was found as forest excluding the categories such as plantation and grassland. The actual crop land agriculture area was found to be 49.55%. Similar harmonized Land Use/Land Cover map has been utilized for evaluation by Ahmad et al. 2018 in Arunachal Pradesh of India.

We have evaluated the forest fire events with respect to various LULC categories, which represent the forest. The highest forest fire percent was found in the category 'Deciduous Broadleaf Forest' (38.1) followed by 'Mixed Forest' (25.6), 'Evergreen Broadleaf Forest' (16.5), 'Deciduous Needle leaf Forest' (11.5), 'Shrub land' (5.5), 'Evergreen Needle leaf Forest' (1.5) and 'Plantations' (1.2). No forest fire events were found in the category of 'Mangrove forest'. The deciduous forest approximately occupy the highest fire percent equivalent to 50%, whereas evergreen forest 18%. Similar spatial relationship has been analysed by Ahmad et al. 2018, whereas risk/vulnerability of forest from fire was also observed by FAO (2001) in India.

Climate change anomalies and forest fire events' characterization

Anthropogenic activities have considerably changed the Earth's climate at both global and regional scales. In recent

Table 1. The Land Use/Land Cover (LULC) area statistics for the year 2005 of India

LULC Classes	Area in km^2	%
Deciduous Broadleaf Forest	314456.6	9.59
Deciduous Needle leaf Forest	57409.7	1.75
Mixed Forest	151760.7	4.63
Evergreen Broadleaf Forest	178709.9	5.45
Evergreen Needle leaf Forest	19681.4	0.60
Shrub land	186820.4	5.70
Mangrove Forest	891.2	0.03
Plantation	79010.1	2.41
Grassland	55088.1	1.68
Cropland	1624280.9	49.55
Aquaculture	214.83	0.01
Built-up Land/Barren Land/ Fallow Land/ Wasteland/ Salt Pan	413575.1	12.61
Water Bodies/Permanent Wetlands/ Snow & Ice	195923.9	5.98

years, the impacts of climatic change and its spatial heterogeneity have attracted the researchers around the globe. Climate is a significant parameter, which decides the fire intensity, extent and behaviour (Flannigan et al. 2000; Fried et al. 2004), whereas extreme weather severity is a predominant factor attributing to forest fire events (Westerling et al. 2006; Stephens 2005). A recent study by Ahmad et al. 2017, 2018 in the states of Jharkhand and Arunachal Pradesh respectively reveals that the weather and climate parameter has strong a association with forest fire events. The temperature has increased globally by roughly 1°C in the year 2016, whereas it shows a continuous increasing trend (https://climate.nasa.gov). The temperature increase of 1°C will increase the duration of wild fire season by 30% (Vorobyov, 2004). The summer temperature acts as an important factor in manoeuvring the climate and leads to forest fire (Wells et al. 2004).

We have examined the seasonal variation of forest fire events. The analysis of month wise forest fire events over the whole of India shows some interesting seasonal trend. The highest forest fire events month were 'March' (55.4%) followed by 'April' (28.2%), 'February' (8.1%), 'May' (6.7%), 'June' (0.9%) and 'January' (0.7%). In one of the studies, it was also found that the weather severities during the month of March and April were significantly reflected in the form of forest fire events (Ahmad et al. 2017). We have also evaluated the predicted temperature anomalies for the year 2030 to understand the future forest fire scenario and its variability over India. The analysis of temperature anomalies for the month of February shows the significant increase from existing temperature over India, in the range of 0.5 °C to 1.8°C approximately for the year 2030. The highest increase in the month of February has been observed in the state of Mizoram, Orissa and parts of Rajasthan and Gujarat (Figure 3). Similarly, the analysis of temperature anomalies for the month of March shows an increase from the existing temperature, roughly in the range of 0.51 °C to 2.01°C for the year 2030. The highest increase has been found in the state of Uttaranchal, Himachal Pradesh, Mizoram, Orissa, parts of Rajasthan and the southern part of Assam (Figure 4). The analysis of temperature anomalies for the month of April shows an increase from the existing temperature roughly in the range of 0.55°C to 1.43°C for the year 2030. The highest increase has been found in the Sivalik mountain range of the Himalayan states of Uttarakhand, Himachal Pradesh and Uttar Pradesh. The increase was also observed in the western part of Madhya Pradesh, Assam and Arunachal Pradesh (Figure 5). In the month of May, the temperature increase was in the range of 0.56 °C to 2.13°C all over India and has intensified more in the same Sivalik mountain range of the Himalayan state of Uttarakhand, Himachal Pradesh, Uttar Pradesh and Jammu Kashmir (Figure 6). In the month of June, although the forest fire events were significantly low, but the temperature increase was in the range of 0.56°C to 1.21°C all over India, whereas it was found to be the highest in the state of Chhattisgarh, Orissa, Jharkhand and Uttar Pradesh (Figure 7).

In the similar way, we have also analysed the predicted annual precipitation anomalies for the year 2030. The spatial arrangement also shows a significant change in the precipitation pattern over India (Figure 7). The precipitation decrease was observed in some part of Jammu and Kashmir, Himachal Pradesh, Haryana, Punjab, Rajasthan and Chhattisgarh, whereas a significant increase was observed over the northern part of the North East region and the western part of Maharashtra (Figure 8). The increase of seasonal variation in temperature and deficit in precipitation in future (prediction, 2030) will certainly adversely affect the forest of some of the central part of India and North Eastern states of India. The fire frequency will be more intensified in future in large parts of India, whereas it will be more crucial for some states like Orissa, Chhattisgarh, Mizoram, Assam and in the lower Sivalik range of Himalaya. The deciduous forest will further degrade in future, which is a serious concern for policymakers because of its significant response (Chakraborty et al. 2018) to the climate change. The study by Sinha Ray, De (2003) in India also finds similar findings on future climate change, which will be reflected in the form of extreme events. Similar increase in temperature in India for the year 2040 will be in the range of 0.7–1.0°C and this was predicted by Lal et al., 1995. Some studies also reflect that the frequent intense rainfall pattern such as the number of rainy days and annual precipitation have decreased (Lal 2003; Goswami et al. 2006; Dash et al. 2007). A very important study on the impact of climate change over India based on the assessment on climate projections scenarios reveals that many forest dominant states of thecentral part of India are projected to undergo change (Chaturvedi et al. 2011).

4. Conclusion

This present study has evaluated the long term forest fire events with respect to India's state administrative boundary, its seasonal monthly trend, and the various forest categories of LULC and future climate anomalies datasets of India. The data sets were further analysed in the spatial domain using the GIS software to understand their invisible relationship and trend. The analysis of fire events with state boundary shows that the highest fire frequency percent was found in the state of Mizoram. Four of the ten highest forest fire percent states fall in the North East region of India. They are: Mizoram (11.33%), Assam (8.45%), Manipur (6.94%) and Meghalaya (4.86%). All the North East states retain roughly 36% of the total forest fire events of India and need policy intervention. The major reason of forest fire in this region is the shifting cultivation widely practiced by the ethnic tribes. They are considerably high in population in these areas suffering from extreme poverty and diminishing livelihood. There is a need to initiate programmes to enhance their livelihood, which will reduce their dependency on shifting cultivation practice. This can be achieved by involving them in forest afforestation/regeneration/conservation/protection work more intensively through empowered village forest management committees (VFMCs) on the line of joint forest management (JFM). Findings of our study shows that the LULC category 'Deciduous Broadleaf Forest' has the highest forest fire percent equivalent to 38.1%. The seasonal monthly trend also reflected that the forest fires are significantly high in the month of March and April (equivalent to 84%). The high weather severity and increased fuel loads (dead and dying leaves) on forest floor during these months are accountable for the high forest fire events. The old methods of Minor Forest Produce (MFP) collection needs to be replaced with some new instruments/tools. The MFP collection such as mahua flower was done by burning the floor (old traditional methods) by fire beneath the tree (for clearing the ground for flower picking purpose) needs to be changed because in most of the cases, it leads to accidental fire due to high severity of weather and fuel load during that period. Fire prevention and control is a state government subject and they need adequate support of manpower, funds, equipment and technology to increase their effectiveness. The evaluation of future climate data (RCP-6 scenario model) for the year 2030 shows an increase in seasonal temperature and abrupt annual rainfall pattern will further increase the future forest fire events. The fire frequency, intensity, size, pattern and their severity will be more pronounced in large parts of the Indian forest, whereas it will be more crucial for some of the states of Orissa, Chhattisgarh, Mizoram, Assam and in the lower Sivalik range of Himalaya. The deciduous forest will further degrade in future due to extreme weather events.

Geospatial technology with various datasets when analysed with advanced tools has enormous capability and can be significantly utilized in mapping, monitoring and examining their spatial relationship to give better a understanding and knowledge of forest health (quantitative and qualitative). Therefore, it should be meaningfully incorporated in decision making for formulating a forest conservation related plan.

Conflict of interests

The authors declare that they have no competing interests.

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Author's contribution

F.A. – designed the idea; FA/MMU – analyzed the satellite and ancillary data in GIS domain; L.G. – supported the analysis, and drafted the manuscript. All authors read and approved the final manuscript.