Type of article : Review Article.

**Forest Fires and Their Multidimensional Impact in India: A Comprehensive Review.**

**Abstract:** Forest fires pose a significant threat to ecosystems, biodiversity, climate stability, and human livelihoods, particularly in fire-prone regions like India. This review study investigates the causes, socioeconomic and environmental effects, and current management techniques of forest fires in order to better understand their complicated dynamics. The frequency and intensity of fires are rising due to both natural and man-made factors, such as shifting farming, climate change, and uncontrolled resource extraction. In addition to lowering biodiversity, degrading soil quality, and upsetting forest-based economies, forest fires also emit significant amounts of greenhouse gases, which exacerbate global warming. The study emphasizes how forest fires affect tourism, endanger non-timber forest products (NTFPs), and worsen socioeconomic vulnerabilities, particularly in tribal groups. It also looks at how community-based forest management, remote sensing, and satellite data are being used more and more for early detection and reaction. This review, which draws from recent research and policy developments, highlights the necessity of integrated fire management strategies that combine community involvement, policy enforcement, and technology innovation in order to reduce the danger of forest fires and promote ecological resilience in India.

**Keywords:** Biodiversity, Forest Fire, Climate Change, Community Participation, Remote Sensing.

**Introduction:** Forest fire occurs globally and has dire implications for ecology, environment, populations, and property [1]. Globally, forests cover 31% of land area, but an average of 36% of forested land is impacted by forest fires. Approximately 98 million hectares of forest, predominantly in tropical regions, were impacted by fire in 2015 [2].Forest fires cause the loss of flora and fauna, disrupt ecological functions, affect soil health, release greenhouse gases, and threaten the livelihoods of those reliant on non-timber forest products (NTFPs) such as bamboo and tendu leaves [3]. These recurring events necessitate a thorough analysis using multi-temporal remote sensing data and socio-economic assessments. In India, fires affect over 55% of the 67.5 million hectares of forest cover per year [4]. The forest ecosystem, the variety of plants and animals, and the financial richness are all severely harmed by forest fires. Drought, heat waves, lightning, and human activities like farming, grazing, and arson are some of the natural and man-made ingredients that frequently cause the nation's forest fires. Extreme wild fires occur all over the world every year, affecting millions of hectares of forest and having an impact on ecosystem functioning, biodiversity, and landscape stability. The most severe fires are crown fires, which are driven by high winds and spread quickly across tree canopies [5].

Over time, forest fires have been a growing problem that has devastated businesses, communities, and ecosystems [6]. Changes in land use and global warming have changed the dynamics of wildfires globally, as well as heat intensity, drought, and precipitation patterns [7]. These changes have increased the risk and frequency of forest wildfires [8][9]. Forest fires are distinct from other types of flames because they can spread over a wide region, even via highways. They pose a hazard to forest ecosystems, which leads to significant disturbances in all fauna and flora, which impacts biodiversity, ecology, and the environment [10][11]. The ecology, economics, and public health are all significantly impacted by forest fires, whether they are caused by human activity or natural causes [12]. Numerous elements, including the fire's origin, frequency, history, vegetation types, and degree of destruction, influence how it affects ecosystems [13].

Around the world, forest fires are frequent and have the potential to seriously harm the environment. A fire can spread swiftly and destroy houses, trees, and other structures due to the hot, dry conditions needed for it to begin. Both people and animals may be harmed by the smoke and heat from a fire. One of the things that have the biggest impact on forest biodiversity is forest fire. Not only can forest fires impact the flora and animals, but they also alter the qualities of the soil. By a variety of processes, such as volatilization, oxidation, ash transfer, and erosion, forest fires reduce the nutrient pool and impact the biological and physico-chemical quality of soils [14]. Traditional hunting methods that involve burning, destructive methods of gathering Minor Forest Produce (MFP), such as Boda (truffles) and Futtu, which unintentionally turn into infernos, are common causes of forest fires. These practices also serve to keep pests and wild animals at bay. Socially, fires have the potential to destroy property and human life, uproot communities, and affect livelihoods that depend on forest resources [15]. Numerous things, including arsonists, negligent campers, and lightning, can cause forest fires. Putting out a forest fire usually involves a large number of people and organizations, including firefighters, police, and forestry personnel.

In the past, forest fires were primarily identified by human monitoring from fire lookout towers using crude implements. The use of geospatial tools to identify fire activity has increased significantly in recent decades. Particularly effective methods for researching multi-scale forest fires, examining recurrent fire regions, offering useful data on fire numbers, and supporting both spatial and temporal fire detection are remote sensing data and geospatial approaches. Global fire data is obtained using remote sensing, with varying temporal and spatial resolutions [16][17].

This paper summarizes the body of research that has been done on forest fires in India from an environmental, social, and planning standpoint. This report provides an overview of India's forest and forest fire situation, along with information on the effects and fire safety measures. This study offers a fresh perspective on the Indian forest fire situation.

**Forest Fire Situation in India:** Fires have a significant negative impact on society, the economy, and the environment. Fire affects 55% of India's forest area on average, whereas grazing affects 78%, according to inventories done by the Forest Survey of India [18]. An estimated Rs. 440 crores is lost annually in India as a result of forest fires. According to the Forest Survey of India, there are 71.22 million hectares of forest cover in India, making up 21.67% of the country's total area. Of this, 3.02% is very thick, 9.39% is moderately dense, and 9.26% is open forest [19]. Recurrent annual fires affect 51% of the forest area in Assam and Gujarat, 93% in Arunachal Pradesh, 67% in Bihar, 69% in Himachal Pradesh, 46% in Jammu & Kashmir, 45% in Karnataka, 76% in Madhya Pradesh, 94% in Meghalaya and Orissa, 87% in Nagaland, 58% in Uttar Pradesh, and 33% in West Bengal, according to a study by the Forest Survey of India [20]. Very few fires in India are caused by natural causes. Human activity is the primary cause of 99 percent of the nation's forest fires. It is commonly known that the majority of these fires are intentionally started by humans, and that their socioeconomic circumstances are closely linked to this.

**Causes of Forest Fire:** There are many different causes of forest fires, including both natural ones like lightning strikes and man-made ones like arson, industrial processes, and agricultural practices.

**Natural causes -** Forest fires can start when lightning strikes during thunderstorms. The friction of bamboos swaying from high wind speeds, Volcanic eruptions, rolling stones that produce sparks to ignite fires in highly flammable leaf litter on the forest floor, and lightning that ignites trees are some of the natural causes of many forest fires [21].

**Anthropogenic causes -** Human activities and forest management practices are the causes of human-related issues. These can be purposeful or inadvertent. For instance, the centuries-old practice of shifting cultivation (particularly in the northeastern part of India and parts of the states of Orissa and Andhra Pradesh), the use of fires by villagers to ward off wild animals, the purposeful fires lit by residents near forests for recreation, and the occasional throwing of un-extinguished cigarettes, bidis, and matchsticks in the forest areas by picnickers, travelers, nomadic grazers, villagers, or even forest workers [21][22].

**Effect of Forest Fire:** In addition to affecting biological variety, ecosystem services, human lives, and natural habitat, forest fires also fuel global warming. Forest fire damages soil characteristics as structure, fertility, porosity, productivity, and hydraulic conductivity in addition to having an impact on biodiversity [23]. Forest fires have a number of ecological and socioeconomic effects, including a decline in biodiversity, global warming, the loss of fuel wood, feed, and non-timber forest products, a reduction in natural regeneration, a loss of wildlife habitat, an increase in soil erosion, and harm to natural water supplies.

**Biodiversity -** Forest fires have a significant impact on biodiversity worldwide, contributing to climate change and releasing enormous amounts of carbon into the sky. Intense flames have the potential to destroy ecosystems, reduce forest carbon stores, and hinder plant photosynthesis on a regional level. Due to the absence of fire-resistant adaptations in tree bark, rainforests are susceptible to fires during extreme droughts. The extensive use of slash-and-burn farming methods, such growing Jhum, has resulted in severe deforestation and the extinction of many endangered plant species. Numerous lichens, mosses, fungus, and other organisms are also lost as a result of these enormous fires [24].

**Effect of Fire on Soil Properties -** The composition and soil structure of post-fire forests are significantly impacted by forest fires [25]. The biological, chemical, and physical characteristics of soils are greatly impacted by forest fires [26][27]. Due to the consumption of soil organic matter, intense burns may negatively impact the physical characteristics of the soil. The changes that take place during the fire are directly caused by heat transmission from burning biomass both on the soil's surface and inside it [28]. The intensity, duration, and frequency of fires determine their impact on soil parameters [29][30]. Direct heating of the soil below 7 to 10 cm is always a result of the most intense forest fires. The soil in the fire-affected area thus loses its ability to retain water and becomes susceptible to erosion [31].

**Impact of Fire on Soil Micro-organism -** As sources and sinks of essential nutrients and catalysts of nutrient transformations, soil microorganisms play a variety of roles in forest ecosystems. They also act as engineers and maintainers of soil structure and develop reciprocal relationships with roots that enhance plant fitness [32]. Forest fire has the power to drastically change microorganisms that impact large-scale functions including the cycling of nutrients [23]. Both direct and indirect effects of fire are felt by biological beings. Soil micro-organisms fire has a direct effect on soil micro-organisms. Long-term environmental changes are typically caused by indirect effects.

**Effect on Socio-economic -** Forestry makes up almost 1.5% of the country's GDP and is the second-largest land use after agriculture [33]. Forest fires negatively impact livelihood resources, particularly for tribal people who live in or close to forests. Forest fires have a direct impact on an estimated 65 million tribal people in India who rely on gathering non-timber forest products from forested regions for their livelihood [21]. Since smallholders depend on the forest for a variety of services and purposes, the financial losses resulting from forest fires might be significantly higher for them than for largeholders [34]. NTFPs, a significant source of income for communities that depend on forests, are extremely susceptible to fire. Tribal economies are directly impacted by Chhattisgarh, which is one of the top five states with the highest number of fire alerts [3]. Socio-economic stability is significantly impacted by the depletion of cropland, the loss of forest resources, and the rise in health problems brought on by smoke exposure.

**Climate Change -** It has been noted that the dominating anthropogenic activities, which have been surpassing the limits of natural variability, are causing climate change. Forest fires are one of the many effects linked to climate change [35]. Forest fires are impacted by climate change, and climate change may be impacted by forest fires. The long-term climate impacts of trace gas emissions from forest fires have been extensively studied [36]. Smoke from wildfires can transcend continents and influence air temperature, cloud formation, and monsoon patterns. An average temperature increase of 1°C might lengthen the wildfire season in North Asia by 30%, according to [37]. More experimental research on artificial grounds is necessary in this context. Climate change is predicted to cause more severe and frequent wildfires in some parts of the world in the future [38][39].

**Effect of Forest Fire on NTFPs -** An assessment of the impact of forest fires on NTFPs was conducted. Deliberate burning, FRA encroachment, and setting fire to gather Boda, Mahua, and Tendu leaves are the primary causes. Depletion of vegetation that yields non-timber forest products (NTFPs), a reduction in species diversity and changes in the quality and availability of these goods were the direct effects. Negative impacts on non-timber forest product (NTFP) supply chains, financial losses for local residents who depend on NTFP harvesting, and modifications to biological interactions that affect pollination, seed distribution, and the suitability of habitats for NTFP species are all examples of indirect consequences [40].

**Reducing Tourism Values -** A pleasant tourist experience is negatively impacted by smoke and haze produced by fires, particularly when mountain views play a major role in the trip. Tourists get a bad perception of fire in the forest. Fire smoke degrades air quality and visibility, which has a negative impact on the travel and tourism sector. Smoke production must be reduced from the standpoint of the entire tourism sector, particularly during the busiest travel months of April through June.

**Global Warming -** Forest fires both directly and indirectly contribute significantly to global warming. Large volumes of greenhouse gases (GHGs), including carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O), are released by them. These gases trap heat in the atmosphere and exacerbate the greenhouse effect. Forest fires cause the plants and soils that naturally absorb CO2 to be destroyed. In addition to decreasing the ability of forests to sequester carbon, this might turn them from carbon sinks to carbon producers. Particularly in the Arctic, black carbon aerosols from forest fire smoke settle on snow and ice, decreasing their albedo (reflectivity) and hastening ice melt. Global warming is exacerbated as a result of this additional positive feedback loop contribution to the climate system [41].

**Fire management strategies in India:**

**Detection Techniques -** In the fight against wildfires, prompt and efficient detection is essential.  The goals of early detection initiatives were to prioritize fire hazard, provide reliable results both during the day and at night, and enable early response. Currently, there are several ways to detect forest fires early on, including ground and aerial patrols, fire lookouts on towers, and public hotlines. Wireless sensor networks that function as automated weather systems, measuring temperature, humidity, and smoke, are examples of detection systems [42]. However, satellites and ground-based measurements are currently used in India to identify fires. More accurate findings may be obtained by using multi-feature fire-based detection [43].

**Implementing satellite and remote sensing approaches in forest fire management and limitations -** Utilizing distant observation techniques and satellite data distant sensing has emerged as a crucial tool for fire monitoring and analysis. For determining active fire locations, assessing burn intensity, and tracking changes in vegetation cover over time, MODIS, Sentinel, and Landsat provide useful data [44]. The Visible Infrared Imaging Radiometer Suite (VIIRS) and the MODIS (Moderate Resolution Imaging Spectroradiometer) sensor are used in India for satellite-based hotspot observation for active forest fire detection systems [45]. In 2007-2008, India introduced the first forest fire alert system using satellite detection. Research is being done to develop fire-resistant plant species that can help reduce wildfire spread [46]. Remote sensing is a helpful tool in managing forest fires, but it does come with some challenges. For one, thick clouds and smoke can block satellite sensors, making it harder to spot fires in real time. Also, many satellites don’t have high enough resolution to catch smaller or less intense fires, which can still be dangerous. There’s often a delay in data updates, which means fire alerts might not come quickly enough when a fire is spreading fast. On top of that, using this technology effectively requires skilled personnel and costly equipment, which aren’t always available in all regions. Finally, without enough on-the-ground support, satellite data alone might not give a full or accurate picture of what’s happening in the forest.

**Involvement of Communities in Forest Fire Management -** To engage people in forest conservation and protection, Joint Forest Management (JFM) Committees has been formed at the village level in India [47]. The forest service employs local seasonal fire monitors to help with fire detection and response. No proper equipment or training materials are provided to these fire watchers [45]. Proactive fire management relies heavily on government-NGO cooperation, local fire departments, and awareness campaigns. Community awareness programs should be implemented, and state forest administrations should allocate sufficient funds for these projects. The efficacy of community-based forest management (CBFM) is becoming more widely acknowledged. Several regions have demonstrated the effectiveness of empowering local stakeholders through early detection systems, fire-line construction, and education [48].

**Preventive Measures -** The clearing of forest debris throughout the entire forest perimeter helped to minimize summer fires during the British era. The "Forest Fire Line" was the name of this. This line was used to stop fire from spreading from one compartment to another within the forest. Litter that had been gathered was burned separately. The Government of India has undertaken several key initiatives to manage fire, including the formulation of the National Forest Policy in 1988, the development of The National Master Plan for Forest Fire Control, and the creation of Guidelines in 2018. For the first time, the state has created a forest fire management policy to help the government coordinate efforts with other agencies and concentrate on fire prevention issues. The policy combines community-based firefighting tactics with contemporary firefighting techniques. To raise public awareness of the detrimental impacts of forest fires, a Fire Week celebration should be held. Additionally, laws pertaining to fire prevention and management should be strictly enforced. Early fire detection, real-time monitoring, and prompt response planning are made possible by the use of sensor networks, drones, and satellite data. A startling lack of research demonstrating the efficacy of wildfire prevention education (WPE) initiatives was noted [49]. It is imperative that an adaptive management plan be established at this time. The deployment of early warning systems, like the Forest Fire Alert System (FAST), which employs satellite data to identify forest fires and notify authorities, is one such initiative [50].

**National Action Plan on Forest Fire (NAPFF):** The Ministry of Environment, Forests, and Climate Change (MoEFCC), Government of India, introduced the National Action Plan on Forest Fire (NAPFF) in 2018 as a strategic framework. It was created in reaction to India's increasing forest fire frequency and severity, particularly in ecologically vulnerable areas like the central tribal belts, the Western Ghats, and the Himalayan region. In India, forest fires threaten biodiversity, local livelihoods, and climate resilience in addition to causing enormous ecological and financial losses and releasing large amounts of carbon emissions. The NAPFF is a policy-level program that uses a coordinated, proactive, and responsive strategy to reduce the risk of forest fires. The plan's fundamental tenets are community involvement, prevention, early detection, quick response, and recovery. One of its main aims is to reduce the number of forest fires, not just by responding quickly when they happen, but also by putting long-term preventive measures in place. It also focuses on empowering forest departments and local communities by providing them with training, modern tools, and spreading awareness about how to manage and prevent fires. Another key goal is to encourage sustainable ways of managing forests—by combining age-old traditional knowledge with advanced technologies like remote sensing, GIS mapping, and tools that help predict fire risks before they escalate.[51]

The National Action Plan on Forest Fire is a well-rounded initiative that aims to protect both nature and the people who depend on it. It brings together science, strong institutions, and local community efforts to tackle the growing threat of forest fires. More than just a firefighting plan, it plays a vital role in fighting climate change, preserving biodiversity, and ensuring that India’s rich forest resources are protected for the generations to come.

**Case Study:** In the Uttarakhand Himalaya, a striking increase in seasonal forest fires has had serious ecological consequences. A study by Bargali et al. (2024) mapped fire patterns over the past decade and found a 25% rise in fire frequency, attributed to both climate change and human activity. Using satellite data alongside field surveys, the researchers discovered that intense fires had devastated vegetation, causing a 40% drop in tree density in severely impacted regions. Moreover, the fires depleted soil health soils lost an average of about 15% of their organic matter, jeopardizing the forest’s ability to recover and support biodiversity.[52]

Despite these threats, the study also points to promising paths forward. It highlights management strategies like prescribed burning to reduce fuel loads and engagement of local communities, both shown to enhance prevention. The paper underlines the importance of weaving ecological, social, and institutional perspectives together, advocating for science-informed, community-involved fire strategies that can help restore resilience in Uttarakhand’s forests.

**Conclusion:** A major environmental and socioeconomic issue in India, forest fires is made worse by both human activity and climate change. The review emphasizes that human activity, originating from customs, carelessness, and a lack of knowledge, is responsible for the great majority of fires in India. Carbon storage, biodiversity, soil health, non-timber forest products (NTFPs), and the livelihoods of populations that depend on forests are all negatively impacted by these fires. By changing the dynamics of forest carbon and releasing significant amounts of greenhouse gases, they also contribute to global warming. In areas like Arunachal Pradesh, Madhya Pradesh, and Chhattisgarh, where the yearly recurrence of fires is startlingly high, the situation is especially dire. The long-term ecological effects of fire episodes are shown by changes in biodiversity, soil deterioration, and microbial life loss. When paired with satellite-based fire alarms, remote sensing technologies like MODIS and VIIRS have greatly enhanced fire monitoring and detection. Investment in adaptive forest management, public education, enforcement of policies, and active community involvement are necessary to support technology solutions. India's fire management strategy needs to encourage early warning systems, increase preventive education initiatives, and combine contemporary methods with indigenous expertise. The establishment of a resilient forest ecosystem requires stronger legal frameworks, community incentives, and the strengthening of local forest departments' and Joint Forest Management Committees' capabilities. Multi-stakeholder cooperation, cross-sector policy integration, and more research on fire ecology, socioeconomic adaptability, and fire-resistant plant species are desperately needed to reduce the escalating hazards. India can only effectively manage and lessen the destructive effects of forest fires by implementing a comprehensive, inclusive, and scientifically supported policy.

Disclaimer (Artificial intelligence)

We, Manikchand and Dr. Ayushi Trivedi, hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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