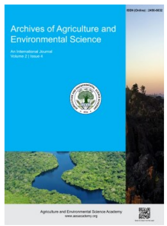
Archives of Agriculture and Environmental Science 5(4): 592-602 (2020)
https://doi.org/10.26832/24566632.2020.0504024

e-ISSN: 2456-6632

This content is available online at AESA

Archives of Agriculture and Environmental Science

Journal homepage: journals.aesacademy.org/index.php/aaes



REVIEW ARTICLE

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A review on status, implications and recent trends of forest fire management

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ARTICLE HISTORY

Received: 16 October 2020
Revised received: 07 December 2020
Accepted: 17 December 2020

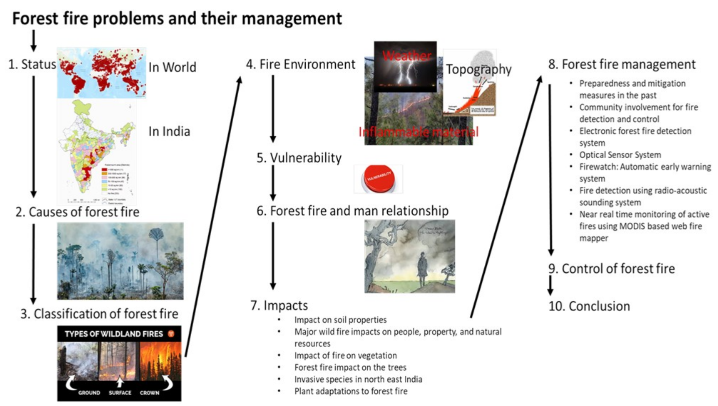
Keywords

Forest fire
Nutrient cycling
Soil properties
Vegetation change

ABSTRACT

Forest fire spread out in an area having combustible material in the summer season with high temperature. It burns the area and looks like a misery. Forest fire is one of the factors that severely affects the forest biodiversity. Burning actions in a forest affects not only flora and fauna but also soil properties changed due to the forest fire. In summer season on sloppy topography forest fire originates in tropical forests. While in coniferous forests, forest fire outbreaks during the resin extraction activities. More than 350 million hectares (ha) was estimated to be affected by vegetation fires globally. In India about 55% of forest area is prone to the fire. Fires can be natural or man- made, but manmade fire affects mostly. Several forest types and areas are more susceptible to forest fires because of suitable weather, topography and inflammable material. Forest fires adversely affect the soil, water, flora and fauna and disrupt the ecological functions. The new advances in fire control are remote sensing and GIS where real time information can be gathered about the fire break and immediate follow can be done. The chemicals (as borate, ammonium sulfate and ammonium biphosphate) are used for fire control and various other types of fire retardants are used to keep the fire under control. Forest fire changes the composition of vegetation, extinction of species, development of the various adaptations in unwanted plants. Nutrient cycle and soils are affected. Frequent forest fire events cause global warming. Forest fire needed to be controlled at initial stage and the large fires should not be allowed to occur, the modern techniques of monitoring, detection and control must be used for avoiding the large fires happenings.

GRAPHICAL ABSTRACT



Citation of this article: Attri, V., Dhiman, R. and Sarvade, S. (2020). A review on status, implications and recent trends of forest fire management. *Archives of Agriculture and Environmental Science*, 5(4): 592-602, https://dx.doi.org/10.26832/24566632.2020.0504024

AEM

INTRODUCTION

Forest fire starts from the ignition point and spread outwards leaving behind only a burnt area. It is a very common problem in tropical as well as in temperate forests of the country and world. Abundant combustible material, high temperature, high wind speed and sloppy topography were made favorable environment for forest fire. Forest fire also known as as wildfires, brush fire, bushfire, grass fire, hill fire, peat fire, vegetation fire, veld fire and wild land fire depending on the type of vegetation being burnt (Gupta *et al.*, 2014). Forest fires made them different from other fires as they spread in large area even through crossing the roads. They create threat to the forest ecosystems, therefore entire fauna and flora was seriously disturbed and affects whole bio-diversity and the ecology and environment (Sarvade, 2014; Gupta *et al.*, 2015; Kaushal *et al.*, 2017). During summer, when there is no rain for months, the forests become littered with dry leaves and twigs, which could burst into flames ignited by the slightest spark. Forest fire affects severely to the forest composition, diversity and soil properties. Due to these effects exotic species encroach the burnt area and spreading of such species affects vegetation diversity (Jhariya and Raj, 2014; Lee *et al.*, 2015; Juarez-Orozco *et al.*, 2017). So that the study of forest fire, its impacts and management is very essential for the conservation flora and fauna of the forest.

Status of the forest fires in the world

Globally, more than 350 million hectares (ha) area were estimated to be affected by vegetation fires each year, about half or more of this area accounts in Africa. Annually, 150 to 250 million ha of tropical forests were affected by wildfire. Ninety to 95% of all such fires caused due to the human activities. According to the EM-DAT 2013, American global region was mostly affected by the wildfires, followed by European and Asian regions (Table 1). As per the global analysis of forest area affected by fire from 2003 to 2012, approximately 67-million-hectare area was annually affected (Van Lierop *et al.*, 2015). Around 98-million-hectare forest was affected by fires (FAO, 2020).

Status of forest fires in India

According to a Forest Survey of India Report, about 55 % of forest areas in the country are fire prone (ranging from 50 % in some states to 90 % in the others). About 6 % of the forests are prone to severe fire damage (Table 2).
In India there are very few cases of fire due to natural causes. The majority of the forest fires (99 %) in the country are human caused. It is widely acknowledged that most of these fires are caused by the people deliberately and have a close relationship to their socio-economic conditions.

Causes of forest fire

Natural causes: Natural causes accounts for only 5% of all the fires reported in forest areas. Many forest fires start from natural causes such as lightning, rubbing of dry bamboos, collision of the stones and subsequent spark produced etc. which set trees on fire. However, rain extinguishes such fires without causing much damage in most cases. High atmospheric temperatures and dryness (low humidity) offer favorable circumstance for a fire to start (Jhariya and Raj, 2014; Satendra and Kaushik, 2014; Juarez-Orozco *et al.*, 2017).

Man-made causes: This type of fires account for about 95% of fires. The fires made by man can be voluntary or accidental. Fire is caused accidentally when a source of fire like naked flame, cigarette, electric spark or any source of ignition comes into contact with inflammable material. The irresponsible behaviour of tourists when they put fire and forget to put it off, villagers and tribal's fire for flush of fresh grass in coming dry season etc. at times get uncontrolled causing massive fires. The illicit collectors of honey, scaring away of the wild animals from the village and destroy the stumps of the felled trees. The forestry personnel are also when negligent and without due precautions put fire in controlled burning leads to big fires (Jhariya and Raj, 2014; Satendra and Kaushik, 2014; Juarez-Orozco *et al.*, 2017).

Table 1. Impact of wildfire on human and economic losses (1984 to 2013).

Global regions	No. of events	People killed	Total people affected	Death rate per event	Economic loss (Million US$)
Africa	25	272	21672	11	440
America	118	234	1229175	9	25229
Asia	50	748	3188257	30	11892
Europe	89	462	1295562	18	12619
Oceania	21	224	74320	9	2121
Total	303	1940	5808986	78	52301

(Source: EM-DAT 2013).

Table 2. Forest fire status in India.

State/ District	Forest area (ha)	Sample plots (No.)	Extent of fire incidents (ha)						Total
			Very Heavy	Heavy	Frequent	Occasional	No Fire	Unrecognized	
Andhra Pradesh	14826.71	2037	60.58	5.75	521.99	3335.27	10016.34	886.78	14826.71
Assam	15427.88	2482	70.91	0	590.25	4551.13	10176.68	38.01	15427.88
Bihar	5317.01	296	57.718	0	452.6223	3330.7426	1505.927	0	5317.01
Himachal Pradesh	10269.40	4878	163.7	0	671.45	3811.38	5054.92	567.98	10269.40
Jammu & Kashmir	3331.75	428	7.5	0	60.98	1089.58	2088.05	85.64	3331.75
Haryana & Punjab	1180.72	45	0	0	41.54	332.48	807.7	0	1180.72
Karnataka	13223.30	1780	59.71	30.33	470.64	3342.94	9309.79	9.89	13223.30
Manipur	15154.00	1880	0	151.54	454.62	5758.52	8789.32	0	15154.00
Madhya Pradesh	1962591	1947	136.53	23.07	1838.83	10644.29	6983.19	0	19625.91
Maharashtra	8165.54	1355	0	0	186.83	4222.57	3756.94	0	8165.54
Meghalaya	9905.00	1659	26.75	0	269.12	3347.25	5230.91	1031.6	9905.66
Nagaland	14954.91	1128	0	0	1084.231	12038.703	1831.976	0	14954.91
Orissa	20143.38	2972	204.42	78.5	923.19	11345.345	5258.182	333.52	20143.38
Rajasthan	20178.79	2446	71.39	0	99.03	4348.12	14763.26	896.99	20178.79
Sikkim	1707.77	401	47.12	0	18.14	544.84	1097.67	0	1707.77
Tripura	6445.36	555	34.59	0	361.75	5293.65	755.37	0	6445.36
Uttar Pradesh	23164.09	2825	871.43	0	2092.51	11124.1	907605	0	23164.09
West Bengal	5764.81	1471	4.77397	0	656.4338	1356.5246	3444.318	302.76	5764.81
Dadra&Nagar	186.49	62	0	0	0	180.8953	5.5947	0	186.49
Grand Total	208973.5	307.47	1817.122	289.19	10794.16	89998.3305	101952.188	4154.07	208973.5
Percentage			0.87	0.14	5.16	43.06	48.79	1.99	100.00

CLASSIFICATION OF FOREST FIRE

On the basis of the place of their action forest fire is of following types:

Creep fire: This type of fire goes under cover for several days unnoticed under the leaf litter and then suddenly comes up as wild conflagration. It is very difficult to detect.

Ground fire: Ground fires burns the ground cover only *i.e.*, the carpet of herbaceous plants and low shrubs, which covers the soil.

Surface fire: A forest fire may burn primarily as a surface fire, spreading along the ground as the surface litter and also burns away the undergrowth of the forest.

Crown fire: The other type of forest fire is a crown fire in which the crown of trees and shrubs burn, often sustained by a surface fire. A crown fire is particularly very dangerous in a coniferous forest because resinous material given off burning logs burn furiously. On hill slopes, if the fire starts downhill, it spreads up fast as heated air adjacent to a slope tends to flow up the slope spreading flames along with it (Source: Schmerbeck *et al.*, 2007; Satendra and Kaushik, 2014; FSI, 2017).

FIRE ENVIRONMENT

Fire occurs as result of the certain circumstances which constitute its environment. when proper environment has been created the causes of the fire start governing leading to the conflagrations.

Weather: In weather the most important factors working are the temperature and wind. Higher temperature makes the ignition temperature approach easier. The time when it is hottest it's at the highest risk of the fire spread. Winds promote the fire and cause it to extend to break all the barriers. Even the firebreaks, ditches and rivers are crossed through when the wind is blowing.

Inflammable material: Dry leaves, Dry twigs, broken branches and felling refuse in the in the case of forest felling has taken place in recent months. In Chir pine, presence of resin in pots hung on trees and that present in the channels constitutes the inflammable material, the *Eucalyptus* forest has essential oil. Similarly, the sawn wood in forests constitutes inflammable material.

Topography: In hills the topography adds another dimension to the environment. Altitude and aspects both have a great effect on temperature, rainfall etc. and thus affect the formation of the environment. As the southern and south western aspects are hotter there is a greater risk of fire on these aspects as compared to northern and north eastern aspects. In lower altitude the temperature is higher they are more prone to fires then the higher altitude. Slope also affects the behavior, fire spreads faster while travelling up a hill slope but slows down when it moves downhill slope. (Source: Satendra and Kaushik, 2014; Martin *et al.*, 2016; FSI, 2017).

The youngest mountain ranges of Himalayas are the most vulnerable stretches of the world susceptible to forest fires (Table 3). The forests of Western Himalayas are more frequently vulnerable to forest fires as compared to those in Eastern Himalayas.

Table 3. Occurrence of fire in different forests in India.

S.N.	Type of forests	Fire frequent (%)	Fire occasional (%)
1	Coniferous	8	40
2	Moist Deciduous	15	60
3	Dry Deciduous	5	35
4	Wet/Semi-Evergreen	9	40
5	North-eastern Region	50	45

This is because forests of Eastern Himalayas grow in high rain density. With large scale expansion of chirr (Pine) forests in many areas of the Himalayas the frequency and intensity of forest fires has increased. The species as *Pinus roxburghii* has adapted in manner that it has a very thick bark which makes it fire –hardy. In the Himalayas Chir pine is one the most susceptible species as it is rich in the resin the forest floor has thick leaf litter which invites and promotes fire. Various regions of the country have different normal and peak fire seasons, which normally vary from January to June. In the plains of northern and central India, most of the forest fires occur between February and June. In the hills of northern India fire season starts later and most of the fires are reported between April and June. In the southern part of the country, fire season extends from January to May. In the Himalayan region, fires are common in May and June (Nair, 1992; Joshi and Sharma, 2015; Dobriyal and Bijalwan, 2017; FSI, 2017).

Forest fires are influenced by weather, fuels, and topography, but the relative influence of these factors may vary in different forest types. Compositional analysis can be used to assess the relative importance of fuels and weather in the boreal forest. In the Canadian boreal forest, aspen (*Populus tremuloides*) has been found to burn in less than the proportion in which it is available. We used the province of Ontario's Provincial Fuels Database and fire records provided by the Ontario Ministry of Natural Resources to compare the fuel composition of area burned by 594 large (>40 ha) fires that occurred in Ontario's boreal forest region, a study area some 430 000 km2 in size, between 1996 and 2006 with the fuel composition of the neighbourhoods around the fires. We found that, over the range of fire weather conditions in which large fires burned and in a study area with 8% aspen, fires burn fuels in the proportions that they are available, results which are consistent with the dominance of weather in controlling large fires (Joshi and Sharma, 2015; Dobriyal and Bijalwan, 2017; FSI, 2017.

RELATIONSHIP WITH HUMAN

The history of fire, especially in the context of the increased dominance of humans, has produced a progressively fire-adapted ecology, which argues for human-free wildlife areas and against prescribed burns under many circumstances (Caldararo, 2002**).** Urban air quality monitoring plays an important role due to high concentration of particle sources and a large population exposed to elevated particle concentrations. Continuous ground -based measurements of black carbon (BC) aerosol; carbon monoxide (CO) and ozone (O_3) were carried out in the tropical urban region of Hyderabad, India, during the forest fire season. Julian day variation of BC, CO and ozone showed high values on certain days. In order to ascertain the additional sources for observed high concentration of BC and CO, DMSP-OLS night time satellite data over the Indian region were processed for occurrence of forest fires. Results of the analysis suggested a higher incidence of forest fires on days with higher concentrations of BC and CO and a spatial distribution of forest fires; wind trajectories were observed to have a bearing on the higher values of BC, CO and ozone (Badarinath *et al.*, 2007).

IMPACTS OF FIRE

They are ecological, economic and social impacts. Loss of timber, loss of bio-diversity, loss of wildlife habitat, global warming, soil erosion, loss of fuelwood and fodder, damage to water and other natural resources, loss of natural regeneration. Estimated average tangible annual loss due to forest fires in country is Rs.440 crores (US$ 100 million approximately).

Impact on soil properties

Fire may alter several physical soil properties, such as soil structure, texture, porosity, wettability, infiltration rates, and water holding capacity (Jhariya and Raj, 2014).

Soil structure: Intense burns may have detrimental effects on soil physical properties by consuming soil organic matter. Soil organic matter holds sand, silt, and clay particles into aggregates, therefore a loss of soil organic matter results in a loss of soil structure. By altering soil structure, severe fires can increase soil bulk density, and reduce soil porosity through the loss of macrospores (>0.6 mm diameter).

Soil porosity: Soil porosity can also be reduced by the loss of soil invertebrates that channel in the. When fire exposes mineral soils, the impact of raindrops on bare soil can disperse soil aggregates and clog pores, further reducing soil porosity. Intense fires (> 400 C) may also permanently alter soil texture by aggregating clay particles into stable sand-sized particles making the soil texture coarser and erodible.

Erosion: Intense burns may also induce the formation of a water repellent soil layer by forcing hydrophobic substances in litter downward through the soil profile. These hydrophobic organic compounds coat soil aggregates or minerals creating a discrete layer of water repellent soil parallel to the surface. Water repellent soil layers are reportedly formed at temperatures of 176-288°C and destroyed at >288°C. Extensive water repellent layers can block water infiltration and contribute to runoff and erosion. While single prescribed burns may not have significant effects on soil, the high frequency of fires can have cumulative effects on soil physical properties. Soil organic matter is usually lower in soils that are repeatedly burned, and early researchers noted that burned soils were harder, denser, and less permeable than unburned soils.

Changes in soil microorganism in fire areas

Changes and effects of a natural fire on ectomycorrhizal inoculum potential of soil in a *Pinus halepensis* forest. A typically Mediterranean forest of *Pinus halepensis* was studied. During two years following fruiting fungal species, the number of sclerotia in soil, and the percentages and types of mycorrhizas present were determined. In burned stands ascomycetes were typical carbonaceous while basidiomycetes were strongly reduced. The sclerotia extracted from soils were mainly Cenococcum. The number of sclerotia in burned stands was greater than in unburned stands. Seven types of mycorrhizas were recognized in *Pinus halepensis* root systems from bioassays: Cenococcum, E-strain, Rhizopogon, Suillus, Tuber, Xerocomus, and one non-identified. Nearly 100% of the roots were colonized by mycorrhizal fungi. Ectendomycorrhizas represented 50–90% of the total number. The predominant type is ectendomycorrhizas formed by ascomycetes included in the E-strain group (Pilar Torres and Mario Honrubia,1997).

Major wild fire impacts on people, property, and natural resources

During the 1990s, several forest fires occurred in the hills of Uttar Pradesh and Himachal Pradesh. From 1995 to 1999, fire hazards in these two states assumed dangerous dimensions. An area of 6,77,700 hectares was affected by these fires. The estimated timber loss from these hazards was US $ 43 million. Other losses due to these fires included loss of soil fertility, soil erosion, loss of employment, drying up of water resources, and loss of bio-diversity. These fires brought a major change in the microclimate of the region in the form of soil moisture balance and increased evaporation (Flannigan *et al.*, 2005). The dense smoke from the fires affected visibility up to 14 000 feet (Jhariya and Raj, 2014; FSI, 2017; WWF, 2017).

Impact of fire on vegetation

In present scenario when the conservation of endemic flora and fauna is the priority object certain exotics have become a real menace and threat to the local natives. (Srivastava, 1994, Mathew 1965). *Acacia mearnsii*, *Eupatorium glandulosum* and *Cytisus scoparius* have become a menace in Western Ghats and have replaced the valued flora at places. Fire is one of the major factors for such species, which is not only depleting undergrowth but also facilitating the germination of above-mentioned weeds (Gupta *et al.*, 2014).

Forest fire impact on the trees

Wood properties of *Pinus taeda* L. trees submitted to different burning levels (increasing fire intensity, I–IV). Wood samples were collected from trees in each of the burning levels and also from trees not affected by fire (control). Specimens were then extracted to evaluate the physical and mechanical wood properties; chemical composition was evaluated only for burning level IV and control. The analysis of the results showed that fire effects over the physical–mechanical properties and chemical composition in all burning levels did not cause sufficient chemical degradation and strength reduction, which could be cause for rejection of those woods for normal use. In the case of structural use caution should be adopted for the wood from burning levels III and IV, which had their mechanical property values reduced (Bortoletto and Moreschi, 2003).

Invasive species in north east India

The dwarf bamboo '*Sinarundinaria rollaona* (Gamble) Chao & Renv.', invades the surrounding forested areas following a fire and becomes the dominant component suppressing other native species. The dwarf bamboo is endemic to eastern Himalayas and also grows in the Dzukou valley and surrounding hills of north-east India. Over the past several years we have observed that the pristine forests of Dzukou valley and the surrounding hills are being destroyed extensively by frequent annual forest fires due to anthropogenic activities, causing a serious threat to biodiversity. The main cause of the fires is the thick growth of native dwarf bamboo in the valley and open spaces in the hills that gets burnt easily during the dry season. The dwarf bamboo grows more vigorously after the fire resulting in rapid colonization and invasion of the open spaces created by the forest fire. The fire–dwarf bamboo cycle has become an annual affair (Mao and Gogoi, 2010).

Plant adaptations to forest fire

Plants in wildfire-prone ecosystems often survive through adaptations to their local fire regime. Such adaptations include physical protection against heat, increased growth after a fire event, and flammable materials that encourage fire and may eliminate competition. For example, plants of the genus Eucalyptus contain flammable oils that encourage fire and hard sclerophyll leaves to resist heat and drought, ensuring their dominance over less fire-tolerant species. Dense bark, shedding lower branches, and high-water content in external structures may also protect trees from rising temperatures.

FOREST FIRE MANAGEMENT

Preparedness and mitigation measures in the past

During the British period, fire was prevented in the summer through removal of forest litter all along the forest boundary. This was called "Forest Fire Line". This line used to prevent fire breaking into the forest from one compartment to another. The collected litter was burnt in isolation.

Community involvement for fire detection and control

In India, Joint Forest Management (JFM) Committees have been established at the village level to involve people in forest protection and conservation (Khanna, 1998). At present there are 36 165 JFM committees throughout the country, covering an area of more than 10.24 million hectares. These JFM committees also have been given responsibilities to protect the forests from fires.

The forest fire management deals with the forest before the occurrence and during the fires. Before occurrence of the incidence, it aims at going for the early detection and reducing the damages to the minimum. The conventional methods of fire protection in India cover an elaborate network of fire lines, fire watchtowers, block lines etc., with very minimum human resources, which at times end up with inefficient fire control and management strategies due to accessibility constraints in forested regions. Satellite remote sensing with its synoptic and temporal coverage can augment the ground operations in terms of fire detection, damage assessment and mitigation planning in a time and cost-effective way.

Monitoring and management of forest fires is very important in tropical countries like India where 55 percent of the total forests cover is prone to fires annually causing adverse ecological, economic and social impacts (Gubbi, 2003). Studies on the impacts of tropical wildfires on the environment indicated high carbon emissions (Hao *et al.*, 1996; Fearnside, 2000), emissions of large amounts of trace gases and aerosol particles (Crutzen and Andreae, 1990), black carbon (Dwyer *et al.*, 1998) release of almost 100 million tons of smoke aerosols into the atmosphere as a result of biomass burning. These sub-micron smoke aerosols play a major role on the radiation balance of the earth atmospheric system (Kaufman *et al.*, 1998). Also, there is widespread concern about the loss of biodiversity, effects on atmospheric chemistry and increase in surface albedo and water runoff due to biomass burning. Synergy of Indian Remote sensing Satellite (IRS) systems covering IRS-P6, IRS-1D, and data given by TERRA/AQUA Moderate resolution Imaging Spectroradiometer (MODIS), National Oceanic and Aeronautic Administration - Advanced Very High Resolution Radiometer (NOAA-AVHRR), Defense Meteorological Satellite Program-Operational Line scan System (DMSP-OLS), Environment Satellite (ENVISAT) are useful in forest fire detection, active fire progression monitoring, near real time damage assessment, and mitigation planning. The Decision Support Center (DSC) is established at National Remote Sensing Centre (NRSC) as part of Disaster Management Support Programme of Department of Space (DOS), for working towards effective management of disasters in India. Considering the importance of forest fire management in India, a comprehensive Indian Forest Fire Response and Assessment System (INFFRAS) is invoked under DSC activities of NRSC, which integrates multi-sensor satellite data and ground data through spatially and temporally explicit GIS analysis frame work. The INFFRAS is designed to provide services on Fire alerts: Value-added daily daytime TERRA/AQUA MODIS fire locations and DMSP-OLS derived daily nighttime fire locations.

- **Fire progression:** Progression of fires using daily day and night fire location information given by MODIS/DMSP-OLS and burnt area expansion derived from temporal high-resolution data sets.
- **Burnt area assessment:** Mapping episodic fire events using moderate and high-resolution optical data sets
- Forest fire mitigation plans.

Earliest detection is done by the use watchtowers, which are being guarded by the forest guards. The watchtowers now may be equipped with various new gadgets to help in early detection and speedy transmission of the fire information if any.

Satellite remote sensing

Synergy of satellite systems covering IRS P6, IRS 1D, TERRA/AQUA, NOAA, DMSP, ENVISAT. National Remote Sensing Agency is providing services on Fire alerts, Fire progression, Burnt area assessment and Mitigation planning.

Fire alerts

Advances in remote sensing technology to derive information covering a broad spectrum of infrared region (IR) in multiple bands have facilitated detecting and monitoring fires. Dissemination of such information on active fire locations would be useful for efficient planning of control operations, understand trends in the expansion of fire occurrences both in time and space over larger geographic extent. Coarse resolution satellite data of sensors like MODIS, ASTER and AVHRR detect active fires based on the brightness temperature levels recorded in short wave and thermal IR wavelength bands. The coarse resolution fire products are validated using high resolution data sets of IRS P6 AWIFS, ASTER etc. The Defense Meteorological Satellite Program- Operational Line Scan System (DMSP-OLS) which can detect low levels of visible and near-infrared (VNIR) radiance at night is used in detecting the active fires during nights. Detection of active fires as a function of the pixel brightness temperature above that of background depends on fire temperature and size (area under burning) relative to the ground resolution of the sensor, fire and smoldering intensity levels, vegetation type and background land cover and atmospheric interferences.

Detection of fire

Fast and effective detection is a key factor in wildfire fighting. Early detection efforts were focused on early response, accurate results in both daytime and nighttime, and the ability to prioritize fire danger. Fire lookout towers were used in the United States in the early 1900s and fires were reported using telephones, carrier pigeons, and heliographs. Aerial and land photography using instant cameras were used in the 1950s until infrared scanning was developed for fire detection in the 1960s. However, information analysis and delivery were often delayed by limitations in communication technology. Early satellite-derived fire analyses were hand-drawn on maps at a remote site and sent via overnight mail to the fire manager. During the Yellowstone fires of 1988, a data station was established in West Yellowstone, permitting the delivery of satellite-based fire information in approximately four hours. Currently, public hotlines, fire lookouts in towers, and ground and aerial patrols can be used as a means of early detection of forest fires. However, accurate human observation may be limited by operator fatigue, time of day, time of year, and geographic location. Electronic systems have gained popularity in recent years as a possible resolution to human operator error. These systems may be semi- or fully-automated and employ systems based on the risk area and degree of human presence, as suggested by GIS data analyses. An integrated approach of multiple systems can be used to merge satellite data, aerial imagery, and personnel position via Global Positioning System (GPS) into a collective whole for near-real-time use by wireless Incident Command Centers. A small, high risk area that features thick vegetation, a strong human presence, or is close to a critical urban area can be monitored using a local sensor network. Detection systems may include wireless sensor networks that act as automated weather systems: detecting temperature, humidity, and smoke. These may be battery-powered, solar-powered, or tree-rechargeable: able to recharge their battery systems using the small electrical currents in plant material. Larger, medium-risk areas can be monitored by scanning towers that incorporate fixed cameras and sensors to detect smoke or additional factors such as the infrared signature of carbon dioxide produced by fires. Additional capabilities such as night vision, brightness detection, and color change detection may also be incorporated into sensor arrays. Satellite and aerial monitoring can provide a wider view and may be sufficient to monitor very large, low risk areas. These more sophisticated systems employ GPS and aircraft-mounted infrared or high-resolution visible cameras to identify and target wildfires. Satellite-mounted sensors such as Envisat's Advanced Along Track Scanning Radiometer and European Remote-Sensing Satellite's Along-Track Scanning Radiometer can measure infrared radiation emitted by fires, identifying hot spots greater than 39°C (102° F). The National Oceanic and Atmospheric Administration's Hazard Mapping System combines remote-sensing data from satellite sources such as Geostationary Operational Environmental Satellite (GOES), Moderate-Resolution Imaging Spectro-radiometer (MODIS), and Advanced Very High Resolution Radiometer (AVHRR) for detection of fire and smoke plume locations. However, satellite detection is prone to offset errors, anywhere from 2 to 3 kilometers (1 to 2 mi) for MODIS and AVHRR data and up to 12 kilometers (7.5 mi) for GOES data. Satellites in geostationary orbits may become disabled, and satellites in polar orbits are often limited by their short window of observation time. Cloud cover and image resolution and may also limit the effectiveness of satellite imagery (Ramachandran *et al.*, 2008).

Electronic forest fire detection system

Firehawk is a computer aided forest risk management system that is controlled by a human operator. The Firehawk system consists of the following elements (Figure 1).

- Cameras with zoom lenses.
- Pan tilt head, which allows for the movement of cameras.
- Masts (typically the camera assembly and transmission equipment are mounted on masts of either 30 to 72 meters in height depending on the surrounding topography).
- Microwave transmitters and receivers (used for the transmission of video from remote sites to the central control base).
- Radio telemetry links (the actual movement of cameras, i.e. pan, tilt and zoom, are controlled via these links, from the central base).
- Firehawk processor and software.
- Monitors (to display individual camera visuals at the control base.

Firehawk has been designed to be installed in remote areas where cameras can cover a radius of 6 to 8 km from the point of installation. Although the capability of cameras is far beyond the 6 to 8 km radius, weather conditions do not always allow detection of fires beyond this safe margin.
Real time video images can be transmitted up to 30 km. without repeating being required. These video images are fed to a central command base where they are processed and filter out unwanted image alarms and reporting only those required. During the past nine years the system has been installed and tested in various forestry areas throughout South Africa. The first installation was in the Richmond area of KwaZulu-Natal. This area was chosen for various reasons. Topographically it is very mountainous, extreme temperature changes occur, hot summers and very cold winters with snow on high ground often occurring. This ensured that the system was tested developed to not only work under severe weather conditions, but also be accurate enough to guide foresters to the source of a fire in the shortest possible time once detected. Presently Firehawk is installed in two regions of South Africa, and is continuously being expanded. Forestry companies (Mondi, Sappi, NCT, SQF and Masonite), Private growers and Government Agencies have committed themselves to the Firehawk system (Bonta *et al.*, 2017).

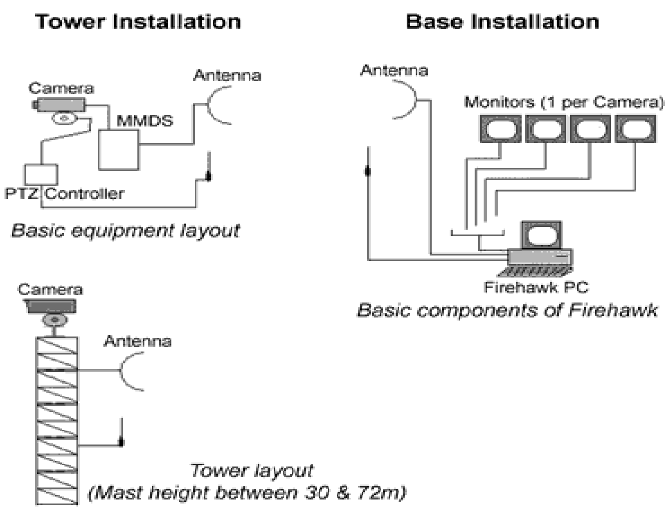


Figure 1. *Forest fire detection and risk management system (Firehawk).*

Optical sensor system

Optical Sensor System is a sensor with high resolution 1,360 × 1,024 pixel (total used for detection) and dynamics 16,384 grayscales. It works in the dark in night mode with increased sensitivity in NIR (Near Infra-Red). It has increased contrast for smoke detection. Night filter bloods out artificial lights. Quick response times even under night vision. Same resolution by the day and by the night. Each OSS rotates 360° in 4 to 10 minutes in 10° steps. Data transfer takes places through the tower site have a wireless connection with the office computer. Central Office the forest workers are provided with a workspace (computer, two fire monitors and a printer). The major purpose of work detection is done in this manner only. During a 360° rotation the sensor takes 3 images every 10°.For a better presentation of the smoke clouds 36 images are combined to form a panorama view in the control office. Reported smoke areas are marked on electronic maps. The operator evaluates all events by mean of the data transferred to the Central Office and his experience and knowledge (Sabri *et al*., 2013; Yadav *et al*., 2018).

Firewatch: Automatic early warning system for forest fires

Fire Watch is a terrestrial, digital, remote surveillance system which is capable of observing larger wooded regions, and to analyze, evaluate, link and store the collective data. Due to its sensitivity, accuracy and reliability the system enables an early recognition of forest fires. Fire Watch is able to evaluate and classify the incoming data in multiple ways, connected to a central station. In the event of a recognized source of fire, it automatically sends out an alarm. Fire Watch protects entire ecosystems and cultural landscapes. Fire Watch takes care of the economic resources of the endangered areas was tested successfully and has been installed in Germany, in the states of Brandenburg, Mecklenburg-Western Pomerania, Saxony-Anhalt and Saxony for several years. The technical performance of the system allows the usage in other states and / or countries (Fern´andez-Berni *et al*., 2008).

Fire detection using radio-acoustic sounding system

Forest fires are one of the most important and prevalent type of disasters and they can create great environmental problems for Nature (Guha-Sapir *et al*., 2017). It is known that they are detectable and easily preventable. When a wildfire burns out of control, the size of the losses can be almost immeasurable. The cost of such disaster may be millions of trees, in addition to losses of structures, animals (wild and farm), and human life. Sahin and Ince (2009) proposed system for early detection of crown and surface but not ground fires using radio-acoustic sounding system (Figure 2). In addition, that system can be combined with existing systems to augment the efficiency of fire detection for all types of wildfires.

Animals as mobile biological sensors for forest fire detection

Forest fires are the most prevalent type of disasters studied in the literature since they are relatively easy to prevent, and with the threat of global warming they are gaining increasing importance. Early detection of forest fires, containment at the beginning of the fire, and extinguishment before spreading has vital importance. For this reason, for many years, a large number of academic and theoretical studies and practical applications have been conducted on early detection of forest fires. Simultaneously, many environmental studies have been conducted on creatures that live in the forest habitat, especially those which are under the threat of extinction.

Near real time monitoring of active fires using MODIS based web fire mapper

With the availability of some satellites in recent past, it has now become possible to detect active forest fires in near real time and take remedial measures. MODIS (Moderate Resolution Imaging Spectroradiometer) is one such satellite system launched by the NASA (USA) which detects active forest fires. FSI has recently (since November 2004) taken initiative in active forest fire detection. It is using spatial information available on a website –the Web Fire Mapper (http://maps.geog.umd.edu) which displays active fire locations based on MODIS Rapid Response System- collaboration between NASA and University of Maryland, USA. The coordinates of active forest fire locations from these sites are projected on the forest cover map of India to select active fire locations within forest cover. The information is then disseminated through fax/e-mail to the concerned State Forest Department for confirmation as well as remedial measures.

Acquisition of data from the website (www.maps.geog.umd.edu): The attribute information of active forest fire is collected from the website (Web Fire Mapper). Main attributes include geo-coordinates, temperature, confidence level etc.

Processing of the point Data: The points taken from the website are saved in the excel sheets. The points showing zero confidence limit are removed from the database and then converted into text (.txt) file. The txt file is converted into ASCII (American Standard Code for Information Interchange) format for further conversion into the arc coverage (point coverage) using Erdas Imagine 8.7 software.

Geometric correction: The point coverage so obtained is then geo-referenced into Geographic Lat\Long projection system.

Joining of Attributes: The points are joined with other attributes such as state, district, and SOI toposheet number using Arc Info 8.2 Software. These points are overlaid on the forest cover map prepared by FSI. Points, which are not falling over the forested region, are removed and points that are falling on the forest are retained for further processing.

Dissemination of information: Details of the points falling within the forest cover like date of occurrence, geo-coordinates, state, district, and SOI toposheet no. are transferred to the excel sheet. The information so generated is disseminated to the concerned States through FAX/e-mail for taking remedial measures.

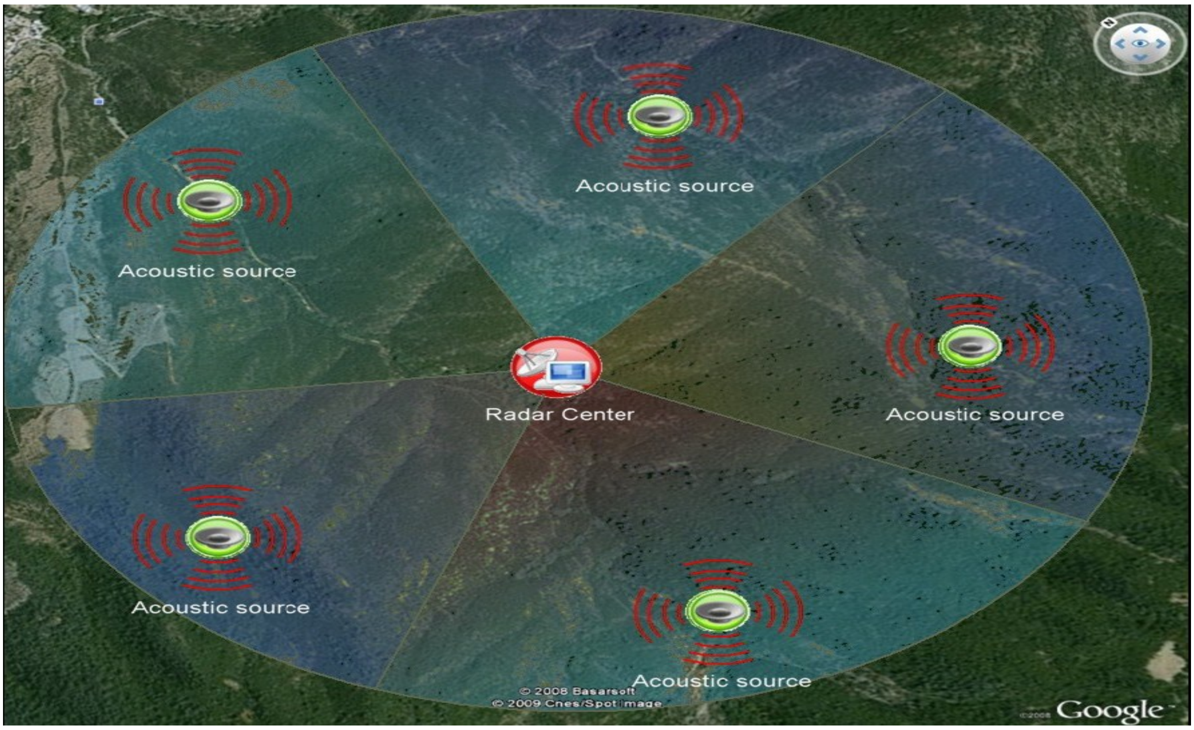


Figure 2. *Forest fire detection using radio-acoustic sounding system (Adopted from Sahin and Ince 2009).*

CONTROL OF FOREST FIRE

Fire lines: Creation of patches across an area where there are chances of fire spread is there. It has to be cleared afresh every year. As the continuity may be created by the grown vegetation. It can be roads also or vice versa.

Aerial firefighting: Aerial firefighting is the use of aircraft and other aerial resources to combat forest fires. The types of aircraft used include fixed-wing aircraft and helicopters. Smoke-jumpers and rappellers are also classified as aerial firefighters, delivered to the fire by parachute from a variety of fixed-wing aircraft, or rappelling from helicopters. Chemicals used to fight fires may include water, water enhancers such as foams and gels, and specially formulated fire retardants.

Air tankers: Airtankers or water bombers are fixed-wing aircraft fitted with tanks that can be filled on the ground at an air tanker base or, in the case of flying boats and amphibious aircraft, by skimming water from lakes, reservoirs, or large rivers. Air tankers are large planes equipped with tanks for transporting and dropping fire retardant (e.g., diammonium phosphate) or water in order to slow a fire down in support of fire line construction operations on the ground. Air tankers are primarily used for initial attack and structure protection. Typically, a red dye is added to chemical retardants to provide pilots with visual markers of drop accuracy. Capacities range from 2,000 to 3,000 gallons, although feasibility tests have been conducted for larger capacities (e.g., a 747 jumbo jet). Single engine air tankers have less capacity but greater mobility, an added advantage in mountainous areas.

Lead planes: Lead planes are smaller, mobile airplanes used to provide reconnaissance of burning areas from above and guide air tankers to desirable drop locations.

Infrared reconnaissance planes: Infrared reconnaissance planes are small airplanes equipped with specialized infrared mapping systems for detecting hot spots inside and outside a fire perimeter. Highly sensitive scanners are able to detect heat with a high degree of accuracy (6 inches spot from 8000 feet elevation). Geographic referencing of hot spots via global positioning systems (GPS) provides useful reconnaissance information.

Helicopters: Helicopters provide cargo and personnel support for firefighters working a fire perimeter. Helicopter can slow a fire spread by dropping water, foam, or retardant on burning trees, shrubs, and structures. Large helicopters carry up to 2000 gallons of liquid. Medium and light helicopters have lower capacities, down to 300 gallons or less.

Fire retardant: Borate salts were used in the past to fight wildfires but were found to sterilize the soil, were toxic to animals, and are now prohibited. Newer retardants use Ammonium sulfate or ammonium polyphosphate with attapulgite clay thickener or Diammonium phosphate with a guar gum derivative thickener. These are not only less toxic but act as fertilizers to help the regrowth of plants after the fire. Fire retardants often contain wetting agents, preservatives and rust inhibitors and are colored red with ferric oxide or fugitive color to mark where they have been dropped. Brand names of fire retardants for aerial application include Fire-Trol and Phos-Chek.

Chemical fire control: Retardants and foams make water more efficient as a suppressant by spreading water out over a surface and penetrating more deeply into porous fuels, much like a detergent extends water's usefulness for cleaning purposes. Some retardants also lower ignition temperatures, thus quickening fuel conversion while discouraging flaming and hastening extinction. Fire engines on the ground control operation make use of water and water enhancers such as fire retardants and foams. The retardant (slurry) dropped by airtankers and helicopters consists of water (85%), diammonium phosphate or sulfates (10%), and minor ingredients (5%). The mixture weighs about 9 lb per gallon, or approximately 1 kg per liter. Diammonium phosphate is the active ingredient that inhibits combustion and fertilizes the soil after the fire is out. Minor ingredients include iron oxide (a red dye, allowing the pilot to check the accuracy of the drop by providing visual evidence of spray pattern), and gums and clay thickeners. Use of aerial retardants may be restricted near creeks and streams due to possible toxicity effects on water fauna.

Conclusion

The forest fires are as old as forests but the human interaction has promoted the chances and ways in which the forest fire can occur. The uncontrolled and repeated forest fire have adversely affected the ecosystem completely with the change in the composition of vegetation, the extinction of species, the development of the various adaptations in plants which are not useful for man. The nutrient cycle and soil characteristics are affected, the soil erosion is promoted and subsequently man life is adversely affected. The cause of pollution and the global warming when the fires occurs frequently. The forest fire needed to be controlled at the start itself and the bigger fires should not be allowed to occur, the modern techniques of monitoring, detection and control must be used for avoiding the big fires.

ACKNOWLEDGEMENT

The authors desire to acknowledge Head, Department of Silviculture and Agroforestry, College of Forestry, Dr. Y. S. Parmar University of Horticulture and Forestry for providing necessary facilities and valuable support to accomplish this work.

Conflict of interest

The authors declare there are no conflicts of interest.

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