



FOREST FIRE DYNAMICS IN HIMALAYAN ECOSYSTEMS OF UTTARAKHAND AND CONTROL STRATEGIES

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ABSTRACT

In Himalayan region of Uttarakhand, forest fires have become a major environmental worry and serious issue of environmental concern, negatively affecting the region's biodiversity and delicate ecosystems. This study offers a thorough examination of the underlying causes, ecological effects and spatiotemporal patterns of forest fires in this mountainous area. Further, it also aims to understand the detrimental impacts of forest fire on Himalayan ecology. This study is a composite document of reports, research publications and other pertinent sources of informations including field surveys, remote sensing data and meteorological records to identify the main factors responsibly aggravating the incidences of forest fire such as anthropogenic activities, climate variability and difficulties with forest management. The role of localities for this disaster cannot be ignored. The results show that longer dry spells and higher temperatures are associated with a considerable rise in fire frequency and intensity, which is made worse by human-caused factors such as shifting land uses and unsustainable resource extraction. In order to reduce fire risks and foster ecosystem resilience, the study emphasises the need for improved fire monitoring systems, community involvement in fire prevention, public awareness and campaign programs and the application of adaptive forest management practices. For stakeholders and policymakers seeking to protect forest landscapes of Uttarakhand in the face of mounting environmental pressures, the results will offer vital insights.

KEYWORDS: Forest fire, Natural causes, Anthropogenic activities, Global warming, Himalayan ecology

INTRODUCTION

For ages, forest fires have remained an incidence occurring in several ecosystems and presumed to be required for regeneration of forests (Li et al. 2022; Rybansky, 2022). However, the frequency and severity of forest fires have increased as a consequence of land-use patterns, human-induced climate changes and other anthropogenic interventions, causing serious harm to the environment, economy and public health (Maurya et al. 2022; Namburu et al. 2023). Developing efficient fire management and mitigation plans require an understanding of the variables affecting the frequency and severity of fire impacts. Often, forest fires occur at the lowest level but gradually become uncontrollable. Among three required components of fire-fuel, oxygen and heat, the two earlier are available in forest environment (Yan et al. 2022), though, the heat (very crucial for this devastation), being the main cause of forest fires, can be produced by both natural and man-made sources. The known natural causes of forest fire are volcanic eruptions, stone-to-stone friction, lightning and others (Kirsanov et al. 2020). In any terrestrial forest landscape, fire incidences may occur by natural causes like

lightning or volcanic eruptions or it can be anthropogenic in nature (intentional or unintentional). Forest fires can be grouped as surface, ground and crown fires (Pyne et al. 1996). Further, the anthropogenic interventions, on the other hand, can be envisaged in the form of campfires, picnic cooking, smoking and drinking, shifting farming and villagers destroying forest cover for road construction and sparking in electric supply systems. The forest fires are detrimental for ecosystem and the environment at local, regional, national and ultimately at global levels (Gupta et al. 2022). Such harmful effects are quite common in India. The pathetic episodes of forest fires occur mostly during the summer season in hills of Uttarakhand. Both the anthropogenic disturbances and climate change are accountable for increasing the frequency of forest fires. Satellite pictures help us in monitoring the damages caused by forest fires and synoptic coverage of the area. These can be used to record and monitor the substantial damage caused by forest fires to natural resources (Gupta et al. 2018). The release of large volumes of carbon dioxide and other greenhouse gases in atmosphere worldwide contributes to forest fires due to changes in the climatic conditions which finally culminates in the form of global

warming (Gale et al. 2021). Forests are carbon sinks and their burning releases stored carbon and decreases their ability to absorb emissions in the future. Forest fires worsen natural habitats and mount serious threats to the survival of many plant and animal species in India, where forests constitute a vital part of the nation's varied ecosystems (Hao et al. 2022). Furthermore, fire-related smoke and particle matters exacerbate air pollution and cause detrimental effects on both the environment and human health. The already severe air quality problems are further aggravated due to forest fires in our country and also adversely affects the climate conditions and the environmental deterioration (David et al. 2022).

Conventional field procedures can be beneficial in evaluating the fire risk potential and predicting fire likelihood. Regardless of its importance for ground validation these procedures are labour and cost intensive along with time consuming (Avetisyan et al. 2022). A variety of models have been developed to analyse and quantify forest fire risk for helping academicians and practitioners to anticipate, prevent and manage the unseen dangers of wildfires. (Chen et al. 2022). These models range from fire danger rating systems (FDRS)- accountable for measuring the risk of fire ignition and prospective fire management challenges to fire behaviour prediction (FBP) models which forecast potential fire behaviour such as rate of spread, intensity and flame length. While some of these models use remote sensing and machine learning techniques to improve forecast accuracy, others integrate geographic information systems (GIS) to spatially analyse the landscape and fire-related variables (Feng et al. 2022).

The ecosystem, biodiversity and the livelihoods of populations, depending on forest resources, are all seriously threatened by forest fires, especially in areas with varied topography like Pauri Garhwal District of Uttarakhand. This work uses a combination of remote sensing and GIS-based analysis to give a geospatial approach to forest fire risk zone. Approximately 575 forest fire incidences occurred in Uttarakhand from November 1, 2023 and destroyed 689.89 hectares of green cover zones along with a damaging loss of more than of Rs.14 lakhs. High temperatures and dry conditions make the state more vulnerable to summer forest fires, which calls for concerted prevention efforts, community involvement and legislative changes (<https://www.mypunepulse.com/forest-fires-in-uttarakhand-threaten-nainital-region-boating-activities-stalled/>). With 1,524 forest fires recorded in Nainital during 2024, the city is known primarily affected by the continuous forest fires in Uttarakhand followed by Champawat with 1,025 and Almora with 909 incidences. From 804 in March 2023 to 5,710 in April 2024, data demonstrate a dramatic rise in fire incidences. The climax of forest fires is seen to occur usually between March and May the April alone witnessed more over 110 hectares loss. Despite obstacles brought on by inaccessibility and circumstances that encourage fire spread, the Indian Air Force and NDRF work as main supporters of firefighting efforts. High temperatures, insufficient precipitation and urbanisation, which results in decreasing the forest cover zones, are the contributory factors to increase the forest fire incidences (<https://theprint.in/india/5710-forest-fires-in-april-alone-uttarakhands-burning-problem-whats-behind-it/2062428/>).



(source: google)

Fig a. Nainital, Champawat and Almora have been the most severely affected districts by the ongoing forest fires, with 1,524 fires reported in 2024 (<https://theprint.in/india/5710-forest-fires-in-april-alone-uttarakhands-burning-problem-whats-behind-it/2062428/>).



LITERATURE REVIEW

Forests are considered as the most significant terrestrial ecosystems of land and support rural communities as well as wildlife. These resources are constantly being degraded and depleted due to human indulgences and alterations in the climate (Arya, 2022). Fire is one of the primary causes of forest degradation in India and has a number of negative ecological, economic and social repercussions. The forests in Uttarakhand have predominantly different *Pinus* (Chir) species and may be divided into four zones: sub-tropical, temperate, sub-alpine and alpine. In summers, the dry chir leaves create a fire hazard that harming the human life as well as putting in danger the survival and sustenance of wildlife and environment. Due to the accumulation of resin-rich leaf litter on the forest floor throughout the summer, Chir Pine (*Pinus roxburghii*) woodlands with around 16% of Uttarakhand's total forest area (between 1000 and 1800 m ASL), are particularly susceptible to forest fires. Every year, the state government allocates between Rs. 2500 and Rs. 3000 lacs for forest management and fire safety. Regardless of the chip leaves igniting and ablazing the fire in forests, these can be used to make briquettes there by lowering down the fire management expenses, mitigating the forest fire incidences and create more jobs. Besides, this practice will also enhance the income for the state (Singh et al. 2025). In April and early June of 2016, a large forest fire (2069 forest fire incidences), affecting 4423 hectares of forests, occurred in the Chir Pine woodlands of Uttarakhand (Negi, 2019). Throughout history, forest fire has impacted both the evolution of human civilisation and environmental changes (Agee, 1993). "Fire is a good servant but a bad master" is a common saying. Schmerbeck and Seeland (2007) stated that fire can be used to manage wildlife habitats, increase fuel supply, clear forests for agriculture, promote the establishment of fodder for grazing, facilitate the harvesting of non-wood forest products and more.

The mapping of fire occurrence and its susceptibility is crucial for forest managers to comprehend the spatial distribution of forest fires (Singh and Suresh, 2021). Together with the ground observations, gathered from the manual survey, Uttarakhand Forest Department and Forest Survey of India provided the locations of previous forest fire incidents reported between November 2002 and July 2019 (Tiwari et al. 2021). It has been predicted that about 36% of forest cover in India is vulnerable to regular forest fires. It is reported that about 6% of the nation's forest cover is deemed to be extremely fire prone, while nearly 4% of the forest cover is more prone to fire (Yuan et al. 2015; Chowdhury et al. 2015). The Suomi-national polar-orbiting partnership-visible infrared imaging radiometer Suite (SNPP-VIIRS) detected 3,45,989 forest fires during the forest fire season from November 2020 to June 2021

worldwide, while the moderate resolution imaging spectro-radiometer (MODIS) sensor recorded an estimated 52,785 forest fires. Thus, forest fires can have catastrophic effects both for people and animals (Ivanova et al. 2022). Based on these findings, experts may chalk out focused fire prevention and mitigation policies for consequential protection of the environment, economy and human lives (Kant et al. 2012). The Supreme Court of India has approved the government's efforts to maintain these firebreaks in order to prevent wildfires. Firelines, clear strips that prevent the spread of fire; were first made for forest management. On May 17, 2023, the Supreme Court approved silviculture and tree-cutting practices for preserving these firelines. The goal is to improve fire management capacity by clearing 400 kilometres in two years. A significant decrease in the occurrence of forest fire i.e., from 3,084 to 1,347 was noticed since November 1, 2022, however, the state witnessed the highest number of forest fires in India between November 2023 and June 2024. Such high incidences of forest fires badly impacted the local ecosystem and biodiversity (<https://www.hindustantimes.com/india-news/ukhand-looks-to-revive-british-era-firelines-101743273558391.html>). We have endeavoured, through this research review paper, to develop a comprehensive system for assessing the risk of forest fires in different regions of Uttarakhand. Further, this research analysis focuses on ensuring protection to the biodiversity and dependent populations of Garhwal region by underscoring the urgent need for data-driven, region-specific mitigation strategies because of the increasing risks of forest fires.

CAUSES AND ECOLOGICAL DRIVERS OF FOREST FIRES IN UTTARAKHAND

A study in Kangra region of the western Himalaya of India was conducted to determine the optimal forest fire conditions by superimposing geographic coordinates over many theme layers. The *Pinus roxburghii* forest with low elevation, high temperatures, high slope, south-west facing aspect, May month and human disturbances were identified as the primary causes of forest fires. Half of the forest cover was determined to be fire-sensitive and 10.7% of the forest cover was classified as high fire-prone (Kumar et al. 2015). The Chir Pine is the most important species in India, with a span of 8900 km and a rich cultural and mythological past (Tiwari 1994). It forms a straight, cylindrical bole and is one of the most important timber trees in forestry plantations. Mass regeneration for resin tapping was promoted during the British era, despite the Chir Pine's long history in Himalaya (Rawat 1991). Pine trees are important because they produce valuable resin from their bole. In terms of resin manufacturing, India comes in sixth place out of the top 10 countries worldwide. Human pressure has accelerated deforestation and forest degradation processes. It is known that forest fires posed serious harms in South East Asia, the Amazon and the

Rocky Mountains. These fires not only hurt people, alert invading species and change atmospheric gases, but also endanger biodiversity and affect adversely the environmental factors including humidity, temperature and solar radiation.

Numerous tree species, such as chir pine, blue pine, ban oak, sal, sissoo, eucalyptus and others, can be found in the forest of Uttarakhand. Its transition zone with sal at lower elevations, which has the largest density of habitation (11% of the total forest area), the banj oak zone at higher elevations, and the chir pine zone, which represents 17% of the overall forest region, are the areas most prone to fire. Controlled forest fires help to remove the dried-out garbage

and promote the growth and development of fresh vegetation. However, the biodiversity of forests is greatly diminished by uncontrolled forest fires, particularly the summer fires. During summer season, the moisture content in forests decreases at alarming rates and it, thus, increases high risk of fire and its rapid spread across a wide area of forest land. In Uttarakhand, man-made fires are more common than lightning-related fires, despite the fact that lightning has been found to be the primary source of forest fires. All fires in Chir pine forests of Uttarakhand, whether deliberate or unintentional, are caused by human activity. In Uttarakhand, 63% of all fires were malevolent, while 37% of all forest fire occurrences were



inadvertent (Chauhan et al., 2018).

(source: google)

Fig b. One of the main causes of forest fires is the dry pine needles. In Uttarakhand, pine trees make about 26% of the total forest area (<https://www.downtoearth.org.in/forests/here-are-some-ways-to-combat-forest-fires-in-chir-pine-belt-of-uttarakhand-89422>).

IMPACTS OF FOREST FIRES ON HIMALAYAN ECOSYSTEMS AND LIVELIHOODS

It is critical to have a thorough understanding of how fire affects our economy. Animals are killed and vegetation is destroyed by the heat effects of fire including its burning impacts. The residual chemical effects also affect the soil (Brown and Davis 1959). Animals are killed, vegetation is

destroyed, soil and water streams are heated, air pollution is exacerbated and daily wage workers suffer as a result of forest fires. Forest fires also affect the soil productivity, forest structure and biodiversity. Climate change and human misuse of fires are serious threats to forests and their biodiversity, besides, affecting adversely the health of ecosystems (Dennis et al. 2001). Carbon emitted by the forest fires destabilise the biodiversity and global warming



conditions including negative impacts on the hydrological cycle, biomass stocks, coral reefs, plants and animals. Dry trees in forests serve as fuel and thus increase the likelihood of fires and promote the growth of species susceptible to them. In tropical rain forests, fires can disrupt the ecological balance by causing insect colonisation and illnesses (Turvey, 1994). Severe fires have significantly reduced plant diversity. Agricultural clearing is one of the primary causes of fire in tropical forests. Sometimes, deforestation fires in the forests, due to increased human activity, put on fire the entire forests leaving only the barren lands. In forests that are not fire-adapted, fire can destroy nearly all seedlings, sprouts, lianas and young trees since they are not protected by thick bark. Damage to the seed bank, seedlings and saplings hinders the recovery of the original species (Woods, 1989). Forest fires promote species that have evolved to withstand fire and survive including Lodgepole pine and Jack pine. Despite this, these fires cause stress and habitat loss for the animals. The loss of significant biological organisms slows down the regrowth of forests (Boer, 1989). Small mammals including lemurs and bats lose their territory, habitat and shelter due to forest fires and thus the biodiversity is

disrupted. Hornbills and other bird species do not get the required food from fruit trees in tropical woods. The decline in small carnivore population is also a result of rats running away. Fire in the forest is also known to significantly decrease the number of arthropod population-serving as food for both carnivores and omnivores (Kinnarid and O'Brien, 1998). Concerns have been expressed regarding the level of damage to the state's vital green cover due to a disagreement between Uttarakhand Forest Department and the Forest Survey of India's (FSI) reports on forest fires. Approximately 180,890 hectares of Uttarakhand forest land was known damaged by the forest fires and thus ranked the state as ninth most harmed ones in the country (FSI's 2023 report). Sorry to note that fire incidence in forests could not stop despite assertions of massive forest protection initiatives including the controlled burning. Further 1,771 hectares of forest land were allegedly affected by 1,276 fire incidences in 2024, despite the state's forest department conducting controlled burning over 201,253.94 hectares in 25 forest divisions (<https://www.newindianexpress.com/nation/2025/Jul/17/forest-fire-data-in-uttarakhand-shows-massive-discrepancy->



between-state-central-agencies).

(source: google)

Fig c. Massive disparity in Uttarakhand's forest fire (<https://www.newindianexpress.com/nation/2025/Jul/17/forest-fire-data-in-uttarakhand-shows-massive-discrepancy-between-state-central-agencies>).

METHODOLOGY

We conducted a thorough literature review on the chosen topic by looking through a variety of sources, such as review papers, journal volumes and PDF files. Several search engines, including Google Scholar, Research Gate, Google Chrome, Google and others, were used to record these observations. As a result, sufficient knowledge was gathered on the subject of our interest, which greatly added in evaluating and comprehending the concept of selected topic under study.

OBSERVATION

Garhwal region of Uttarakhand has seen a sharp rise in forest fire incidents, particularly during the pre-monsoon summer months. The most frequently affected areas are chir pine (*Pinus roxburghii*) forests, as demonstrated by satellite imagery, secondary data processing and field observations. These forests are highly combustible due to the accumulation of dried resin-rich needles that act as potent fire fuel. Localised fires that often started near human populations were shown to be caused by

anthropogenic triggers, such as careless rubbish burning, agricultural residues and resin tapping methods. Concern over how climate change, which is marked by longer dry spells, less winter precipitation and rising temperatures, has increased the vulnerability of forests is also growing. In many areas, it was found that fire lines were either nonexistent or poorly maintained, allowing the fires to spread rapidly. Higher elevations where broadleaf forests, like oak, are more prevalent faced fewer fire incidences, but when they did occur, the ecology suffered greatly. The repeated fires have often resulted in a reduction in local water sources, soil fertility and forest biodiversity. Additionally, there is a noticeable deficiency in community-based fire management strategies and preparedness in many affected areas. This research highlights the urgent need for an integrated fire prevention strategy that includes ecological restoration, climate adaptation and local community engagement.

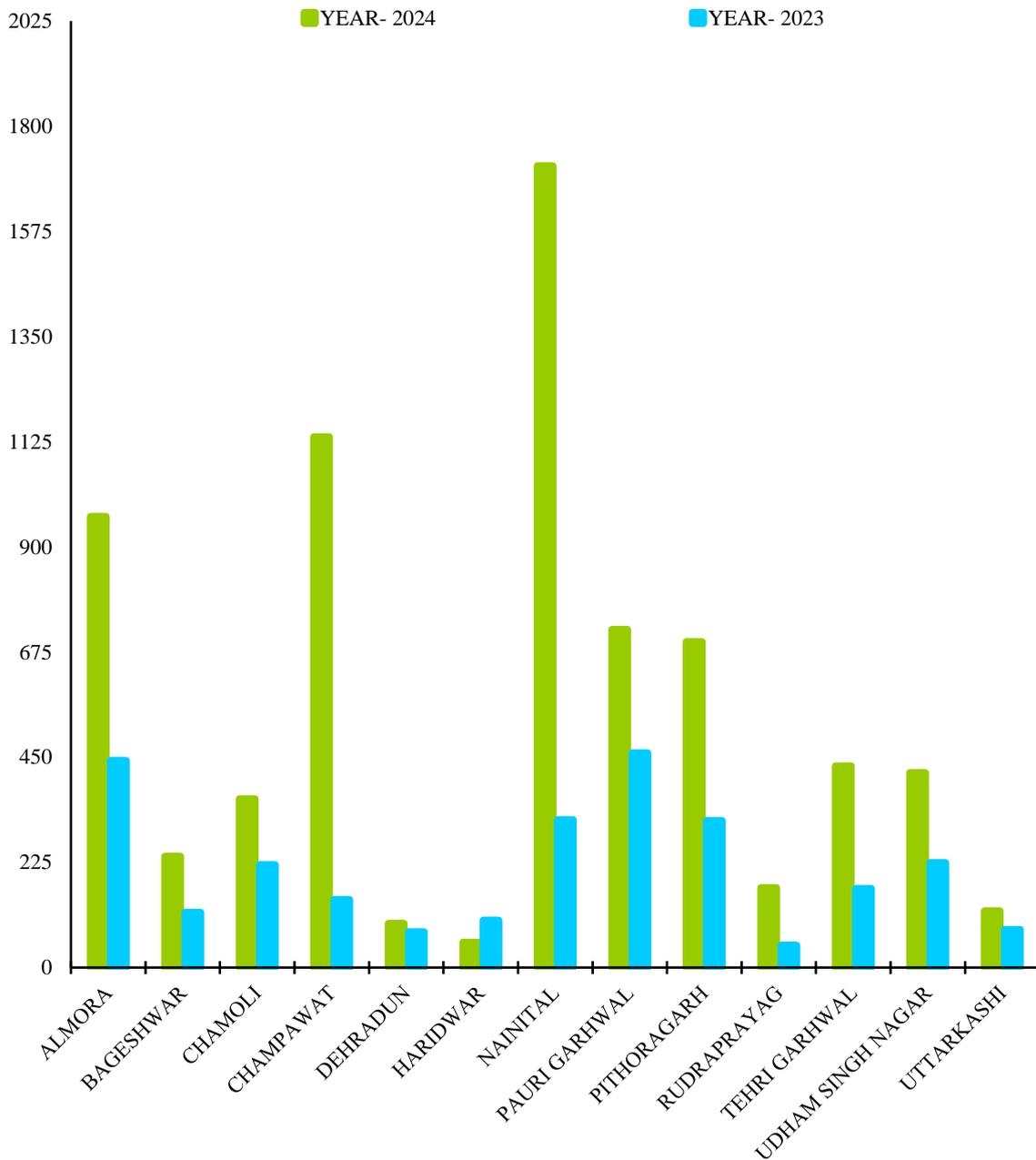
From January to April 24, 2024, the Nainital district experienced the most forest fire incidences, approximately five times more than the previous year, according to a district-by-district analysis of the incidence of forest fires.



Next in line were Champawat, Almora, Pauri and Pithoragarh (Table I).

DISTRICT	YEAR 2023	YEAR 2024
ALMORA	443	965
BAGESHWAR	118	238
CHAMOLI	220	361
CHAMPAWAT	145	1135
DEHRADUN	76	94
HARIDWAR	101	54
NAINITAL	316	1715
PAURI GARHWAL	459	723
PITHORAGARH	314	697
RUDRAPRAYAG	48	171
TEHRI GARHWAL	169	431
UDHAM SINGH NAGAR	224	417
UTTARKASHI	81	121
TOTAL FIRE COUNT	2714	7122

(source: google)
Table I. Incidences of forest fires in Uttarakhand from February 1 to April 24, 2023 and 2024 (<https://science.iirs.gov.in/satellite-based-observations-of-forest-fires-2024-in-uttarakhand/>).



Graph 1. Showing the incidences of forest fires in Uttarakhand from February 1 to April 24, 2023 and 2024 (<https://science.iirs.gov.in/satellite-based-observations-of-forest-fires-2024-in-uttarakhand/>).

Conclusion

Due to the intricate relationship between human activity, forest composition and climate change, forest fires have

become a persistent ecological and socioeconomic issue of serious concern in the Himalayan state of Uttarakhand. More so, Garhwal region is now considered as far more susceptible to wildfires due to



long dry seasons, rising temperatures and the prevalence of Chir pine forests with their highly inflammable needle litter. Ineffective forest management and human negligence further adds to fire the problem of forest fires. The already noticeable environmental repercussions, such as soil erosion, biodiversity loss and disruption of water cycles, are endangering the delicate natural equilibrium of Himalayan ecosystem. Furthermore, these flames pose serious health and livelihood risks to nearby people. Although government agencies have made some efforts to manage and reduce forest fires, infrastructure, labour and community involvement remain major issues. A long-term solution requires an integrated approach that includes active community involvement, climate-resilient forest management, the promotion of broadleaf species and the sustainable use of Chir pine resources. The annual cycle of forest fires would increase without vigorous and consistent action, raising the risk to both the ecosystem and human lives.

CONFLICT OF INTEREST: Authors have no conflict of interest.

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