Forest Fires in India: A Review

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Abstract: Forest fire has become extreme and has increased in frequency worldwide with India being no exception. In view of this, the present-day knowledge about the forest fire condition in India has been reviewed. The forest cover in India is divided into four clusters namely North Himalayan, North-Eastern, Southern, and Central. Of these clusters, it has been found that though the North-Eastern cluster encompasses the maximum area (55%) of all the clusters in India, it accounts for meagre 16% of the burnt forest area. The central cluster has been found to be the most vulnerable to forest fires as ~56% of the total burnt area lies in this region, though it covers only 28% of the forest cover. In North-East fires tend to concentrate in a smaller area that is subject to repeated burns whereas in Central and Southern India they are more expansive. The impacts of forest fires on biodiversity, forest species, climate change, and soil characteristics in India are presented and various strategies adopted by the Indian government in order to detect and control the forest fires are presented. Additionally, the economic impact of forest fires is estimated to be over INR 1101 crore/year.

Keywords: Forest Fire, Clusters, MODIS, Forest Survey of India, Flora, Fauna

1.   Introduction

Forests are crucial to life; they sustain biodiversity and provide endless incalculable products and important ecosystem resources such as storage of carbon, flood & landslide control, clean supply of water, medicines, and crops (Bonell et al., 2010; Krishnaswamy et al., 2009). The global forest comprises 4.06 billion hectares of the area which is equivalent to 31% of the total land area (FAO, 2020). Approximately 1.6 billion people across the world depend on these forests, including 300 million people living within them (WWF, 2011). Between the years 2000 to 2010, a decline of the forest area by about 5.2 million hectares per year (0.1% of the total forest area) has been discerned (FAO, 2020). Forests face various aggravations that can cause harmful effects to their health and productivity along with decreasing their ability to supply products and services. Forest fires being one of them, is ubiquitous and can take place in nearly any ecosystem (Archibald et al., 2013). While fire has been used in crop rotation, agricultural plowing, and

the production of pasture for domesticated animals since ancient times, socioeconomic changes have caused traditional uses to be abandoned (Vidal-Macua et al., 2018).

Forest fires are accounted to be a burgeoning phenomenon over the years ravaging ecosystems, communities, and economies (Jhariya & Raj, 2014). Increasing human reliance on forests for a number of reasons leads to their fragmentation which further aggravates fire events (Cochrane, 2003). Various studies (Cochrane, 2003; Grutzen & Andreae, 1990; Penner et al., 1992) mention that forest fires have become extreme and have increased in frequency worldwide. The impact of forest fires have been documented on biodiversity (Granström, 2001), human life (Finlay et al., 2012; Fowler, 2003), climate change (Wotton et al., 2003, 2010) along with their associated economic impacts (González-Cabán, 2013; Kim et al., 2011; Úbeda & Sarricolea, 2016). India with 21.67% (7,12,249 km^2) area under forests is no exception to forest fires. 55% of forests in India are vulnerable to intermittent fires (Forest Survey of India, 2011a) and fires affect around 3.73 million hectares of forests annually (Chandra & Kumar Bhardwaj, 2015). In addition, population growth in India has triggered substantial deforestation, causing further fragmentation of existing forests. "Present biotic pressures like logging, grazing, and collection of non-timber forest products have also rendered Indian forests susceptible to fires" (Narendran et al., 2001).

This study reviews the scientific literature available to date that examines the forest fires in India from an environmental, social, and planning perspective. This study presents the overall forest and forest fire scenario in India, including the impacts and fire prevention strategies. This paper presents a new contribution to the knowledge of forest fire scenario in India.

2. Forest fire in India: general trends

India occupies just only 2.5% of the global geographical area, 1.8% of the overall forest area and it supports 16% of the total human population (Ashutosh & Satendra, 2014). The forest cover in India, according to the Forest Survey of India is 71.22 Mha, constituting 21.67 % of the total area, which represents 3.02% very dense, 9.39% moderately dense and 9.26% as open forest (Forest Survey of India, 2011b). Out of the 647 districts in India, nearly 380-445 districts encountered fires every year from 2003 to 2016 (World Bank, 2018). According to MODIS (Moderate Resolution Imaging Spectroradiometer) forest fire detections, approximately 37,059 fires were detected in 2018 (Forest Survey of India, 2011b). The classification of Indian forests is shown in Table 1, which shows that nearly 4% of the forest area in the country is extremely vulnerable to fire, while more than 6% is found to be highly vulnerable to fire.

Table 1: Classification of Indian Forests

Forest fire prone classes	Forest cover (in km^2)	% of total forest cover
Extremely fire prone	25,617	3.89
Highly fire prone	39,500	6.01
Fire prone	75,952	11.5
Moderately fire prone	96,422	14.7
Less fire prone	4,20,625	63.9
Total	**6,58,116**	**100**

Source (World Bank, 2018)

With respect to the forest area and the fire ecology variation therein, India can be divided into four geographical clusters viz. North Himalayan, North-Eastern,

Southern, and Central as shown in Figure 1. These clusters encompass ~ 90% of the total forest cover in India and encountered 98% of the total fire points detected in India from the year 2003-16. Although fires are spread across the identified clusters, they happen more frequently in certain areas and affect the forest more than in others. The North-Eastern cluster accounts for the maximum forest cover of 36% and the number of fire detections (40%), however, the maximum forest burnt area (56%) is in the Central cluster (Figure 2), which suggests that the Central cluster is the most vulnerable region in India.

The Central cluster encompasses states like Madhya Pradesh and some districts of Chhattisgarh and Rajasthan. With a subtropical climate, this cluster encounters average rainfall from 800 mm to 1,800 mm with the mean annual temperature varying between 22°C to 25°C. It mainly consists of forest species such as Tectona grandis, Shorea robusta, Lagerstroemia parviflora, and fires therein are caused by slashing and burning agricultural practices that help to collect non-timber forest products (Saha, 2002).

Forest fires are common and widespread in this cluster's dry and humid deciduous forest areas in the borderlands of Chhattisgarh, Maharashtra, and Telangana. (World Bank, 2018). States including Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, and Tripura are primarily part of the North-Eastern cluster. It experiences rainfall of 2,100 mm to 3,500 mm. During the winter months (October-January), temperature varies from 11 °C to 24 °C, while during the summer months (March-June) it encounters temperature ranging from 18 °C to 29 °C. Important species include Schima wallichii, Tectona grandis, Callicarpa species, and Pinus kasya, etc.

The maximum number of fires detected (55%) were in the North-Eastern cluster which also accounts for the maximum forest cover of 36% (Figure 2). In this cluster, fires tend to concentrate in a smaller area that is subject to repeated burns. "This repeated pattern of burning on small forest area is consistent with the practice of shifting cultivation (jhum) seen throughout the northeast. Fires in North-Eastern cluster, occur mainly from slash and burn agriculture"(World Bank, 2018). Due to population growth, there has been a reduction in time between fires, is has reduced from 20-30 years to 2-3 years (Puri et al., 2011), breaking the ecosystem's resilience.

Coniferous forests in the North Himalayan cluster region comprise species such as fir, spruce, and pine. Due to the harsh conditions, tree growth in this cluster is minimal. The annual rainfall ranges between 1200 mm to 1500 mm and the temperature varies from sub-zero to 35°C. The North Himalayan cluster is spread over states such as Kashmir, Uttarakhand, and Himachal Pradesh. Important species include Shorea robusta, Pinus roxburghii, Quercus leucotrichophora, and Mallotus philippinensis. Fire is used as a tool by indigenous communities of the area to clear grass that contributes to forest regeneration (Bahuguna & Upadhay, 2002).

Southern Cluster consists of states like Karnataka, Kerala, Tamil Nadu, Andhra Pradesh, Telangana, and some districts of Maharashtra. This cluster encounters average rainfall from 1000 mm to 1,800 mm, while the mean annual temperature varies between 20°C to 26°C. Important species include Dipterocarpus indicus and Vateria indica. Fires in Southern clusters are more expansive and occur due to human accidents, for management of forest, and due to slash and burn practices (Kodandapani et al., 2004).
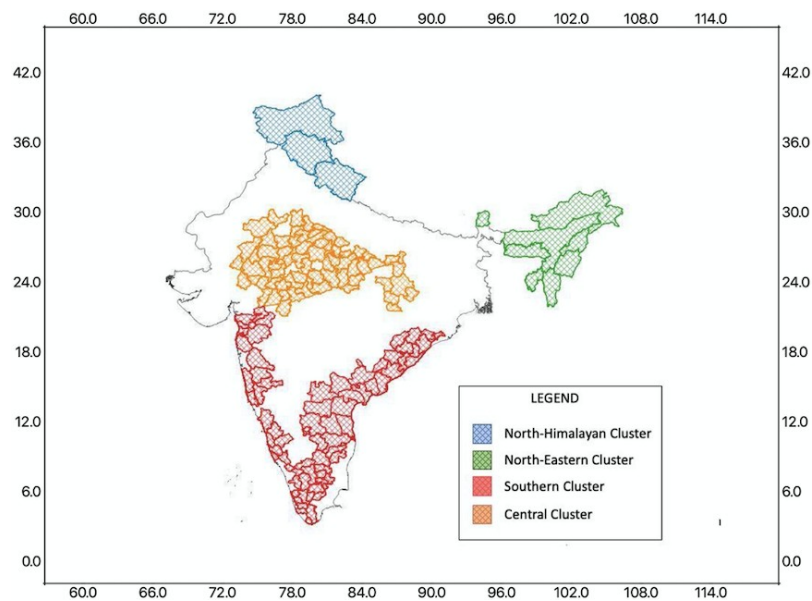
Figure 1: Map showing forest clusters found in India

Of the total forest fire detections in India from the year 2003-16, 20 districts accounted to 40% of all forest fire detections (World Bank, 2018), majority of them lie in the North Eastern cluster. Those 20 districts are listed in Table 2.

Table 2: Total number of fire detections in top 20 districts, 2003-2016

| District, State	Cluster	Share of fire detections, 2003-2016 (%)
Lunglei, Mizoram	North East	3.82
Karbi Anglong, Assam	North East	3.48
Dima Hasao, Assam	North East	3.3
Churachandpur, Manipur	North East	3.15
Mamit, Mizoram	North East	2.56
Lawngtlai, Mizoram	North East	2.42
Tamenglong, Manipur	North East	2.32
Aizawl, Mizoram	North East	1.91
Gadchiroli, Maharashtra	Central	1.78
Dhalai, Tripura	North East	1.77
Champhai, Mizoram	North East	1.69
W. Khasi Hills, Meghalaya	North East	1.48
Narayanpur, Chhattisgarh	Central	1.45
Ribhoi, Meghalaya	North East	1.37
Kandhamal, Odisha	Central	1.35
E. Garo Hills, Meghalaya	North East	1.33
Ukhrul, Manipur	North East	1.32
Chandel, Manipur	North East	1.32
Bijapur, Chhattisgarh	Central	1.31
North Tripura, Tripura	North East	1.16
Top 20 total		**40.28**

Source (World Bank, 2018)

Conversely, with regard to the total area affected by forest fires, the top 20 districts which represented 48% of the total area affected by fire between 2003 and 2016, majority of them belong in the central cluster, (World Bank, 2018). These 20 districts in the central cluster are listed in Table 3

Table 3: Total area affected by fire in top 20 districts, 2003-2016

District, State	Cluster	Share of burnt area, 2003-2016 (%)
Gadchiroli, Maharashtra	Central	8.24
Bijapur, Chhattisgarh	Central	5.29
Khammam, Telangana	Southern	3.86
Narayanpur, Chhattisgarh	Central	2.7
Warangal, Telangana	Southern	2.56
Koriya, Chhattisgarh	Central	2.35
Adilabad, Telangana	Southern	2
Chandrapur, Maharashtra	Central	1.95
Surguja, Chhattisgarh	Central	1.9
Kurnool, Andhra Pradesh	Southern	1.8
Amravati, Maharashtra	Central	1.78
Y.S.R., Andhra Pradesh	Southern	1.71
Prakasam, Andhra Pradesh	Southern	1.7
Dakshin Bastar, Chhattisgarh	Central	1.61
Bilaspur, Chhattisgarh	Central	1.6
Raipur, Chhattisgarh	Central	1.56
Betul, Madhya Pradesh	Central	1.46
Champhai, Mizoram	North East	1.42
Lawngtlai, Mizoram	North East	1.35
Dima Hasao, Assam	North East	1.34
Top 20 total		**48.18**

Source (World Bank, 2018)
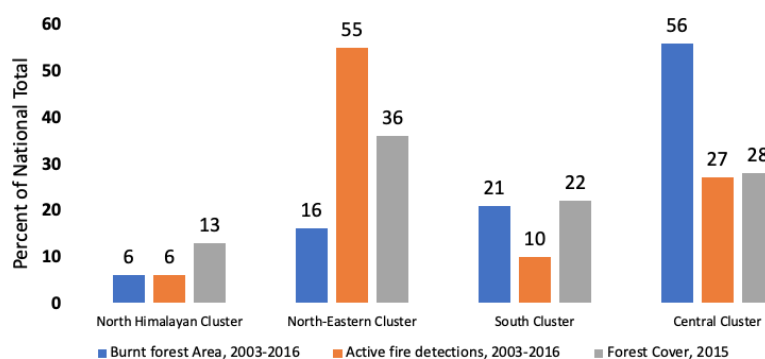
Figure 2: Burnt forest area, Active forest fire detections and Forest Cover from 2003-2016 (World Bank, 2018)

Impact of forest fires

Impact on biodiversity

India is rich with rare and complex floral and faunal resources, accounting collectively for 60-70% of the world 's biodiversity (Creswell I, 2018; Producer et al., 2006). Wildfires can have devastating effects on biodiversity by destroying trees, ecosystems, and food supplies and by increasing the resulting susceptibility to predation of surviving animals (Green & Sanecki, 2006; Kodandapani et al., 2008; Letnic & Dickman, 2005; Pelegrin & Bucher, 2010).

Flora

Spatial factors such as the location of a plant's dormant bud, the sub-surface distribution of reproductive structures, and the depths below the surface from which new shoots emerge depict an individual plant's growth behavior post-fire (Flinn & Pringle, 1983; Paula et al., 2009). Depending on the intensity and return period, fires can be beneficial or harmful (Verma & Jayakumar, 2012). According to Cochrane et al., 2009, there has been a "drastic alteration" in the species structure and abundance found in the Nilgiri Biosphere Reserve in the southern cluster, with reduced seedling density observed in the forest area. In the Central cluster Jhariya, M.K. S.S. Bargali, 2014 find similar trends in the Bhoramdeo wildlife dry deciduous forests of Chhattisgarh. Kittur et al., 2014 observe that the regeneration and size structure of economically significant species of plants such as Sal is disrupted by repetitive fires. In the North Himalayan cluster, fire has been a cause for damage to seedlings in Uttarakhand's pine, oak, and mixed deciduous forests (Parashar et al., 2003). Human pressures such as burning, lopping, grazing, and collection of leaf litters have slowly resulted in the transformation of Uttarakhand's oak forests into pine forests, as fires promote the growth of chir-dominated pine forests (Singh et al., 1984).

Fauna

In the North Himalayan cluster, the loss of flora and fauna triggered by wildfires during the summer in these forests is higher than any other human induced factor (Hussain et al., 2018). Evaluating the role of fire (Rodgers, 1986) finds that fires in some areas can be beneficial for wild herbivores. Regulated patchwork burning can improve habitat for grazing species such as swamp deer and chital for small areas of moist grassland. However, the advantages of fire decrease as habitats get drier and fire frequency increases. Also, while fire may be helpful to some degree in promoting habitat for some wild herbivores, not all species benefit. Nests, dens, and eggs can be destroyed by even low-intensity surface fires, killing young animals that cannot escape fast enough. (Rodgers, 1986).

Impact on soil properties

Forest fires have a significant impact on post-fire forest composition and structure of soil (Jain et al., 2008). It can affect many physical and chemical soil properties including "loss of organic soil and structure, reduced porosity, and increased pH" (Certini, 2005; Debano, 1991). Indirect consequences, include increased water repellence resulting in reduced penetration and increased runoff, which leads to increased erosion (DeBano, 2003). Fires of higher intensity can considerably deplete the soil and alienate it of nutrients and organic matter (Chandra & Kumar Bhardwaj, 2015). In South Kashmir of the North Himalayan cluster (Khaki, B.A., Singh. V.R.R., Wani A.A. & Thakur, 2015) discovered evidence that the overall soil carbon and nitrogen content in burnt areas were lower than unburnt areas, while "phosphorus and potassium" were higher in burnt areas. "The shortening of fire-associated jhum cycles in North-Eastern cluster has had a negative impact on soil fertility". Shortened jhum cycles lower the amount of fallow biomass available for combustion, and offer less time to recuperate soil fertility resulting in lower economic yields and output (Ramakrishnan, 2007).

Impact on climate change

Climate change has been observed to be on the rise due to the dominant anthropogenic activities that have been exceeding the bounds of natural

variability. One of the numerous consequences associated with climate change is forest fires (Stephens, 2005). Forest fire and climate change possess a feedback effect. Human-instigated climate change has attempted to put more prominent pressure on numerous forest species and has weakened their ability to withstand fires. Within certain regions of the world, more extreme and recurrent wildfires are expected to occur in the future due to climate change (Hemp, 2009; McKenzie et al., 2004; Pitman et al., 2007; Wilson et al., 2010). The appropriate period to find out the fire sensitivity (frequency and intensity) is during the summer when the moisture content and wind speed in the atmosphere is low (Murthy et al., 2019; North et al., 2015; Piñol et al., 1998). This can be regarded as one of the major reasons for how the drought-prone areas are easily drawn to wildfires. The effect of fluctuating climatic patterns on the forest fires of India has also been pointed out by Joseph et al., 2009. They were able to show the shift in the extent of grasslands and forests in response to climate change through their study. (Joseph et al., 2009 and references cited therein).

Economic impact of forest fires

"Forestry is the second-largest land use after agriculture and accounts for about 1.5 % of the nation's GDP" (World Bank, 2005). With 65 million people identified as tribal groups, they rely on the collection of non-wood forest products from forest areas for their livelihoods and are directly affected by forest fire. (Ashutosh & Satendra, 2014). The economic losses associated with forest fires can be much greater for smallholders than for large holders, because they rely on the forest for a wide range of services and uses (Daniel Nepstad Adriana Moreira & 1999a). The existing estimates of the potential cost of forest fires in India are likely underestimated at approximately INR 1,101 crore (US$ 164 million, 2016 prices) per year (Bahuguna, 1999; World Bank, 2018). The loss of biodiversity, timber, increased carbon sequestration, soil moisture, and nutrient loss, etc., are not taken into account in this estimate. Furthermore, there is a lack of comprehensive data in India that can indicate forest losses in terms of area burned, values, and volume and regeneration destroyed by fire. The available forest fire estimates are not correct because the measured fire numbers and the area burned are underestimated. The rationale behind this is due to the absence of accountability (Bahuguna, V.K. & Singh, 2001).Monetary damage from forest fires is usually only measured in terms of timber value for the loss of standing (natural or planted) trees, which is usually negligible in the case of low-intensity surface fires.(World Bank, 2018). Estimates may be enhanced by considering the direct and indirect effects on other industries like, for example, transport, utilities, loss of environmental services, etc. Thus, the estimate of INR 1101 crore/year is underestimated and the actual economic impact of forest fires is likely to be much higher.

4.   Fire management practices in India

Detection practices

Globally, various wireless sensors, satellite systems, and neural network-based techniques are being employed in order to detect or manage forest fires. However, in India, currently, fires are detected using satellites and ground-based measurements.

Using Satellites and Remote Sensing

In India, active forest fire detection systems rely on the MODIS (Moderate Resolution Imaging Spectroradiometer) instrument and the Visible Infrared Imaging Radiometer Suite (VIIRS) for satellite-based hotspot observation (World Bank, 2018). Using satellite detection, the forest fire alert system was first introduced in India in 2007-2008. Madhya Pradesh (Central Cluster) pioneered its Fire Warning Messaging System to distribute warnings to field workers through SMS text alerts (FAMS). After undergoing a significant number of improvements since 2004, the Forest Fire Alert System has shown a 10-fold upgrade of its version to Forest Fire Alert System Versions 3.0 (Fast 3.0) in the year 2019. This system is based on collaborative arrangements between NASA-ISRO (National Aeronautics and Space Administration- Indian Space Research Organization) and ISRO- FSI (Indian Space Research Organization-Forest Survey of India) (Forest Survey of India, 2011a).

Ground-based detection of fires by field staff

Even with advancements in remote sensing technology and warning systems, ground monitoring of forest fires will continue to be important. However, this mechanism is under-resourced in India. The forest service employs seasonal fire watchers from the local community to help with fire detection and response. These locally employed watchers are facing payment delays or shortages. No proper training instructions or equipment is provided to these fire watchers (World Bank, 2018). Thus, its important on the Indian government's part to strengthen the ground-based fire detection system.

Some of the commonly used fire detection techniques employed in India have been compared in terms of their cost and practicality in Table 4.

Table 4: Comparison Amongst Different Forest Fire Detection Techniques

Name of the Fire Detection Technique	Cost	Practicality	References
Wireless Sensor Based Techniques	Medium	High	(Aslan et al., 2012), (Díaz-Ramírez et al., 2012), (Bayo et al., 2010), (Bouabdellaha et al., 2013)
Satellite Based Systems	Very High	Very High	(Oliva & Schroeder, 2015), (Filizzola et al., 2016), (Coppo, 2015), (Koltunov et al., 2016)
Digital Camera Sensor	High	Medium	(Narasimha Rao et al., 2018), (Wong & Fong, 2014), (Çetin et al., 2013), (Q. X. Zhang et al., 2018)
Air Borne Techniques	High	High	(Krüll et al., 2012), (Cruz et al., 2016), (Allison et al., 2016),(Dennison & Roberts, 2009)
Neural Network Based	Low	Low	(Soliman et al., 2010), (Chauhan et al., 2013) (Giriraj et al., 2008), (Zhang et al., 2009)

Prevention Strategies

Formulation of National Forest Policy in 1988, The National Master Plan for Forest Fire Control, and Guidelines in 2018 are some of the key initiatives that the Government of India has taken to manage the fire. Common methods for prevention of fire used in India include - fire line clearance and controlled burning to limit fuel loads, silvicultural practices such as selective thinning and fire-adapted tree species planting in fire-prone areas, early warning, and fire hazard rating systems. The implementation of Joint Forest Management (JFM) village level committees was another significant step in the micro-level management of forest fires in India.

The knowledge in systematic forest fire control is limited to the short term. There are weaknesses in the evaluation, ranging from fire detection to the coordination of preventive steps. At this time, the need to establish an adaptive management plan is critical. Sector-wise, with short- and long-term visions, clear points are suggested for the implementation of a holistic fire prevention plan in the light of climate change. Some of them include mitigation measures to minimize the uncertainty in baseline data, strengthen present fire-fighting programs, developing precautionary measures, integrating institutional efforts, publicity, extension, and training, legal measures, and funding of more programs aimed to improve the current status.

5.   Conclusion

India with 21.67% (7,12,249 km^2,) area under forests is no exception to wildfires. 55% of forests in India are vulnerable to intermittent fires and wildfires affect around 3.73 million ha of forests per year in India. Wildfires in India impact the nation on different fronts, creating three major kinds of problems.

Environmental: The four geographic clusters in North-east, North-West Himalayan Region, Central, and Southern India best describe the fire ecology variation within India. Northeast accounts for the greatest no. of fire detections (nearly 55%) while the Central region accounts for the largest area affected by forest fire (nearly 56%). In the Western Himalayas, the impact of forest fire causes the loss of flora and fauna during the summer and is greater in these forests than any other anthropogenic factor. In the case of the North East cluster, in addition to other stresses, such as intensive grazing and browsing, frequent fires in short succession reduces species diversity and damages natural regeneration. Lastly, shorter duration fires occurred in the Central and Southern regions of the country have a detrimental impact on the composition and structure of forest, and diversity of species.

Social: In addition to reducing their ability to supply goods and services, forests face multiple aggravations that can cause adverse effects on their health and productivity. Being one of them, forest fires are ubiquitous and can take place in almost every eco-environment. Although fire has been used since ancient times in crop rotation, agricultural plowing, and pasture production for domesticated animals, socio-economic changes have caused traditional uses to be abandoned.

Economic: For small holders, the economic losses associated with forest fires may be much greater than for large holders, since a wide variety of resources and uses depend on the forest. At an annual rate of approximately INR 1,101 crore, the current estimates of the economic costs of forest fires in India are almost certainly underestimated (US$164 million, 2016 prices). However, not much data has been reviewed regarding the economic losses during the present forest fire phenomenon due to a lack of accountability. Many aims would be fulfilled by a more detailed accounting of the economic costs and benefits of forest fires in India.

Finally, with varying strategies and techniques adopted for forest fire detection and prevention, the appreciable difference has been discerned in the forest fire trends of the country.

Nomenclature
WHO: World Health Organization
FAO: Food and Agriculture Organization
MODIS: Moderate Resolution Imaging Spectroradiometer

Mha: Million hectares

FSI: Forest Survey of India

Acknowledgments

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