Geospatial Analysis of Forest Fire Dynamics and Community Perceptions of Socio-Economic Impacts in Hoshangabad Forest Division, Central India

Ph.D. Thesis

By

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SCHOOL OF HUMANITIES AND SOCIAL SCIENCES

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MOHD AMIN KHAN

SCHOOL OF HUMANITIES AND SOCIAL SCIENCES
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I hereby certify that the work which is being presented in the thesis entitled "**Geospatial Analysis of Forest Fire Dynamics and Community Perceptions of Socio-Economic Impacts in Hoshangabad Forest Division, Central India"** in the partial fulfillment of the requirements for the award of the degree of **DOCTOR OF PHILOSOPHY** and submitted in the **School of Humanities and Social Sciences, Indian Institute of Technology Indore**, is an authentic record of my own work carried out during the time period from August 2021 to November 2025 under the supervision of **Prof. Pritee Sharma**, Professor, School of Humanities and Social Sciences, IIT Indore and **Dr. Arijit Roy**, G. Scientist, Indian Institute of Remote Sensing (IIRS) – ISRO, Dehradun, Uttarakhand, India

The matter presented in this thesis has not been submitted by me for the award of any other degree of this or any other institute.

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Professor Pritee Sharma — **Dr. Arijit Roy**

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3	**Khan MA**, et al., (2024). Analyzing the Escalation of Forest Fire in India: Exploring Causal Factors and Mitigation Strategies. *Journal of Tropical Forest Science*, 36 (2), 215–223. https://www.jstor.org/stable/48771327	0.9	Q2
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GLOSSARY & NOMENCLATURE

LOCAL TERMS & EXPRESSIONS

Local Term	Meaning / Context
Gulli	Mahua seeds (oil extraction and household use)
Achar/ Chironji	A small almond-flavored seed
Rekha Banana	Making firebreak lines
Bidi	A local cigarette usually made from tendu leaves
Patta	Tree leaves used for fodder, bidi & plate-making, and fuel
Chara	Green or dry fodder collected for livestock

TREE SPECIES & FOREST RESOURCES

Local Name (known as)	Scientific Name
Mahua	*Madhuca longifolia*
Tendu	*Diospyros melanoxylon*
Sal	*Shorea robusta*
Sagaun / Teak	*Tectona grandis*
Amla (Indian gooseberry)	*Phyllanthus emblica*
Achar / Chiraunji	*Buchanania lanzan*
Saaj (Indian Laurel)	*Terminalia tomentosa* (syn. *Terminalia alata*)
Palash	*Butea monosperma*
Dahiman	*Dillenia pentagyna*

ACRONYMS & ABBREVIATIONS

DFID	Department for International Development, London, UK.
FAO	Food and Agriculture Organization
FRP	Fire Radiative Power
GIS	Geographic Information System
JFMC	Joint Forest Management Committee
MODIS	Moderate Resolution Imaging Spectroradiometer
MoEFCC	Ministry of Environment, Forest and Climate Change
NAPFF	National Action Plan on Forest Fires
NTFP	Non-Timber Forest Product
TEK	Traditional Ecological Knowledge
VIIRS	Visible Infrared Imaging Radiometer Suite

CONCEPTUAL & TECHNICAL NOMENCLATURE

Active Fire:

A fire detected at the time of satellite overpass, identified through thermal anomalies recorded by remote sensing sensors.

Fire Radiative Power:

A satellite-derived metric representing the intensity of an active fire, estimated from the rate of thermal energy emitted during combustion.

Analytic Hierarchy Process:

A multi-criteria decision-making method used to assign relative weights to fire risk factors through systematic pairwise comparisons.

Mixed-Methods Framework:

A research design that integrates quantitative geospatial analysis with qualitative and survey-based approaches to achieve a comprehensive understanding of complex socio-ecological phenomena.

Qualitative Interpretivist Approach:

A methodological orientation that prioritises meanings, experiences, and interpretations of social actors to understand environmental processes within their cultural and institutional contexts.

Political Ecology:

An analytical framework that examines environmental change through the interplay of power relations, governance structures, economic forces, and social inequalities.

Non-Timber Forest Products:

The minor forest produce other than timber, including mahua flower and seeds, tendu leaves, fuelwood, medicinal plants, and fruits, which contribute significantly to subsistence and household incomes.

Traditional Ecological Knowledge (TEK):

A cumulative, place-based knowledge, practices, and belief systems developed by indigenous and local communities through long-term interaction with their surrounding ecosystems.

Fire Line/Firebreaks (Fire Lane):

A cleared or maintained strip of land designed to slow, control, or prevent the spread of forest fires by reducing available fuel continuity.

Joint Forest Management:

A participatory forest governance framework in India that promotes shared responsibilities between local communities and the Forest Department for forest protection and management.

Van Samiti:

A village-level forest management committee constituted under Joint Forest Management arrangements to facilitate community participation in forest governance.

Hazard:

A potentially harmful environmental or human-induced event or condition i.e. fire, drought, or extreme weather that communities recognize as capable of disrupting livelihoods, resource access, or everyday activities.

Disaster:

A situation in which a hazard causes serious disruption to daily life and livelihoods because local capacities, coping mechanisms, or institutional support are insufficient to manage its impacts.

Risk:

The likelihood of loss or hardship as understood by local people, emerging from the interaction between hazards, livelihood dependence, exposure to affected spaces, and existing social and institutional conditions.

Vulnerability:

The extent to which households or communities are prone to harm from hazards, shaped by livelihood insecurity, unequal access to resources, social position, and the effectiveness of local governance arrangements.

Exposure:

The degree to which people, livelihoods, and routine practices including farming, grazing, or NTFP collection take place in areas where hazards commonly occur.

Resilience:

The ability of households and communities to absorb repeated disturbances, rely on social networks and local knowledge, and continue livelihood activities without long-term disruption.

Adaptive Capacity:

The ability of individuals/communities to adjust livelihood strategies, resource-use practices, and social arrangements in response to recurring hazards, environmental change, or shifting governance contexts.

ABSTRACT

Forest fires are a recurring feature of India's forest landscapes and are widely regarded as one of the central drivers of forest degradation and socio-economic vulnerability among forest-dependent communities. In recent years, increasing satellite-based detections of forest fires in Central India have prompted management responses that largely prioritize fire suppression and control. However, there is limited empirical research that combines spatial analysis of forest fires with community-level insights to understand how fire affects livelihoods, cultural practices, and governance. This thesis addresses this gap through a mixed-methods investigation of forest fire dynamics and their perceived socio-economic impacts in the Hoshangabad Forest Division of Central India. It integrates long-term remote sensing analysis of fire occurrence (2001–2022), GIS-based spatial statistics, proximity and hotspot analysis, and an Analytic Hierarchy Process–based fire risk model with household surveys (n = 402), qualitative interviews, and ethnographic observations. Geospatial results reveal a gradual increase in fire occurrences over two decades though insignificant statistically, with strong spatial clustering and more dominion of fire occurrence in teak-dominated and degraded forest areas. The fire incidents are closely associated with road networks, agricultural edges, highlighting the role of anthropogenic accessibility and plantation legacies in shaping forest fire risk. Several forest ranges emerge as high to very-high risk areas (such as Itarsi, Banapura, Seoni Malwa, Hoshangabad and Bankhedi forest ranges), particularly where ecological flammability crosses with routine livelihood activities. Building on these geospatial findings, the socio-economic analysis of fire's interaction with tribal communities and local populations challenges dominant fire-centric descriptions. Although communities acknowledge the regular occurrence of fires and report localized impacts including the reduced availability of major non-timber forest products (NTFPs), lengthier collection distances, increased labor burdens, and seasonal income erraticism. But above all these acknowledgements, fire is not perceived as the primary source of livelihood vulnerability in the Hoshangabad region. Instead, the household, key respondents, informal and formal discussions with the local stakeholders were consistently accentuate irregular rainfall, temperature variability, market uncertainty, restricted forest access, and governance-related constraints as more critical stressors than fire. Women along with the elderly NTFPs collectors experience disproportionate impacts, nonetheless these are understood as part of broader structural pressures rather than direct outcomes of fire alone. Further, the ethnographic accounts reveals that fire is deeply rooted within cultural practices that governed and regulated by the inter-generational rich body of traditional ecological knowledge. The local people have been using controlled and low-intensity forest burning for facilitating mahua flower and tendu leaves' collection, restoring grazing areas for upcoming season, clearing pathways in forest, and protecting culturally significant forest sites. These forms of practices are contrast sharply with state-led fire suppression frameworks that criminalise or ban most forms of burning, generating mistrust, feeble institutional interfaces, and restricted community aid in fire governance and management. Thus, drawing on political ecology, resilience and adaptation theory, and livelihood diversification perspectives, the thesis argues that forest fires in Central India, particularly in Hoshangabad forest division had better be understood as socio-ecological processes which are co-produced by landscape characteristics, livelihood systems, cultural practices, and institutional measures. By combining geospatial analysis with community experiences and governance critique, the study encounters reductionist fire-as-disaster narratives and highlights the consequences of technocratic, re-active management approaches. The thesis subsidises in advancing evidence-based recommendations for community-focussed, prevention-oriented forest fire management that recognizes local communities' inter-generational local knowledge systems, reinforces NTFP value chains, and aligns conservation aims with local livelihood safety and security. Collectively, the research contributes to more socially equitable and ecologically grounded approaches to forest fire management in Central India's dry deciduous forest landscapes, as well as in other geographies characterized by forest-dependent socio-economic systems.

Keywords: Forest Fire; Geospatial Analysis; Spatio-temporal dynamics; Fire risk; AHP; GIS; Indigenous (tribal) People; NTFPs: Socio-Economic Impacts; Fire management; Hoshangabad Forest Division; Central India.

CHAPTER-1

Introduction

1.1 Background: Forests, Human Interaction, and Fire

The first land plants on the earth likely simple mosses and liverworts, began to grow during the Ordovician period (485-444 million years ago) (Graham et al., 2014). Over millions of years, plant evolution yielded the modern forest ecosystems that now cover a large portion of the planet. Forests are not only essential for functioning the global climate and biogeochemical cycles[1] but they are also a paramount source of oxygen, timber, food, medicines, and other raw materials for human and animal use. They have sustained and shaped the socio-cultural and economic lives of forest-dependent indigenous peoples and local communities. Over time, the human bond with forests has evolved in form of change from subsistence use to intensive exploitation, particularly just after the Industrial Revolution in Europe, which introduced large-scale technological development, urbanization, and expansion of agricultural territories (Bowman et al., 2009). These human activities have landed into massive forest clearance, fragmentation, and biodiversity loss, compromising both ecological stability and the livelihoods of communities who were dependent on forests for generations. Consequently, environmental issues including land degradation, pollution, global warming, climate change, and forest fires (wildfires)[2] have emerged as pressing worldwide challenges (Bowman et al., 2011; Kelley et al., 2025). Among these, forest fire has become one of the major drivers of ecological damage, disturbing the delicate balance between forests and humans.

Forest fires, expressed as uncontrolled fires that burn in natural landscapes (forests, grasslands, and peatland), are innately shaped and formed through climatic, ecological, and anthropogenic factors (FAO & UNEP, 2020). Historically, fire has performed a central role in maintaining ecosystem dynamics, regulating vegetation succession, nutrient cycling, and habitat structure (Pyne, 2019). However, in the Anthropocene (the current era of human dominion), fire has

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[1] *Biogeochemical cycles* are the natural systems by which fundamental elements like carbon, nitrogen, phosphorus, and water flow between the biotic and abiotic components of the Earth system, making the continuity of different forms of life and ecosystem functioning.

[2] The terms like *forest fire*, *wildfire*, *wildland fire*, and *fire* are often employed interchangeably in the writing of this thesis. These terms may have some distinctions in global fire science discourse, however in Indian context they collectively refer to fires which are occurring in forested or vegetated areas—generally defined as *forest fires*.

accelerated substantially in terms of frequency, intensity, and spatial extent (Bowman et al., 2020). Changes in climate variables (e.g., temperature, rainfall, wind patterns, humidity, and air pressure), paired with alterations in land use and human interventions, have intensified forest fire occurrences globally. As a result, what was once a major significant part of ecological maintenance and functioning (i.e., fire) has changed into a multi-dimensional crisis, with strong effects for ecosystem health, climatic variables, and human livelihood systems (Jones et al., 2024; Kelley et al., 2025).

Fires now transpire across all terrestrial biomes ranging from boreal, temperate, tropical forests to Mediterranean shrublands, and grasslands. In recent decades, wildfire seasons in North America (particularly in the western United States and Canada) has increased severely (Weber & Yadav, 2020; Wilmot et al., 2022). In states like California and Oregon, as well as in British Columbia, extended droughts, rising temperatures, and changes in fire suppression regulations have sparked devastating fires that destroy thousands of acres annually and endanger both human habitation and biodiversity(Abatzoglou et al., 2021; Kreider et al., 2024; Marlon et al., 2012; Parisien et al., 2023; Steel et al., 2015). In South America, the Amazon rainforest and the Cerrado savannas have developed into important wildfire hotspots due to deforestation, increased agricultural production, and land-clearing practices (Da Silva Arruda et al., 2024; Dos Reis et al., 2021). These fires lead in immediate ecological damage and contribute significantly to global carbon emissions which intensifying climate change and threatening the stability of tropical forest ecosystems (Flores et al., 2024; Silva et al., 2021). Similarly, in Sub-Saharan Africa where fires were traditionally used for agricultural and pastoral management, now experiences seasonal savanna fires. While some of these fires are ecologically regenerative (Nieman et al., 2021), extreme droughts and uncontrolled burning can escalate their destructive potential, causing widespread landscape degradation (Lipsett-Moore et al., 2018).

In Asia, countries such as India, Indonesia, and Malaysia are particularly vulnerable to both forest and peatland fires (Page & Hooijer, 2016; Vadrevu et al., 2019). Human-caused slash-and-burn practices, combined with climatic anomalies such as El Niño, intensify fire risk, resulting in extensive haze, health crises, and significant losses of carbon-dense peatlands (Kiely et al., 2021). Mediterranean Europe, covering Spain, Portugal, Italy, and Greece, encounters recurrent summer fires triggered by heatwaves, dry spells, and human negligence (Romano & Ursino, 2020; Turco et al., 2017). Recent observations suggest that wildfire risk is expanding into previously low-risk areas of Southern and Eastern Europe, reflecting shifts in regional climate patterns (El Garroussi et al., 2024; Rossi et al., 2020). Australia provides a striking example of wildfire susceptibility, as its eucalyptus-dominated ecosystems are highly flammable due to volatile oils in the vegetation (Tumino et al., 2019; Younes et al., 2024). The 2019–2020 bushfire season highlighted the catastrophic potential of these fires, resulting in extensive loss of human life, property, and wildlife (Deb et al., 2020; Driscoll et al., 2024). Collectively, these examples highlight the global pervasiveness of wildfires and show how natural fire regimes are influenced and expanded due to human activity and changes in climatic variables.

Fire now becomes one of the major hazards with broad ecological, climatic, and socio-economic consequences. It impacts biodiversity, ecosystem services, carbon cycling, and also threatening human health, livelihoods, and cultural practices. Thereby, recognizing the global magnitude of this problem is essential; however, understanding local and micro-level dynamics is equally critical (Doerr & Santín, 2016; Li et al., 2023). Fine-scale studies of fire behavior, community vulnerabilities, and ecosystem responses enable targeted interventions and inform policy and management strategies that are contextually appropriate and socially equitable (Doerr & Santín, 2016). In this light, the study of fire dynamics, impacts, and management at both macro- and micro-levels is indispensable for promoting resilient landscapes and sustainable human-forest interactions in an era of accelerating environmental change.

1.2. Fire in the Indian Socio-Ecological Landscape

As the global literature shows that wildfires have emerged as complex ecological and socio-economic challenges, understanding fire's dynamics within the Indian context, where forest-dependent communities co-exist with fragile ecosystems, remains critical (Yadav, 2025). India is home to a diverse array of flora and fauna and acknowledged as one of the world's major hotspots for biodiversity (ISFR, 2021). About 0.827 million square kilometers, or nearly 25.17% of the country's total land area are covered by forests and trees, of which 5.32% are classified as legally protected (ISFR, 2023). Despite this significant extent, anthropogenic pressures, climatic variations, and changes in land use patterns are putting India's forests under growing pressure. These pressures have collectively compromised the forest health, biodiversity, and ecosystem stability (Haughan et al., 2022; Roy, 2003; Sharma et al., 2017).

Among the numerous drivers [3] of degradation, forest fires constitute one of the major pervasive and recurring threats (ISFR, 2018; Joseph et al., 2009; Roy, 2003).

In India, forest fire has spatio-temporal variability. This variability is shaped by the diverse ecological, climatic, and socio-economic conditions. The majority of fire incidents occur during the summer and pre-monsoon seasons (particularly between February and June), when rising temperatures, dry vegetation, and high wind speeds create conducive conditions for ignition and spread (Mohd et al., 2024; Srivastava & Garg, 2013). The causes of ignition are heterogeneous, caused by both natural and anthropogenic factors. Natural variables include topography, temperature, rainfall, wind patterns, humidity, vegetation type, soil moisture, and fuel load characteristics. In contrast, human-driven factors include agricultural burning, grazing, tourism, urban expansion, industrial activity, and infrastructure development, play prevalent roles. Indeed, human-caused fires account for nearly 90% of the total forest fire incidents across India, occurring both accidentally and intentionally (Bahuguna & Singh, 2002; Roy, 2003; Satendra & Kaushik, 2014). Also, nearly 55% of India's forests are classified as "dry deciduous", which are naturally more fire-prone due to their long dry periods and abundant leaf litter (ISFR, 2019; Joseph et al., 2009). Most major fire events in India are surface or sub-surface fires, which affect the forest floor and organic soil layers rather than full canopy burns (ISFR, 2023; Satendra & Kaushik, 2014).

The ecological and socio-economic consequences of recurrent forest fires are widespread. Fires alter soil properties, nutrient cycles, and regeneration patterns, and influence wildlife habitats and carbon fluxes (Bargali et al., 2023; Chandra & Bhardwaj, 2015). Equally significant are the socio-economic and cultural repercussions for local and Indigenous forest-dependent populations. These communities often experience loss of non-timber forest products (NTFPs), reduced access to forest resources, and declining livelihood opportunities (Banerjee et al., 2024). The degree of vulnerability, however, varies across regions and is shaped by the relationship of economic dependence, resource availability, adaptive capacities, and the broader ecological context of the forest landscape.

In the Central Indian context, however, dominant policy and academic descriptions tend to portray fire primarily as a unidimensional ecological and livelihood threat- an agent of forest

[3] Other drivers of forest degradation in India include (1) unsustainable and illegal timber extraction, (2) fuelwood and small-scale charcoal use, (3) grazing pressure, (4) encroachments and shifting cultivation, (5) linear infrastructure expansion (roads, transmission lines), and (6) invasive species such as *Lantana camara* and *Prosopis juliflora* (MoEFCC, 2018; Roy et al., 2003).

degradation, biodiversity loss, and rural vulnerability. Such descriptions, while partially valid, often fail to capture how local communities interpret, adapt to, and manage fire within their socio-ecological systems (Yadav, 2025). For instance, communities across Central India deliberately use small, controlled fires for specific livelihood and ecological purposes such as clearing undergrowth for Mahua (*Madhuca longifolia*) flower collection, preparing forest floors to enhance Tendu (*Diospyros melanoxylon*) leaf yield, or setting light fires prior to the monsoon to promote fresh grass growth for livestock (Bhadoria et al., 2022; M. A. Khan et al., 2024; Mohd et al., 2024; Sahu et al., 2024). These practices, rooted in local ecological knowledge, reflect a more grounded understanding of fire as a regenerative and adaptive tool rather than merely a destructive force.

By focusing exclusively on fire as an ecological hazard, mainstream discourses often obscure deeper structural drivers of vulnerability (Kelman, 2024). Climatic anomalies such as irregular rainfall, high temperatures, and hot, dry winds deepen the risk of fire, but governance failures and livelihood insecurities play a more profound role (IPCC, 2022; Jha et al., 2018). Issues such as unfair NTFP pricing regimes, corruption within forest bureaucracies, restricted forest access, inadequate compensation for wildlife-induced crop losses, and the absence of incentives for communities engaged in voluntary fire suppression further amplify local vulnerability (Fleischman, 2016; M. A. Khan, 2023; Robbins et al., 2009). Consequently, fire in Central India often becomes a proxy for governance neglect and developmental inequity rather than the root cause of ecological or livelihood degradation.

This thesis challenges these prevailing assumptions by arguing that fire remains a significant ecological factor, it is not the central disruptor of forest-dependent livelihoods in Central India. Instead, it represents a visible symptom of deeper socio-political and institutional processes that shape vulnerability and resilience. Situated within this context, the present study uses an inductive, empirical inquiry into a micro-regional case in the Hoshangabad Forest Division[4] (HFD) of Madhya Pradesh. It examines how fire is perceived, managed, and positioned within local livelihood strategies and knowledge systems, thereby uncovering the

[4] In India, a *Forest Division* is the primary administrative unit of forest management under the State Forest Department, constituted under the provisions of the Indian Forest Act, 1927 and subsequent state forest laws. A forest division is headed by a Divisional Forest Officer (DFO) and is responsible for implementing forest conservation, protection, afforestation, wildlife management, and regulatory functions such as control of forest produce and prevention of encroachment and illegal felling. Forest divisions serve as the operational link between state-level forest policy and field-level execution.

under explored fire accounts and regional realities that inform community-forest interactions in contemporary India.

1.3 Research Aims, Objectives and Questions

The primary aim of this research is to assess the impact of fires within a spatio-temporal framework, identify high-risk zones, and analyze how communities perceive and respond to the socio-economic and cultural impacts of fire in the central Indian region, with a specific focus on the HFD of Madhya Pradesh. The study also explores how human societies, especially Indigenous and local populations, interpret and coexist with fire. Altogether, the study seeks to understand how fires are often represented as destructive environmental events in policy and media, and how Indigenous and forest-dependent communities are locally perceived, managed, and adapted. By integrating geospatial technology, field observation, ethnographic inquiry, and descriptive statistics, this research attempts to bridge scientific fire analyzes with community-based perspectives and revealing the ground interactions between fire, livelihoods, and resilience.

Research Objectives

1. To investigate the spatio-temporal pattern of forest fires in the Hoshangabad forest division.
2. To conduct a forest fire risk assessment in the study region using socio-economic and physical environmental variables.
3. To assess communities' perceived socio-economic and cultural impacts of forest fires at the household level in the study area. Also, to review the alignment (or misalignment) between dominant fire narratives and the actual livelihood experiences of tribal communities in fire-prone landscapes.
4. To highlight community-informed understandings of fire and identify other, often overlooked, constraints that shape vulnerability.
5. To contribute to a more grounded, community-led approach to forest fire governance and livelihood policy in central India.

Research Questions

Based on the above objectives, this thesis is structured around a set of interrelated research questions that address both the biophysical dynamics of fire and the social dimensions of resilience in the HFD of central India.

The first set of questions focuses on the spatial and temporal dynamics of forest fires, seeking to understand how they have varied across space and time over recent years. It asks - what the key environmental and anthropogenic factors are and how they influence the frequency, distribution, and intensity of fires. Examining these spatio-temporal variations provides the necessary foundation for understanding broader ecological and human processes that drive fire occurrence in the region. Next, the study undertakes a forest fire risk assessment to identify the most vulnerable zones within the division. It questions which areas are most susceptible to forest fires when biophysical variables such as vegetation, topography, and climate are combined with socio-economic indicators like population density, accessibility (to agricultural fields, waterbodies, road, and rail networks), and dependence on forest resources. Furthermore, it explores how effectively geospatial modelling techniques can capture these multi-dimensional fire risk patterns and assist in targeted fire management.

A third strand of inquiry addresses the socio-economic and cultural impacts of fire, as perceived by local and Indigenous households. It asks how communities interpret the effects of fire on their livelihoods, subsistence practices, and cultural traditions, and which livelihood sectors such as NTFPs, agriculture, or wage labor, are most affected according to the community. This line of questioning challenges the conventional assumption that fires uniformly translate into livelihood loss; rarely exploring local variability and adaptive strategies. The study then turns to the narrative alignment between policy and community perspectives. It interrogates the extent to which local understandings of fire correspond with or challenge dominant narratives that portray fire as primarily destructive. It further examines how these divergent views shape governance responses, adaptation mechanisms, and forest management interventions, revealing the complex politics of representation surrounded in wildfire discourse. Closely connected to this is an exploration of community vulnerability and its underlying constraints. The research examines the extent to which non-fire-related factors such as shifting rainfall patterns, temperature variability, lightening, deforestation, and market fluctuations contribute to livelihood vulnerability. It further investigates how these structural pressures interact with local fire regimes, influencing adaptation capacities and shaping the broader socio-ecological resilience of the landscape.

Lastly, the study proposes a community-led framework for forest fire governance and policy. It asks how Indigenous knowledge systems and community practices can inform context-sensitive and participatory approaches to fire management. The research also investigates -

what policy shifts are required to move beyond top-down fire suppression toward co-managed, resilience-based strategies that integrate local knowledge and agency? Relatedly, it explores the practical ways in which community participation can be enhanced to minimize the adverse effects of uncontrolled fires and contribute to long-term resilience and sustainable livelihood development in fire-prone forest ecosystems.

Collectively, these questions aim to produce a more meaningful understanding of wildfire as a socio-ecological process, not purely an environmental hazard. Consequently, it shared that the results of this thesis will contribute to rethinking fire governance and resilience from a bottom-up perspective, rooted in the lived experiences and adaptive capacities of forest-dependent communities in central India.

1.4 Study Site: Situating Fire, Forests, and Livelihoods

This research is situated in the Hoshangabad Forest Division, located in the Hoshangabad (now officially Narmadapuram) district of Madhya Pradesh, Central India (Fig. 1). Covering approximately 1200 square kilometers, the forest division comprises nine forest ranges[5] and 500 forest compartment units[6] (H. U. Khan, 2013). The ecological character of this landscape is shaped by its dry deciduous forest cover, where teak (Tectona grandis) dominates more than half the terrain. Other significant species include Tendu (Diospyros melanoxylon), Saja, Dhaoda, Haldu, and Mahua (Madhuca longifolia), as well as grasses and shrubs essential to both wildlife and human use (H. U. Khan, 2013; M. A. Khan et al., 2024). The region lies along the foothills of the Satpura range and experiences a monsoonal climate, with distinct dry and wet seasons, making it prone to seasonal fire activity. And in terms of demographic features, Hoshangabad is diverse, with 0.2 million tribal populations (constituting about 16% of the district's population) residing in its fringe forest villages, especially reliant on both cultivated agriculture and forest-based livelihoods (Chandramouli & General, 2011).

[5] A *forest range* is a sub-unit of a forest division and functions as an intermediate administrative and managerial unit. Each range is headed by a Range Forest Officer (RFO) and comprises several forest blocks or compartments. The range level is crucial for day-to-day forest protection, execution of working plans, plantation activities, fire control, and community interaction under schemes such as Joint Forest Management.

[6] A *forest compartment* is a small administrative and management unit in a forest range. It is a clearly demarcated area with nearly fixed boundaries, used for scientific forest management, inventory, silvicultural operations, and monitoring of forest resources. Compartments form the basic unit for preparation of Working Plans, assessment of forest produce, and implementation of conservation measures.

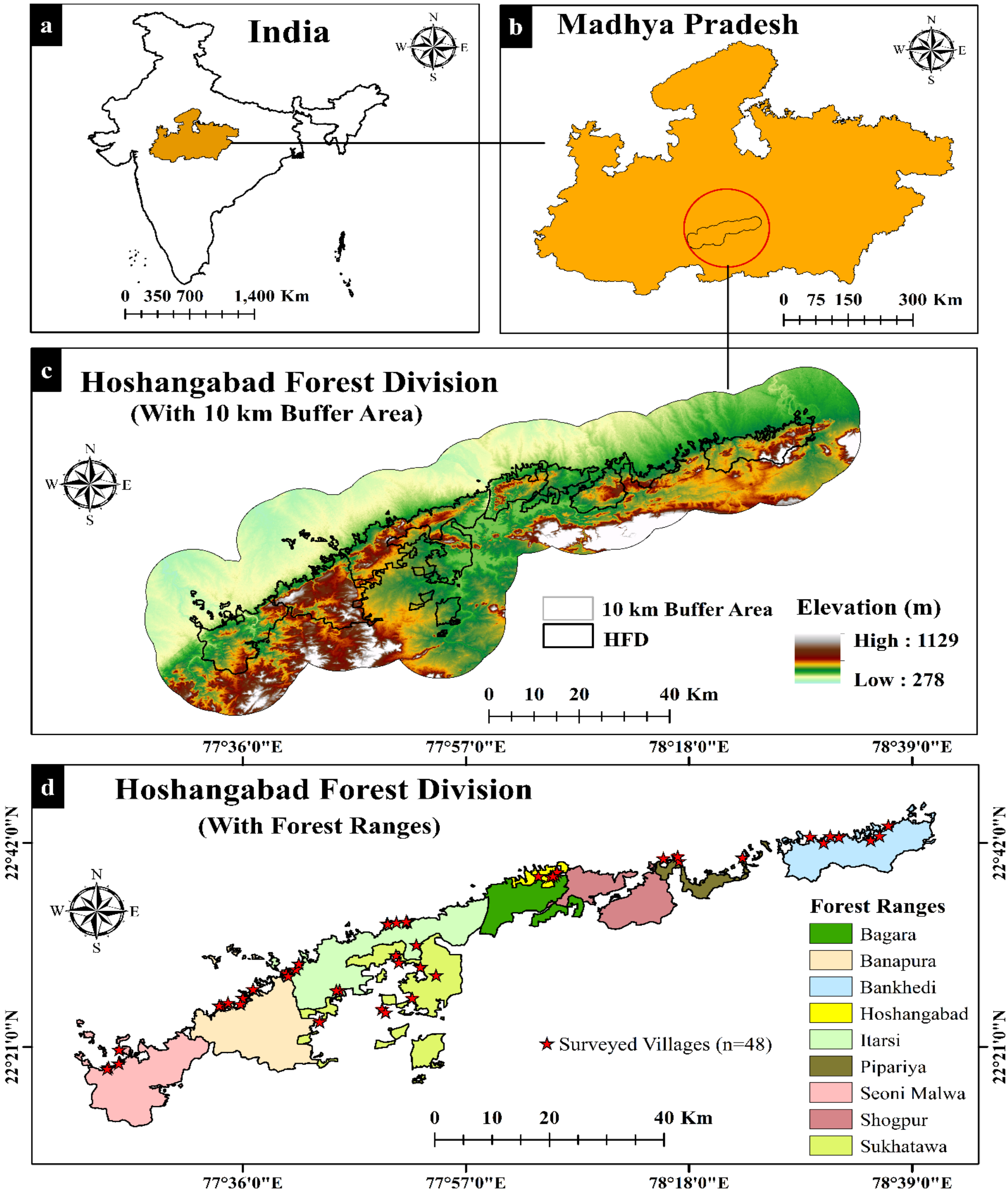


Fig.1. 1 Study area map-(a) India (b) Outlook of Madhya Pradesh in India (c) Digital elevation model depicting land elevation in the HFD and its 10 km buffer areas (d) Administrative Forest ranges in the HFD with surveyed villages *(Source: Author).*

According to the 2011 Census, the district had a population of 1.24 million and a population density of 185 persons/km². Gender and literacy disparities persist, with a sex ratio of 914 females per 1000 males and female literacy lagging male literacy by nearly 17 percentage points. A large proportion of the population of this district resides within 5 km of forest boundaries, across 332 villages. (Chandramouli & General, 2011). These settlements face seasonal isolation during monsoon months due to inadequate road infrastructure, limiting access to markets, healthcare, and public services. As a result, households rely on forests for subsistence and seasonal income, including through the collection of NTFPs as Mahua flowers and seeds, Tendu leaves, Amla, Chironji, wild mushrooms, and medicinal herbs (M. A. Khan et al., 2024). However, this dependence is increasingly strained. The availability of NTFPs and other forest goods has sharply declined due to irregular rainfall, temperature variability, long dry spells and sometimes fire, reflecting broader climate variability rather than isolated fire events. Livelihood portfolios have thus diversified out of necessity, with many households engaging in wage labor or temporary migration to urban-industrial areas, highlighting a transition away from forest-based livelihoods.

Rationale for selecting the study area

Hoshangabad represents a fire-prone landscape where venerable traditional fire practices gradually intersect with standardized fire management interventions. Studies by Mohanty and Mithal (2022) rank the Hoshangabad district among the top ten forest fire hotspots in India (Mohanty & Mithal, 2022). Fire here is not a recent phenomenon, but its current intensification and governance responses are shaped by a combination of anthropogenic triggers and policy logics that frame fire as an external threat rather than as a socio-ecological process. Major fire-inducing practices in the region include intentional burning of dry underbrush to facilitate NTFP collection (e.g., Mahua flowers and Tendu leaves), land clearing for grazing, and crop field preparation (M. A. Khan et al., 2024). However, under prevailing administrative protocols, any burning detected within forest boundaries is automatically classified as a “forest fire,” irrespective of its purpose, scale, or degree of control. This official categorization eclipses the socio-ecological rationale guiding these community-based fire practices, which are often adaptive strategies rather than acts of ecological negligence. Despite this, state fire management policies often lack grounded realities, prioritizing blanket suppression over engagement with community fire regimes or local understandings of risk. This makes Hoshangabad a crucial site for research and inquiry. It represents a region where frequent fire activity intersects with tribal livelihoods, climatic stressors, and governance asymmetries. The landscape is emblematic of the broader fire-livelihood paradox in Central India: despite recurring fires, forest-dependent communities in this region cite climate variability, lack of forest access, and governance neglect as more pressing threats to their livelihoods than fire itself. This disjuncture provides an ideal context in which to weigh dominant fire-centric assumptions and assess whether state fire narratives align with community experiences. By focusing on this setting, the study not only contributes to the growing literature on fire in India's tropical forests but also provides empirical grounding for alternative, community-informed frameworks of fire governance.

1.5 Research Methodology

This study engages a multi-method and interdisciplinary research design that integrates geospatial analysis, field-based socio-economic surveys, and ethnographic inquiry to holistically examine the dynamics and impacts of forest fires in the HFD of Central India. Covering the domains of physical and human geography, remote sensing, and disaster studies, the research framework seeks to bridge spatial data analysis with grounded understanding of community perceptions, governance structures, and power relations that shape wildfire narratives and management practices.

Given this interdisciplinary scope, each chapter follows its own methodological and theoretical orientation fitted to its research questions and scale of inquiry. Thus, the chapter on spatio–temporal dynamics uses satellite-derived fire data and remote sensing tools to map and analyze fire distribution patterns. The fire risk assessment applies multi-criteria geospatial modelling to integrate biophysical and socio-economic indicators. The socio-economic and cultural analysis draws upon household surveys, in-depth interviews, and formal and informal discussions to capture Indigenous and local perspectives on fire, livelihood vulnerability, and adaptation. The interpretive chapters (6, 7) further examine dominant fire governance discourses, to foreground marginalized voices often excluded from fire management narratives.

To ensure conceptual and methodological coherence across these diverse approaches, a comprehensive methodological framework has been developed and illustrated through a graphical representation, seen in Fig 2. This figure presents the integrative methodological framework underpinning the thesis, illustrating the convergence of geospatial analysis, field-based socio-economic inquiry, and critical interpretive approaches. This framework synthesizes the overall research process—linking spatial analysis, field inquiry, and critical interpretation into an integrated model that underpins the analytical and empirical structure.

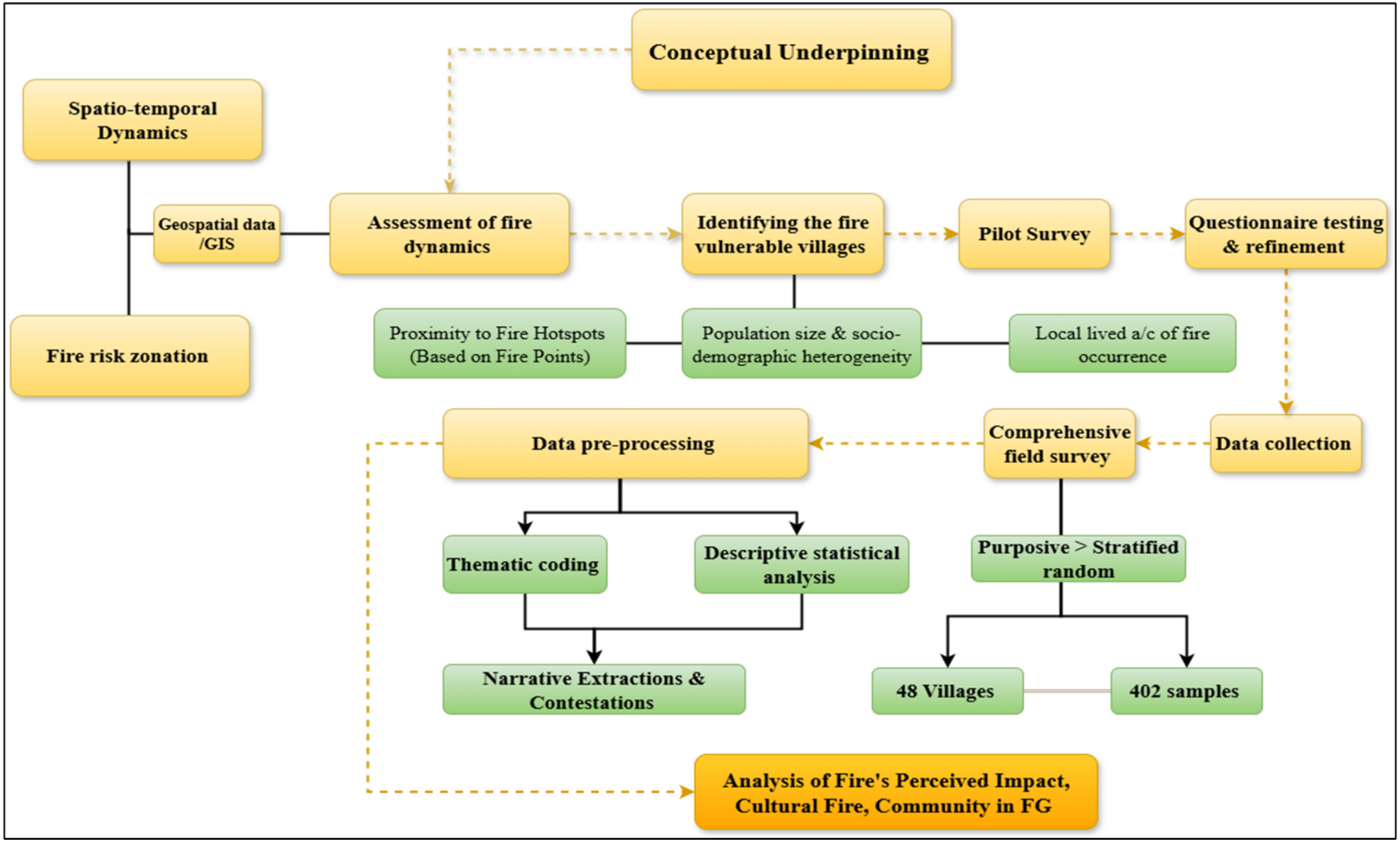


Fig.1. 2 Comprehensive methodological framework of the thesis *(Source: Author)*.

1.6 Thesis Structure

The thesis is organized into eight chapters that together explore the spatial dynamics, risk patterns, and socio-cultural dimensions of forest fires in the Central Indian landscape, particularly within the HFD. It integrates geospatial techniques with ethnographic and political-ecological inquiry to provide a comprehensive, community-grounded understanding of wildfire phenomena.

Chapter 1 introduces the background, rationale, and significance of the study, along with the overarching research aims, objectives, and questions. It outlines the methodological framework and emphasizes the interdisciplinary nature of the research, which crosses physical and human geography, remote sensing, and disaster studies. **Chapter 2** provides a concentrated contextual literature review on forest, fire, socio-economic perceptions of communities and local people, and governance in the global context and in India, positions the research within broader theoretical and empirical debates. It reviews key literature on Indian forest's characteristics, governance, fire ecology, and community-based management in India while incorporating comparative insights from global fire regime and fire management frameworks. This chapter provides the conceptual foundation for understanding how dominant fire tales have evolved and how they often misalign with local livelihood experiences, realities, and indigenous knowledge systems. Finally, it helps in identifying the major research gap and provides the background to build the research objectives for this study. **Chapter 3** presents the spatio-temporal dynamics of forest fires in the HFD using satellite datasets and statistical techniques. It identifies fire hotspots, seasonal variations, and temporal trends, thereby addressing the first research objective. **Chapter 4** advances this spatial analysis through a detailed GIS-based fire risk assessment, integrating environmental and socio-economic variables to delineate areas of varying susceptibility. Together, these chapters establish the physical and spatial context necessary for understanding the human dimensions of fire.

Chapter 5 transitions into the socio-economic domain by examining the perceived economic impacts of forest fires among forest-dependent communities. Drawing on household surveys and interviews, it highlights how local populations interpret the causes and consequences of fire and how these perceptions align (or misalign) with dominant narratives that frame fire primarily as a destructive phenomenon. **Chapter 6** deepens this inquiry by exploring the socio-cultural dimensions of fire, focusing on Traditional Ecological Knowledge (TEK), ritual and symbolic practices, and gendered and caste-based roles in fire management. This chapter addresses indigenous understandings of fire and exposes the friction between traditional fire knowledge and state-imposed policies, reinforcing the argument for more inclusive and culturally grounded governance approaches. **Chapter 7** examines the institutional and participatory aspects of forest fire governance, assessing the functioning of Joint Forest Management Committees (JFMCs), community engagement in fire suppression, and governmental responsiveness. It identifies structural and procedural gaps between policy intent and local realities, proposing pathways for strengthening participatory governance and resilience-based management models.

Conclusively, **Chapter 8** fuses the key results across spatial, socio-economic, and cultural dimensions, reflecting on their theoretical and policy implications. It highlights the value of integrating community-informed perspectives and indigenous knowledge into fire management frameworks and outlines the preferred future directions for research on pyrogeography[7] and community-led forest governance in India.

[7] ***Pyrogeography*** is the interdisciplinary study of the spatial, ecological, and socio-economic dimensions of fire, examining how fire interacts with landscapes, climates, and human systems over time and space (Pyne, 2019).

CHAPTER-2

Forests, Fire, Community Perceptions, and Governance

A Contextual and Comparative Literature Review with Geospatial Perspectives

Understanding fire dynamics requires an integrated examination of ecological processes, socio-political structures, and technological advancements that shape how fires emerge, spread, and are managed across diverse landscapes. This chapter situates the Indian forest–fire context within a broader global framework. It begins by conceptualizing fire as an ecological and biophysical process, outlining its types, mechanics, and functions; this scientific grounding provides the basis for interpreting the ecological and socio-economic dynamics explored throughout the chapter. The review then synthesizes literature on global forest typologies, ecological characteristics, and governance mechanisms to brighten how different regions understand and manage fire. Building from an overview of global forest biomes and their fire regimes, the discussion narrows to a focused examination of Indian forest types, with particular attention to the dry deciduous ecosystems of Central India. The chapter subsequently analyses the evolution of fire governance from international paradigms to India's institutional frameworks, highlighting tensions between suppression-oriented policies, community practices, and local ecological realities. It concludes by examining the expanding role of geospatial technologies, including remote sensing and GIS, in advancing fire detection, burnt-area mapping, and risk assessment. Together, these perspectives provide conceptual and methodological scaffolding for identifying research gaps and situating the present study within wider debates on forest fire management and socio-ecological resilience.

2.1 Conceptualizing Fire

Fire is a fundamental biophysical process that has shaped the Earth's surface, ecosystems, and human evolution (Pyne, 2019). Ecologically, it is defined as a rapid oxidation reaction that releases heat, light, and gaseous products when fuel, oxygen, and sufficient heat interact, commonly represented by the fire triangle (Bowman et al., 2009). In natural environments, fire acts both as a disturbance and a regulating force, influencing vegetation dynamics, nutrient cycling, and habitat structure. The study of these relationships forms the basis of fire ecology and, more broadly, pyrogeography—the interdisciplinary science that examines the spatial and temporal patterns of fire and its interaction with climate, vegetation, and human systems (Bowman et al., 2020; Krawchuk et al., 2009). Forest fires can be categorized into three typologies according to their location and mode of spread within the vegetation strata: ***first***, the ground fires which burn beneath the surface, consuming organic matter such as peat, roots, and buried litter. These types of fires are slow, moving but persistent, frequently smoldering for weeks. ***Second***, surface fires which spread across the forest floor, consuming leaf litter, grasses, and low shrubs. These are the most common types of fire found in the tropical and temperate forests and vary in intensity with fuel moisture and wind speed. ***Finally***, the crown fires which reach up to the tree canopies, often following surface fires that preheat and ignite upper layers. These types of fires are highly destructive and typical of coniferous and dry deciduous forests during severe droughts.

All these forms of fires may occur sequentially or interactively within a single event, depending on fuel continuity, vertical structure, and weather conditions (P. S. Roy, 2003). A schematic representation (Fig. 2.1) shows the vertical stratification of fire behavior across ground, surface, and canopy layers.

Mechanics and Behaviour of Fire

Fire behaviour is determined by the interaction of fuel, weather, and topography, and collectively known as the fire behaviour triangle (Pyne, 2019; Sullivan, 2009).

- **Fuel** characteristics including type, moisture content, size, and spatial continuity that govern the ignition potential and flame intensity. Fine, dry fuels such as grass or leaf litter ignite quickly and sustain surface fires, whereas the coarse woody debris supports longer burning.
- **Weather** parameters such as wind speed, humidity, and temperature directly influence flame spread and direction. Wind provides oxygen, tilts flames toward unburned fuel, and accelerates the rate of spread.
- **Topography** affects both micro-climate and fuel arrangement: fires travel faster upslope due to preheating; however, valleys can trap smoke and heat, altering combustion patterns.

Together, these variables determine a fire's rate of spread, flame height, residence time, and energy release (Popescu et al., 2022).

Fire as an Ecological and Social Process

Fire is integral to the functioning of many ecosystems. Moderate and periodic burning can: a) recycle nutrients through ash deposition, b) stimulate seed germination and resprouting in fire-adapted species, and c) maintain open-canopy structures conducive to biodiversity (W. Bond & Keeley, 2005). Conversely, high-frequency or high-intensity fires may cause soil degradation, species loss, and carbon emissions. The balance between these outcomes constitutes a fire regime (Moritz et al., 2012; Pausas & Keeley, 2009). Fire regimes, in turn, are shaped by climatic variability, vegetation type, and human use patterns. Globally, more than 80 percent of wildfires are now anthropogenic in origin, linked to land clearing, agriculture, and resource extraction (Archibald et al., 2013; FAO & UNEP, 2020). In tropical regions such as India, where livelihood practices link with forest use, fires reflect complex feedback between ecology, culture, and governance (Saha, 2002). Recognizing these interdependencies is central to understanding regional fire regimes and to framing management approaches that are both ecologically sound and socially inclusive.

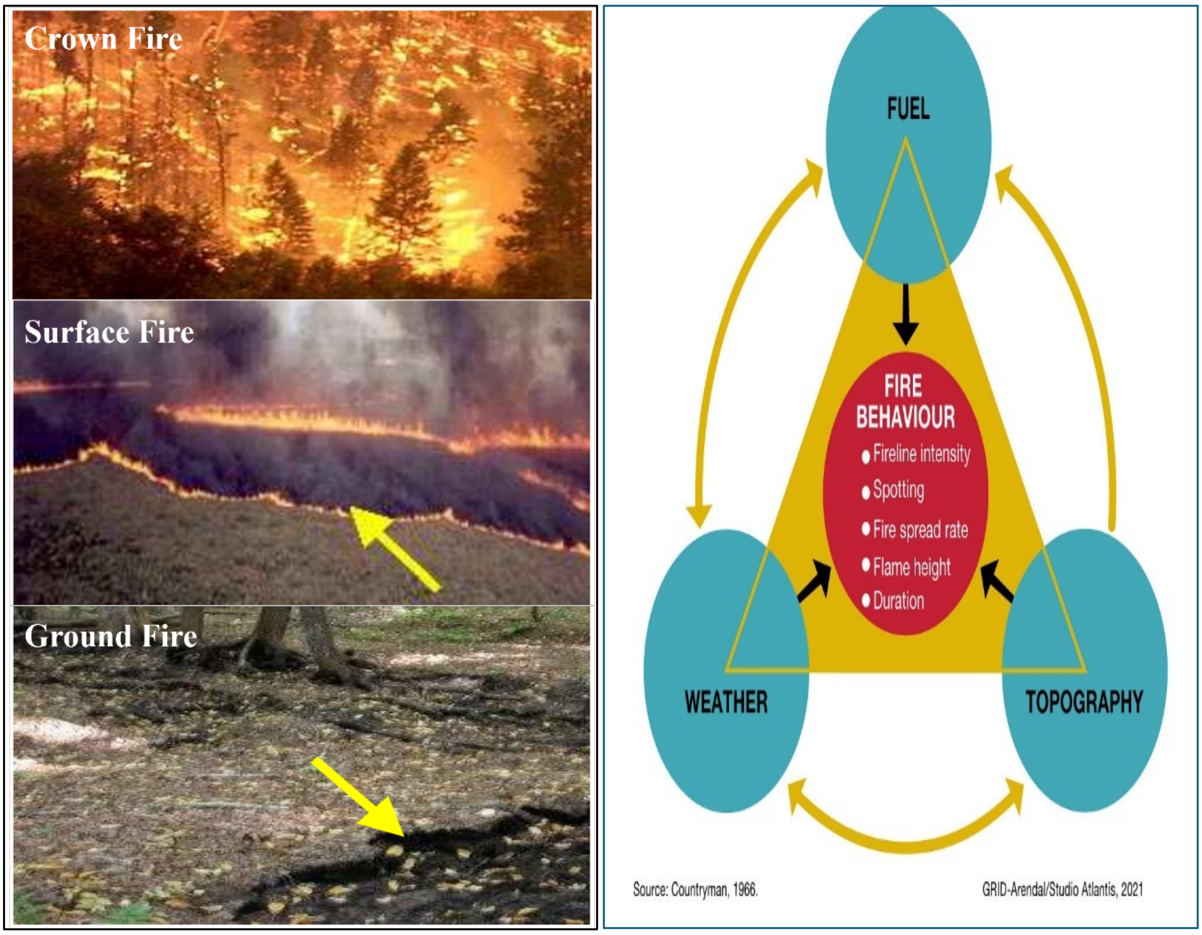


Fig. 2. 1 Schematic representation of major forest fire types (Roy, 2003), including vertical fuel strata and the fire behaviour triangle. Source: Adapted from (Popescu et al., 2022).

2.2 Global Forest Biomes and Fire Regimes

Global forests cover around 4.14 billion hectares, representing about 32 percent of the Earth's land surface and amounting to roughly 0.5 hectares of forest per person. Among the major biogeographic domains, the tropical forests hold the largest share (45 percent), followed by the boreal (27 percent), temperate (16 percent), and rest by subtropical domains (FAO, 2025). These biomes cover a vast diversity of ecological systems, each shaped by distinct climatic, biophysical, and anthropogenic factors. These variations shaped the fire regimes (characteristic patterns of fire occurrence, frequency, intensity, seasonality, and ecological effects) and provides a crucial framework for understanding these distinctions. (W. Bond & Keeley, 2005; Bowman et al., 2009; Pyne, 2019). Fire regimes are ecological phenomena and reflect the historical and cultural engagements of human societies with landscapes. Thereby, the distribution of fire varies across geographies based on differentiation in ecosystem structure, climate, and human–environment relations (see Fig. 2.2).

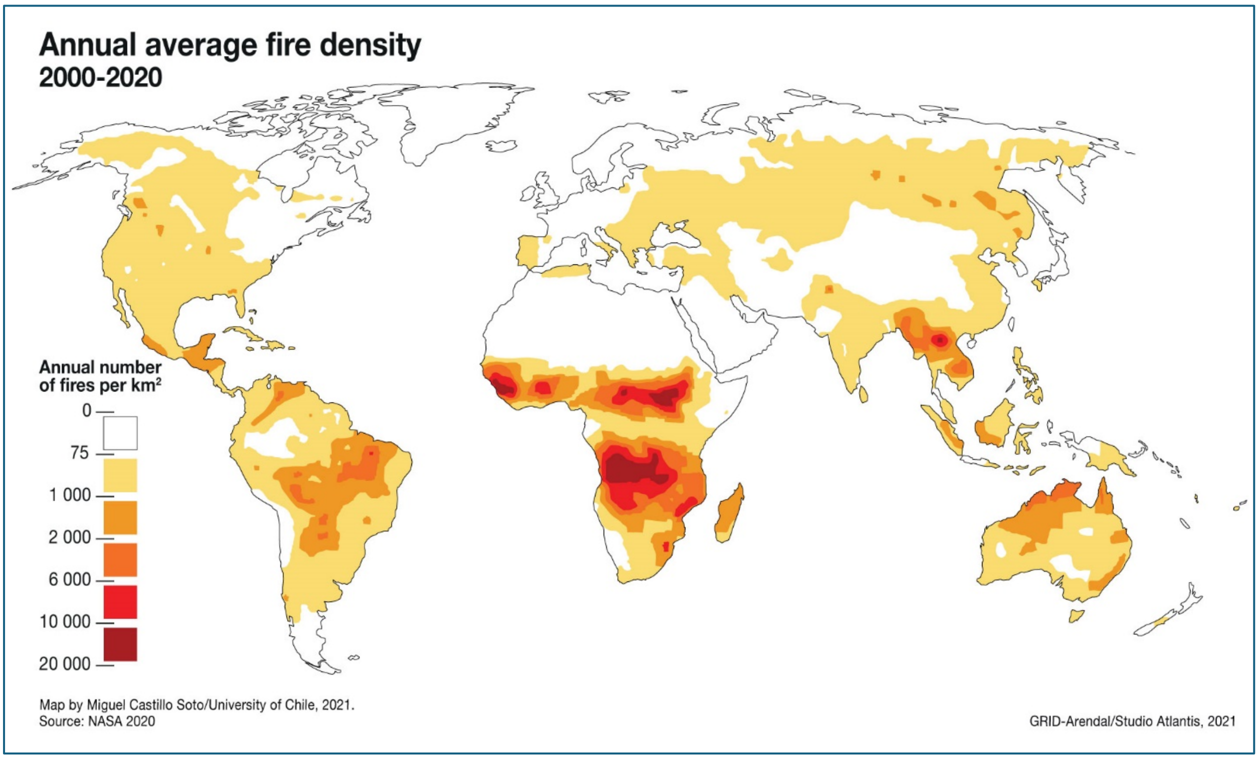


Fig. 2. 2 The distribution of fire intensity across geographies. Source: Popescu et al (2022)

As some forest types have evolved with periodic burning as a natural ecological process, others have developed in environments where fire was historically rare and ecologically disruptive. Understanding these differences is critical to situating India's forest fire dynamics within a broader global comparative context.

Tropical Forests: High Biomass and Human Pressures

Tropical forests are mainly found across the South America, Central Africa, Southeast Asia, and parts of Oceania, represent the planet's richest reservoirs of biodiversity and carbon (Malhi et al., 2014). Their climatic conditions featured by high rainfall and humidity with historically limited natural fire occurrence. However, in recent decades, anthropogenic fires have emerged as a major ecological disturbance (FAO & UNEP, 2020; Kelley et al., 2025). In the Amazon Basin, deforestation and land conversion for agriculture and cattle ranching have fundamentally altered fire dynamics (Brando et al., 2020; Nepstad et al., 2008). Unlike natural fires that usually arise during drought years associated with *El Niño* events, these human-initiated fires are deliberate tools for land clearance (Aragão et al., 2018). The cumulative impact of such fires has created a positive feedback loop: forest degradation reduces canopy moisture, making the ecosystem more flammable and consequently more susceptible to subsequent burning.

In tropical Asia, similar patterns are observed. In Indonesia and Malaysia, widespread peatland fires frequently linked to oil palm cultivation, generate massive haze events and contribute disproportionately to global greenhouse gas emissions (Field et al., 2016). Peat fires are particularly destructive because they smolder belowground, releasing large amounts of carbon over extended periods (Hu et al., 2018). Across tropical Africa, especially in the Congo Basin, fire is less extensive than in South America but remains an important ecological and socio-economic force, used traditionally for land management and shifting cultivation (Archibald, 2016). Collectively, these examples stress that tropical forests, once relatively fire-resistant due to their humid environments, are increasingly being transformed into fire-prone systems through deforestation, fragmentation, and climatic drying.

Temperate Forests: Seasonal Fires and Management Evolution

Temperate forests cover the large portions of North America, Europe, and East Asia, experience moderate climatic conditions with distinct seasonal variability. Unlike tropical systems, fire is an innate ecological process in many temperate forest types, maintaining biodiversity and regulating vegetation structure (Agee, 1993; Pausas & Keeley, 2009). In North America, particularly in the western United States and Canada, natural ignitions from lightning historically maintained fire-adapted ecosystems dominated by coniferous species such as *Ponderosa pine* and *Douglas fir* (Agee, 1993; Stephens et al., 2007). However, over a century of aggressive fire repression beginning with the early twentieth-century in form of "10 a.m.

policy[8]" of the U.S. Forest Service, disrupted natural fire cycles and led to unprecedented fuel accumulation (Pyne, 1997; Stephens et al., 2014; Stephens & Ruth, 2005).

Recent decades have seen a paradigm shift toward prescribed burning and ecological fire restoration, acknowledging that the absence of fire can be as detrimental as its excess. For instance, the 2018 Camp Fire in California and subsequent mega-fires have highlighted the risks of climate–fuel interactions, where hotter, drier conditions amplify fire intensity (Abatzoglou & Williams, 2016). In Europe, temperate and Mediterranean regions including Spain, Portugal, and Greece have similarly faced escalating fire activity driven by land abandonment, heatwaves, and changing precipitation patterns (El Garroussi et al., 2024; Kelley et al., 2025). European fire management more and more emphasizes prevention, early warning systems, and cross-border cooperation under the European Forest Fire Information System (EFFIS), reflecting a shift from reactive suppression to proactive risk governance (Ascoli et al., 2023; Rossi et al., 2020; San-Miguel-Ayanz et al., 2003, 2023).

In East Asia, particularly in China and Japan, temperate forest fires are relatively infrequent due to intensive forest management and humid monsoonal climates. Nonetheless, rising temperatures, changing rainfall pattern (Yuan et al., 2022), and rural depopulation have increased fuel loads in some regions, making them more susceptible to fire (Nakagoshi, 2001; Z. Wu et al., 2020). Overall, temperate forest fire regimes demonstrate a clear transition from natural, low-intensity cycles to human-amplified, high-severity events under contemporary climatic pressures.

Boreal Forests: Fire-Dependent Ecosystems and Climate Feedback

The geographical distribution of the boreal forests (taiga) are found across Canada, Alaska, Scandinavia, and Russia, constitute the world's second largest terrestrial biome. Fire is a natural and necessary ecological agent in these high-latitude regions as well, where long, cold winters and short, dry summers promote periodic burning (Kasischke & Turetsky, 2006; Stocks et al., 2002). Many boreal species including *black spruce* (*Picea mariana*) are fire-adapted, with cones that release seeds only after exposure to ignition or heat (Johnstone et al., 2010). In this biome, fires appear on multi-decadal to centennial scales, shaping forest succession and

[8] The *"10 a.m. policy"* was a U.S. Forest Service fire suppression strategy introduced in 1935, which mandated that all wildfires be controlled or extinguished by 10 a.m. on the day following their initial report. Rooted in early twentieth-century conservation ideology, the policy aimed to minimize forest loss by enforcing rapid, total suppression of all fires. However, it later drew criticism for disrupting natural fire cycles, leading to excessive fuel accumulation and more severe wildfires in subsequent decades (Pyne, 1997; Stephens et al., 2014).

nutrient recycling. However, the intensity and frequency of boreal fires are now increasing, hammered by rapid Arctic warming, permafrost thaw, long droughts, and human actions (McCarty et al., 2021; Walker et al., 2019). These fires release vast amounts of stored carbon, not only from vegetation but also from organic soils, turning the biome from a carbon sink to a potential carbon source. For example, the 2019 Siberian and 2023 Canadian wildfires showed the scale of this shift, burning millions of hectares and injecting massive smoke plumes into the atmosphere (Chen et al., 2025; Kharuk et al., 2021). Consequently, boreal fires have become central to global climate feedback discussions, linking regional ecological change with planetary atmospheric processes.

Savanna and Mediterranean Ecosystems: Fire-Adapted Landscapes

Contrary to tropical rainforests or boreal, savanna and Mediterranean ecosystems have co-evolved with frequent fire (Archibald et al., 2013; Pausas & Keeley, 2009). These landscapes, including sub-Saharan Africa, northern Australia, and southern Europe, are exemplified by grass–tree mosaics, periodic droughts, and seasonal rainfall patterns that promote recurrent burning (W. J. Bond & Keeley, 2005). Fire performs an essential ecological role here: it controls woody encroachment, recycles nutrients, and sustains grazing pastures. In African savannas, fire is both a natural and cultural phenomenon where communities use controlled burning for hunting, pasture renewal, and pest control practice set in their traditional ecological knowledge (Archibald, 2016). In northern Australia, Indigenous fire stewardship often called "fire-stick farming", represents one of the most cultured examples of community-managed fire regimes (Rosemary Hill, Adelaide Baird, Davi, 1999). Through small, frequent burns during early dry seasons, Indigenous land users and catalyst reduce fuel loads and prevent large, destructive late-season fires, a practice now integrated into national carbon abatement programs (Skiba, 2020).

The Mediterranean Basin which covering the parts of Spain, Portugal, Italy, Greece, and Turkey, records recurrent summer fires linked to high temperatures, dry winds, and dense shrubland vegetation (Abrham et al., 2024; Trigo et al., 2022). Historically, fire has maintained the region's biodiversity, but land-use change, rural abandonment, and climate-induced aridity have increased the frequency and intensity of extreme fires (Kelley et al., 2025). These patterns clarify that in fire-adapted systems, the challenge lies not in preventing fire altogether, but in managing its timing, scale, and social implications.

Tropical–Temperate Comparisons and Emerging Global Trends

Throughout the biomes, global fire regimes reflect a composite interaction between climate, vegetation, and human influence (Bowman et al., 2011). In tropical humid forests, fire was historically rare and largely anthropogenic, whereas in temperate and boreal ecosystems, fire forms a natural component of ecological renewal. Savannas and Mediterranean biomes, in turn, demonstrate co-evolutionary relationships between vegetation and recurring fire. What unites these diverse systems in the Anthropocene is the increasing dominance of human drivers such as deforestation, agricultural expansion, urban encroachment, and policy decisions that alter fire frequency and behavior beyond historical baselines. Climate change compounds these effects by intensifying droughts, increasing fuel aridity, and extending fire seasons (FAO, 2025). Between 2000 and 2020, global burned area declined slightly overall but shifted toward higher latitudes and previously low-risk zones, indicating changing geographic patterns (Ritchie & Samborska, 2024; C. Wu et al., 2021). Simultaneously, fire intensity and carbon emissions have increased, particularly in tropical and boreal regions (Van Der Werf et al., 2017). Fire–climate response loops now represent a major concern for global carbon budgets and biodiversity conservation.

Another emerging dimension is the use of remote sensing and geospatial technology in fire science. Global datasets including MODIS and VIIRS have enabled near-real-time detection of active fires and burned areas at unprecedented scales. Long-term satellite archives (e.g., Landsat, Sentinel) support historical analysis of fire frequency and vegetation recovery, and newer radar and LiDAR data provide insights into biomass loss and soil moisture dynamics (Kurbanov et al., 2022; P. S. Roy, 2003). Coupled with GIS, these tools allow for fire risk modeling, spatial vulnerability assessment, and predictive forecasting. In global contexts from U.S. national parks to the Amazon and Australian savannas, geospatial analytics now underpin both operational fire management and academic research (Chuvieco et al., 2020).

The growing integration of geospatial fire science into governance frameworks is also noteworthy. For instance, the European Forest Fire Information System (EFFIS) and the Global Wildfire Information System (GWIS) consolidate satellite data, meteorological inputs, and ground reports to support transnational coordination. Likewise, in the United States, the LANDFIRE and Wildfire Risk to Communities programs employ spatial modeling to guide prevention and resource allocation (EROS, 2020). These examples demonstrate that the intersection of ecological understanding, remote sensing, and governance mechanisms defines the contemporary frontier of wildfire research and management.

2.3 From Global Patterns to Indian Realities

Global fire regimes reflect both ecological variability and a growing convergence of anthropogenic influence. Fire is inherent to many landscapes including savannas, boreal forests, and Mediterranean shrublands, it has become increasingly destructive in ecosystems where it historically played a minimal role, particularly humid tropical forests. Climate variability, land-use transitions, and institutional arrangements collectively shape the patterns and intensities of burning across the world (Kelley et al., 2025; Popescu et al., 2022). Advances in remote sensing and GIS have improved the detection and characterization of fire patterns, enabling several countries to shift from reactive suppression to more anticipatory management (Kurbanov et al., 2022). Nonetheless, these benefits remain unevenly distributed, and many regions in the Global South continue to struggle with limited technological capacity, restricted data access, and governance systems that are often poorly aligned with socio-ecological realities (P. S. Roy, 2003). India represents this tension between ecological change and institutional response. The India's forests are entrenched within a monsoonal climate, diverse ecological assemblages, and dense human–forest interactions, resulting in fire regimes that are neither entirely ecological nor exclusively anthropogenic but hybrid, seasonal, and context-specific (Yadav, 2025). In India, fire develops from biophysical conditions and the interaction of livelihood practices, governance structures, and cultural norms, making the country a distinctive case within the global fire discourse.[9]

As India's forest diversity is formed by its unique biogeographical position, situated at the confluence of the Indo-Malayan, Palaearctic, and Ethiopian realms (Rodgers & Panwar, 1988) and the strong seasonality of the monsoon. The country supports a wide range of forest types

[9] India carries one of the largest shares of forest-dependent populations in the world, with an estimated 275 million people relying directly or indirectly on forests derived resources for their subsistence, income, fuelwood, fodder, housing materials, and NTFPs, which form a significant component of household livelihoods in forest-fringe regions (MoEFCC, 2017; Milne et al 2005; 2014; Sardeshpande & Shackleton, 2019; Boyapati & Muthukumarappan 2025). In tribal-dense landscapes, this dependence extends beyond material needs to cover cultural practices, food security, traditional medicine, and seasonal employment, making forests central to everyday survival and social reproduction (Gadgil & Guha, 2008; Saxena, 1995). Such dependence also builds community sensitivity to environmental change, governance interventions, and access restrictions, influencing how disturbances such as forest fires are perceived and managed locally.

[10] from evergreen and semi-evergreen systems of the Western Ghats and Northeast to the dry and moist deciduous forests of Central India, to pine and oak-dominated montane systems in the Himalayas (Champion & Seth, 1968). The deciduous forest formations, which constitute more than half of India's total forest area, are particularly significant for understanding fire dynamics because their pronounced leaf-shedding and long dry seasons produce an abundant layer of fine fuels (ISFR, 2023). The widespread tropical dry deciduous forests dominated by teak, tendu, and associated species represent the country's most fire-prone landscapes, where annual burning is almost structurally rooted (Joseph et al., 2009). In contrast, evergreen forests remain relatively resistant to fire except under conditions of extreme drought, while Himalayan coniferous forests burn readily due to resinous needle litter (Bargali et al., 2023; Kumar & Kumar, 2022). These ecological patterns demonstrate that fire sensitivity in India is closely tied to vegetation type, moisture regimes, and seasonal drying (Bahuguna & Singh, 2002; Banerjee et al., 2024; Kale et al., 2017; Saha, 2002). They also reveal that Indian fire ecology cannot be understood without acknowledging the dominant role of human activity (Bahuguna & Singh, 2002). Grazing, shifting cultivation, the collection of NTFPs such as tendu and mahua, and the clearing of undergrowth for mobility and visibility shape the season and spatial distribution of fires across much of the country (Mohd et al., 2024).

Human–forest relationships further complicate the ecological picture. For centuries, fire has played a role in traditional ecological management among Adivasi[11] and other forest-dwelling communities. Early-summer burning to stimulate fresh grass, tradition agriculture, facilitate mahua flower collection, improve access for tendu leaf harvesting, or clear accumulated litter before the monsoon replicates a body of ecological knowledge that is adaptive and locally placed (Singh et al., 2023; Kodandapani, 2013; Saha & Howe, 2006; Bahuguna & Upadhay, 2002; Saha, 2002; S. Srivastava & Choubey, 1968). These practices have persisted despite

[10] Champion and Seth's (1968) classification of India forest considered one of the most authoritative forest typologies which categorizes forests into **five broad groups, 16 major types, and over 200 subtypes** based on physiognomy, floristics, and climate. The five major groups include: (1) **Tropical Wet Evergreen Forests**, dense and multi-layered in high-rainfall zones of the Western Ghats, Andaman–Nicobar, and Northeast, with naturally low fire incidence; (2) **Tropical Moist Deciduous Forests**, dominated by *Shorea robusta* across eastern India and the Himalayan foothills, where seasonal litter build-up increases fire occurrence; (3) **Tropical Dry Deciduous Forests**, the most widespread type in Central India and the Deccan, dominated by teak and highly fire-prone due to prolonged dry seasons and livelihood-based burning; (4) **Tropical Thorn Forests,** found in arid and semi-arid regions with drought-resistant species and typically low-intensity fires; and (5) **Montane Subtropical and Temperate Forests**, comprising Himalayan pine, oak, and rhododendron belts, with pine forests (*Pinus roxburghii*) particularly flammable due to resinous litter.

[11] Aboriginal/native people are often characterized by their live-out in forested, hilly and remote areas. They comes under the schedules caste (ST)-an official categorization by the govt. of India, in order to save, secure and protect their unique cultural identity, traditional practices and provide social upliftment.

being frequently criminalized or interpreted as forest degradation by formal institutions (Carmenta et al., 2011; Smith et al., 2024; Yadav, 2025). Religious and cultural traditions, including the maintenance of sacred groves and the philosophical notion of *Vana* (forest) as a moral-ecological space, highlight the long-standing co-existence between people and forests (Gadgil & Guha, 2008; Sharma, 2022). This embeddedness of fire in livelihood paces and cultural norms distinguishes Indian fire regimes from those in many temperate regions, where fire is predominantly understood through a wilderness-management lens (Bowman et al., 2009; Saha, 2002; Stephens et al., 2014). However, institutional frameworks in India continue to privilege a suppression-oriented understanding of fire, set in colonial forestry's emphasis on control and extraction (Jolly et al., 2025; Rangarajan, 1996; Sivaramakrishnan, 1999; Thekaekara et al., 2017). Despite policy shifts such as Joint Forest Management and the Forest Rights Act (Bahuguna & Singh, 2002; Karki, 2002), the operational autonomy of communities in fire governance remains limited. The National Action Plan on Forest Fires promotes early-warning systems and coordination (ISFR, 2018) but does little to integrate Indigenous burning practices or socio-cultural perspectives (Reddy et al., 2019). In contrast, countries such as Australia, Canada and South Africa have moved toward incorporating Indigenous fire stewardship as part of formal policy (Fache & Moizo, 2015; McKemey et al., 2020; Moura et al., 2019; Nikolakis et al., 2024). This divergence mirrors deeper governance constraints in India, where limited financial allocations, bureaucratic centralization, and narrow technocratic approaches often obscure local ecological knowledge (Jolly et al., 2025; K. Yadav, 2025).

These national-level patterns become more pronounced in Central India, which forms the country's largest contiguous forested landscape and its primary "fire belt" (P. S. Roy, 2003; Saha, 2002; Sahu et al., 2024). Central region is covering Madhya Pradesh, Chhattisgarh, parts of Maharashtra, and eastern Gujarat, the region occupies a transitional ecological zone between the moist forests of the east and south and the drier deciduous and thorn forests of the west. Its undulating plateaus, basaltic and sandstone geologies, and monsoon-driven climate create conditions of high flammability from February to June (P. Srivastava & Garg, 2013). Vegetation is dominated by moist and dry deciduous species e.g. Sal, teak, tendu, mahua, whose seasonal leaf fall produces extensive surface fuels (Champion & Seth, 1968). These forests regenerate rapidly through coppicing and rootstock sprouting after the monsoon, making them resilient to low-intensity, early-season fires. At the same time, repeated or late-season burning alters species composition, degrades soil nutrients, and facilitates the spread of invasives such as *Lantana camara* (Hiremath & Sundaram, 2005). The ecological dynamics of

Central India are closely paired with its biodiversity significance; the region hosts one of the significant contiguous tiger landscape in the India (DeFries et al., 2023), and fire regimes influence habitat connectivity, understory structure, and herbivore–predator interactions (Jain et al., 2021; Joseph et al., 2009)

Central India has culturally rich forest landscape (Khan, Sharma, et al., 2024). As it composes major Adivasi communities including Gond, Baiga, Bhil, and Korku groups, maintain livelihoods that depend on NTFPs, grazing, and seasonal forest labor (Bhattacharya et al., 2025; Mishra et al., 2021; Pandey & Saini, 2007; Sahu et al., 2024). Fire shapes many of these livelihood cycles, whether in enhancing tendu leaves productivity, clearing collection spaces for mahua flowers, or stimulating new grass for livestock. These practices exhibit local ecological rationalities but remain misaligned with prevailing state descriptions that equate all burning with degradation. This divergence produces recurring governance tensions, as formal institutions emphasize suppression whereas communities view fire as a customary management tool (K. Yadav, 2025). The result is a landscape where ecological processes, livelihood imperatives, and institutional logics interact in often contradictory ways.

Thus, these contexts demonstrate that fire cannot be understood from a single epistemological frame i.e., fire is a biophysical or purely human phenomenon. However, it is a socio-ecological process designed by climate, vegetation, cultural practice, and governance (CVCGs). Central India in particular resembles hybrid fire-prone systems such as African savannas and northern Australian woodlands, still differs in being primarily anthropogenic and livelihood-driven (Eriksen, 2007; Giriraj et al., 2010; McKemey et al., 2020). Recognizing this hybrid character challenges simplistic binaries of “good” and “bad” fire and emphasizes the need for place-based, culturally attuned approaches to fire governance. This integrated understanding provides the conceptual foundation for examining fire dynamics, community perceptions, and governance interactions in the Central Indian region (particularly in HFD), where the lived realities of fire mirror the broader socio-ecological contradictions of the Indian forest landscape.

2.4 Community Perceptions of Fire and Socio-economic Impacts: A Conceptual Underpinning

Forest fires are commonly analyze through biophysical (frequency, burned area, intensity, emissions) and direct economic damage (loss of crop, house, lives, and other human used properties), however, such metrics are crucial for ecological assessment, economic, and operational management, they do not fully capture how fire is experienced, interpreted, and valued by forest-dependent communities. Fire impacts are not only ecological or economic phenomena, but they are also socially perceived, culturally mediated, and historically situated. Thereby, the socio-economic consequences of fire are not only formed or designed by the occurrence of burning but by how communities understand fire risk, integrate fire into livelihood practices, and negotiate its meaning within existing institutional and governance frameworks. This section is grounded in developing a conceptual footing for analysing community perceptions of fire and its socio-economic impressions, emphasizing lived experience and realities, livelihood sensitivity, and the deviation between scientific, policy, and local living accounts. Rather than presenting pragmatic results, the argument begins the theoretical basis for examining why fire impacts may be perceived as limited, tolerable, or even beneficial in certain contexts, despite dominant representations of fire as a destructive hazard.

2.4.1 Fire Risk, Perception, and Lived Experience

Risk is not an objective condition alone, but a socially constructed phenomenon shaped by experience, familiarity, trust, and cultural context (Douglas & Wildavsky, 1982; Slovic, 1987). In disaster studies, it is well established that communities exposed to recurrent environmental hazards often perceive risk differently from external experts or institutions. Frequent, low-intensity events tend to be normalized, despite the fact that the rare, catastrophic events are perceived as more threatening, even if their cumulative impacts are smaller (Wisner et al., 2004). In the context of forest fires, this distinction is critical. Scientific assessments frequently prioritize extreme fire events based on intensity or area burned, whereas local communities may evaluate fire risk through everyday interactions with forests, seasonal rhythms, and long-term livelihood outcomes. Lived experience shows a central role in shaping fire perception. Communities that have co-existed with fire over generations often develop practical knowledge about fire timing, spread, and controllability. Early-season, low-intensity fires may be regarded as predictable and manageable, but late-season or drought-driven fires are perceived as risky due to their deviation from established patterns (Berkes, 2012). This experiential knowledge influences how fire impacts are assessed at the household level. Losses are not necessarily measured in absolute terms but relative to expectations, coping capacity, and historical baselines. As a result, communities may report limited socio-economic disruption even in landscapes where satellite data indicate frequent burning.

Another central dimension is the distinction between *hazard* and *impact*. Hazard denotes to the physical occurrence of fire. But impact refers to its consequences for livelihoods, well-being, and security. Fire hazard may be high, but perceived impact may remain low if households possess adaptive strategies such as livelihood diversification, flexible resource use, or social safety nets (Scoones, 1998; Chambers, 2009). On the contrary, even small fires can have severe perceived impacts where access rights are restricted, compensation mechanisms are absent, or livelihoods are narrowly specialized. Therefore, understanding fire risk requires moving beyond probabilistic or spatial models to incorporate how exposure, sensitivity, resilience and adaptive capacity are socially distributed and locally interpreted.

2.4.2 Socio-Economic Meaning of Fire for Forest-Dependent Livelihoods

The socio-economic meaning of fire varies significantly across livelihood systems and ecological contexts. For forest-dependent households, fire is often rooted within seasonal cycles of resource collection, NTFPs gathering, agriculture, grazing, and wage labor. Its impacts are mediated by timing, scale, and institutional limitations rather than by fire event alone. Livelihood-based perspectives point out that fire can function simultaneously as a stressor and a facilitator, depending on how it intersects with resource access and production cycles (Ellis, 2000; Scoones, 2009). In many forested landscapes, low-intensity fires contribute to the regeneration of grasses, stimulate flowering or fruiting of certain species, and clear undergrowth, thereby reducing collection effort for NTFPs. From a livelihood standpoint, such effects may enhance short-term productivity or reduce labor costs. Consequently, communities may not perceive these fires as economically damaging, even when they are formally classified as forest degradation. This does not imply that fire is universally beneficial, but rather that its socio-economic valuation is context-specific and contingent upon livelihood dependence, market integration, and tenure security.

Further, livelihood diversification regulates perceived fire impacts. Households that combine forest-based activities with agriculture, wage labor, migration, or state welfare schemes are often less vulnerable to fire-induced disruptions than those reliant on a single resource base (Ellis, 2000; DFID, 1999). In such contexts, fire-related losses may be absorbed or offset by alternative income sources, reducing their salience in household risk assessments. This helps explain why communities may rank other stressors including irregular rainfall, declining market prices, or governance restrictions as more disruptive than fire itself (see chapter 5 for more understanding).

The socio-economic impacts are also shaped by institutional arrangements governing forest access. Where customary rights are secure and locally conferred, communities may adapt fire practices to sustain productivity. On the other hand, where access is regulated through restrictive permits or enforcement-oriented regimes, even minor fire events can translate into livelihood insecurity through fines, confiscation, or exclusion (refer to chapter 5-6). Thus, perceived impact is not plainly a function of fire ecology but of political and institutional contexts that determine who bears costs and who exercises control (Blaikie & Brookfield, 1987; Ribot & Peluso, 2003).

2.4.3 Divergence among Scientific, Policy, and Community Fire Accounts

A persistent theme in fire discourse is the conflict among scientific assessments, policy frames, and community interpretations of fire. Scientific descriptions tend to frame fire through quantifiable indicators such as burned area, fire radiative power, carbon emissions, biodiversity loss, and direct human property damage. Policy frames, particularly within forest bureaucracies, often translate these system of measurement into a discourse of damage, illegality, and risk control, underlining suppression, surveillance, and enforcement. Community accounts, by contrast, are grounded in everyday experience, livelihood outcomes, and moral evaluations of land use (Robbins, 2012). These divergent plots reflect not only differences in knowledge systems but also asymmetries of power. Policy and scientific discourses often dominate decision-making, shaping regulations, funding priorities, and enforcement practices, and often community perspectives are side-lined or dismissed as unscientific or illegal (Scott, 1998). This misalignment can lead to governance outcomes that are poorly adapted to local realities. For instance, blanket fire bans or zero-tolerance policies may criminalize customary practices without reducing fire incidence and simultaneously eroding trust between communities and state agencies.

Hailing from a political ecology perspective, such narrative conflicts are not only accidental but also set in historical processes of state formation, resource control, and colonial forestry legacies (Sivaramakrishnan, 1999; Gadgil & Guha, 2008;2012). Fire becomes a site of contestation where competing claims over knowledge, authority, and legitimacy intersect (Yadav, 2025). Therefore, community perceptions of fire impacts need be understood as subjective assessments and grounded responses to governance structures that regulate access, impose penalties, and define acceptable practices.

For effective fire governance, the recognition of narrative deviation is crucial. Policies that fail to engage with local perceptions risk misdiagnosing the causes and consequences of fire, leading to ineffective or counterproductive interventions. In opposition, integrating community perspectives into fire assessment can improve the relevance of risk mapping, enhance compliance, and support adaptive management approaches. This does not imply uncritical acceptance of all local practices however calls for dialogic governance that acknowledges multiple knowledge systems and aligns ecological objectives with livelihood realities.

Collectively (all conferred just above in 3 subheading), these conceptual perspectives stress that community perceptions of fire and its socio-economic impacts are shaped by lived experience, livelihood strategies, and governance contexts rather than by fire occurrence alone. Fire risk is socially perceived, impacts are livelihood-mediated, and narratives are politically contested. These insights provide a necessary foundation for analysing why, in certain fire-prone landscapes, communities may perceive fire as a secondary or manageable stressor relative to other environmental and institutional pressures. By foregrounding perception and meaning, this prepares the analytical ground for the subsequent examination of fire governance frameworks and for the empirical analysis of household-level perceptions in later chapters of the thesis.

2.5 Fire Governance Frameworks

2.5.1 A Global Perspective

The governance of fires has evolved differently across the world, mirroring distinct ecological conditions, historical legacies, policy paradigms, and socio-political contexts. Globally, the shift from fire suppression to fire management and adaptive governance represents one of the most significant transformations in environmental policy over the past half century (Bowman et al., 2011; Fernandes & Botelho, 2003; Smith et al., 2024). Early approaches emphasized extinguishing all fires as threats to forest productivity and property, however, contemporary models gradually recognize the ecological necessity of fire and the value of community participation and scientific monitoring. In that way, reviewing global fire-management frameworks across major regions and highlighting the governance lessons they offer for India’s evolving forest and fire policies becomes imperative.

2.5.1.1 Conceptual Shifts

Historically, fire management was rooted in protectionist forestry paradigms, viewing fire as destructive to timber and forest capital. The early 20th century, particularly in North America and Europe, institutionalized large-scale fire suppression through centralized agencies (Pyne, 1997). However, scientific research in the latter half of the century revealed that many forest ecosystems are fire-adapted and that total exclusion can increase fuel loads and the severity of future wildfires (Agee, 1993; Pyne, 2019). Consequently, fire governance has transitioned through three broad phases as shown in table 2.1.

Table 2. 1 Evolution of global forest fire governance paradigms.

Governance Phase	Period / Historical Context	Dominant Philosophy	Key Characteristics	Representative Examples	Limitations / Challenges	Key References
Phase I – Fire Suppression Era	Early–mid 20th century (c. 1900–1960s)	Fire as a destructive force; focus on complete elimination.	Centralized control; strict firefighting mandates (e.g., “10 a.m. policy”); exclusion of local participation.	United States (U.S. Forest Service); early European forestry departments.	Fuel accumulation, ecological imbalance, increased future fire severity.	(Calkin et al., 2015; Pyne, 1997; Stephens et al., 2013)
Phase II – Fire Management Era	1970s–1990s	Recognition of fire’s ecological role.	Prescribed burning; ecological zoning; integration of fire ecology in policy.	North America (National Park Service); Australia (early controlled burning programs).	Limited community involvement; bureaucratic dominance; weak implementation in tropical regions.	(Kilgore, 2007; van Wagtendonk, 2011)
Phase III – Adaptive & Participatory Governance	2000s–present	Fire as a socio-ecological process requiring adaptive, inclusive management.	GIS & remote sensing integration; Indigenous and community-based fire management; resilience and prevention focus.	Australia (Savanna Burning Programs), Africa (Integrated Fire Management), Europe (EFFIS & CEMS).	Requires strong institutions, funding, trust-building; uneven adoption in developing countries.	(Archibald et al., 2013; Chuvieco et al., 2020; Fernandes & Botelho, 2003; Gill et al., 2009; Moura et al., 2019; Nikolakis & Roberts, 2020)

These phases reflect a broader movement from *command-and-control forestry* toward *adaptive, participatory, and knowledge-driven governance*, an approach increasingly relevant for India. The imprints of the conceptual shift in the fire governance can be seen differently across the worlds as per their adoption mechanism for the new technology, local knowledge incorporation, and evolution of these shifts in governance with time. Below are the brief details provided to highlight the heterogeneity in this shift across geographies.

a) From Suppression to Resilience-Based Management: North America

The US and Canada provide seminal examples of the transformation in fire governance. In the U.S., the U.S. Forest Service and National Park Service initially enforced forceful fire suppression following catastrophic fires such as the 1910 "Big Burn."(Egan, 2009). The "10 a.m. policy", established in 1935, mandated complete control of fires by the morning after ignition. Although effective in reducing short-term losses, it disrupted natural fire regimes, leading to fuel accumulation and larger, more severe fires in later decades (Pyne, 1997; Stephens et al., 2014; Stephens & Ruth, 2005). By the 1970s, ecological research in parks like Yellowstone prompted a paradigm shift toward prescribed burning and fire-use policies. The National Fire Plan (2000) and National Cohesive Wildland Fire Management Strategy (2014) now emphasize three pillars: (i) resilient landscapes, (ii) fire-adapted communities, and (iii) safe, effective wildfire response (Agriculture & Interior, 2011; Crist, 2023). Geospatial tools such as LANDFIRE, MTBS (Monitoring Trends in Burn Severity), and Wildfire Risk to Communities provide spatial data for prioritizing prevention and mitigation (Modaresi Rad et al., 2023).

In Canada, wildfire management falls under provincial jurisdiction but is coordinated through the Canadian Wildland Fire Information System (CWFIS), integrating satellite data, meteorological modeling, and risk assessment (Tymstra et al., 2020). Recent strategies emphasize co-existence with fire, including Indigenous burning practices into landscape restoration, particularly in British Columbia and the Northwest Territories (Christianson, 2015).

These North American models illustrate the importance of multi-level governance, where federal coordination, regional autonomy, and community participation are balanced within an adaptive framework supported by science and technology.

b) Governance Challenges in the Amazon Basin in South America

In contrast, the Amazon Basin shared among Brazil, Peru, Colombia, and Bolivia, faces a governance crisis rooted in deforestation-driven fires. Fire is largely anthropogenic, used for clearing forest for agriculture, cattle ranching, and logging (Aragão et al., 2018). Brazil's extensive environmental legislation, including the Forest Code (1965, revised 2012) and the National Policy on Climate Change (2009) reflect significant outcome (Barbosa De Oliveira

Filho, 2019), but their thorough enforcement remains uneven (Soares-Filho et al., 2014). The Brazilian Institute of Environment and Renewable Natural Resources (IBAMA) and the National Institute for Space Research (INPE) operate advanced satellite systems such as DETER and PRODES for real-time fire monitoring (Rajão et al., 2017). However, political and economic pressures frequently undermine these efforts (Rajão & Jarke, 2018). Weak coordination between federal and local authorities, combined with land conflicts and illegal deforestation, perpetuates large-scale, recurring fires (Stokstad, 2017). The Amazon case demonstrates that technological capacity alone is insufficient without strong institutional accountability and community engagement. It stresses the importance of aligning fire governance with land-use and socio-economic policies, a challenge also relevant in India's forest-fringe regions.

c) Integrating Indigenous Fire Knowledge in Australia

Australia's fire governance is widely regarded as one of the innovative frameworks, blending scientific management with Indigenous ecological knowledge (Russell-Smith et al., 2009). Australian ecosystems, particularly the tropical savannas and eucalyptus woodlands are highly fire-adapted, still unprecedented changes in land cover driven by human activities, coupled with intensifying climate variability, have increased their susceptibility to fires (Andersen et al., 2012). Historically, colonial-era policies sought to suppress fire, but by the late 20th century, ecological research and Indigenous advocacy led to a profound policy shift (Moura et al., 2019). Now, programs such as the Northern Australia Savanna Burning Projects integrate traditional Aboriginal burning practices (small, early dry-season burns), to reduce fuel loads and prevent destructive late-season fires (Ansell et al., 2020). These projects also generate carbon credits under Australia's Emissions Reduction Fund, linking fire management with climate mitigation and Indigenous livelihood enhancement. The Australian model shows a form of "bio-cultural governance", where Indigenous knowledge, scientific monitoring, and market mechanisms operate collaboratively. Its success lies in acknowledging fire as a cultural and economic process, an approach proposing critical lessons for India's tribal forest regions.

d) Trans-national Cooperation and Climate Adaptation: Europe

In Europe, wildfires are primarily concentrated in Mediterranean countries such as Spain, Portugal, Italy, and Greece (Abrham et al., 2024). Governance frameworks emphasize transnational coordination, knowing that fire and smoke transcend national boundaries (Meier et al., 2023). The European Forest Fire Information System (EFFIS) and the Copernicus

Emergency Management Service (CEMS) provide integrated fire monitoring, early warning, and post-fire assessment across the continent (San-Miguel-Ayanz et al., 2003, 2023). Policy emphasis in Europe has shifted from reactive firefighting to landscape-scale prevention, including fuel management, rural revitalization, and reforestation with fire-resistant species (Rossi et al., 2020). The EU Forest Strategy (2021) links wildfire prevention with climate adaptation and biodiversity targets (EC. Directorate General for Environment., 2021). Especially, Europe's governance approach relies heavily on multi-actor partnerships which involve local municipalities, research institutions, and civil society, to implement fire resilience strategies (Ascoli et al., 2023). This cooperative model highlights the significance of institutional integration and cross-border data sharing, providing a precedent for multi-state collaboration in India, particularly across Central Indian Forest walkways.

e) Fire as a Tool of Ecological Management: Africa

In sub-Saharan Africa, fire has long been an integral component of savanna ecology and land management. Unlike temperate or tropical rainforests, African savannas are fire-dependent ecosystems, where periodic burning maintains grass–tree balance and nutrient cycling (Archibald, 2016). At this juncture, governance highlights controlled burning rather than suppression. Countries like South Africa have developed Integrated Fire Management (IFM) strategies under the National Veld and Forest Fire Act (1998). These frameworks promote community fire associations, early-warning systems, and cooperative prevention activities. Fire Protection Associations (FPAs) bring together landowners, local authorities, and conservation agencies to plan and implement prescribed burns (*A Guide to Integrated Fire Management*, 2016). African models validate the feasibility of decentralized, participatory fire governance in resource-limited contexts (Govender et al., 2006). Their success depends on local legitimacy, capacity building, and clear property rights, factors highly relevant for India's joint forest management and community-based fire programs.

2.5.1.2 The 3Cs Framework: Contextual, Comparative, and Critical

Across the world, fire governance has evolved in response to changing ecological understanding, climate pressures, and the recognition that many landscapes are fire-adapted rather than fire-excluded systems (see comparative global forest fire governance in Tab 2.2). These global comparative frameworks offer valuable lessons for India, where fires are predominantly anthropogenic and closely tied to livelihood practices, yet governance remains largely suppression centric.

Table 2. 2 Comparative overview of global forest fire governance frameworks *(Source: Based on author's understanding)*

Region / Country	**Dominant Ecosystem & Fire Context**	**Governance Approach / Frameworks**	**Key Institutions & Tools**	**Core Lessons for India**
United States & Canada (North America)	Temperate and boreal forests; historically fire-suppressed but fire-adapted ecosystems.	Transition from strict suppression ("10 a.m. policy") to *adaptive fire management* emphasizing resilience, prescribed burns, and community safety.	U.S. Forest Service (USFS); National Park Service; National Cohesive Wildland Fire Management Strategy; Canadian Wildland Fire Information System (CWFIS); LANDFIRE, MTBS datasets.	Move from suppression to *resilience-based governance*; integrate scientific models and risk zoning; balance federal coordination with local autonomy.
Brazil & Amazon Basin (South America)	Humid tropical forests: deforestation and agricultural burning dominate.	Policy–practice gap: advanced monitoring but weak enforcement and governance fragmentation.	IBAMA, INPE (DETER, PRODES satellite systems).	Technology must be paired with institutional accountability and land-use regulation; align fire policy with socio-economic and deforestation control strategies.
Australia	Fire-adapted tropical savannas and eucalyptus woodlands.	*Biocultural governance*: integration of Indigenous burning practices with national carbon and biodiversity policy.	Northern Australia Savanna Burning Projects; Emissions Reduction Fund; Aboriginal ranger programs.	Recognize and institutionalize Indigenous fire knowledge; link fire governance with livelihoods and climate mitigation (carbon credit models).
Europe (Mediterranean & EU)	Mediterranean forests and shrublands; frequent summer fires due to heatwaves and land abandonment.	Transnational, *risk-based governance* emphasizing prevention, early warning, and cross-border cooperation.	European Forest Fire Information System (EFFIS); Copernicus Emergency Management Service (CEMS); EU Forest Strategy (2021).	Promote interstate cooperation, shared databases, and multi-actor partnerships; integrate fire prevention with land-use and rural development policies.
Sub-Saharan Africa	Fire-dependent savannas where periodic burning maintains	*Integrated Fire Management (IFM)* with community-based	National Veld and Forest Fire Act (1998, South Africa); FPAs,	Encourage *decentralized, participatory fire management*;

	ecological balance.	Fire Protection Associations (FPAs).	local councils, NGOs.	empower local forest committees; develop low-cost community fire networks.
Cross-Regional Synthesis	Diverse ecosystems are increasingly shaped by climate change and human pressure.	Convergence toward *adaptive, participatory, and technology-enabled governance*.	Use of GIS, remote sensing, and data-sharing networks (EFFIS, CWFIS, MODIS, VIIRS).	India should integrate community knowledge, geospatial monitoring, and adaptive policies under a multi-scalar, inclusive framework.

2.5.2 Governance in Indian Landscape

In India, forest governance has forwarded from colonial-era exclusionary control and resource extraction toward post-independence conservation and participatory models (see table 2.3), still fire management rests largely framed by a protectionist, suppression-oriented paradigm (Bisht, 2020; Gadgil & Guha, 2008; Rangarajan, 1996; Yadav, 2025). Colonial forestry, codified through the Indian Forest Acts (1865, 1878, 1927) established state ownership, prioritized timber extraction, and criminalized customary burning for grazing, shifting cultivation, or NTFP collection, embedding a technical view of fire as a threat to commercial species such as teak and Sal (Bhumika & Kumar, 2024; Ekka, 2025; Guha, 1985; Thekaekara et al., 2017). Post-independence policies reserved much of this institutional framework; the National Forest Policy (1952) emphasized state control and utilitarian objectives, whereas the subsequent interventions including *Social Forestry* (1970s), the Forest Conservation Act (1980), and the National Forest Policy (1988), gradually hosted conservation and community welfare into the discourse without fully overturning a suppression approach and state domination (Basu & Mukherjee, 2023; Baumann, 1998).

A significant shift toward participatory governance emerged with Joint Forest Management (JFM) from 1990 onwards, which sought to involve adjacent communities in protection and regeneration in exchange for benefit sharing (Maksimowski, 2011; Saigal, 2003). JFM established local institutions such as Village Forest Committees, but implementation has been uneven; in many contexts forest departments retained decision-making authority and community engagement remained nominal or consultative (Behera & Kirchhoff Engel, 2006; Sundar, 2001). Consequently, community fire knowledge which was long practiced as early-season low-intensity burning to enhance traditional cultivation, fodder and NTFP yields, was rarely integrated into official fire plans, and fire control under JFM often translated into community-led suppression rather than collaborative management (Darlong, 2002).

Legal reforms have created openings for deeper decentralization for instance, PESA (1996) extended statutory powers to local self-governance in scheduled areas (Government of India, 1996), and the Forest Rights Act (FRA, 2006) legally recognized customary rights and empowered Gram Sabhas to decide on forest use (Dandekar & Satpathi, 2022). In principle, these instruments enable community-led governance, including fire management. In practice, however, coordination between FRA institutions, PESA bodies, JFM committees and state forest departments remains limited, producing institutional plurality without effective horizontal integration (CFR, 2016). The result is overlapping mandates, jurisdictional ambiguity, and persistent centralization of operational authority.

Conceding recurring fire events, the Ministry of Environment, Forest and Climate Change (MoEFCC) launched the National Action Plan on Forest Fires (NAPFF) in 2018 to strengthen prevention, early warning, detection, and rapid response (ISFR, 2021). Key components include satellite and meteorology-based early warning, capacity building for forest staff and community fire squads, fuel-break creation, and stakeholder training. The Forest Survey of India (FSI) supports these efforts through the FAST 3.0 alert system (MODIS/VIIRS) and the Large Forest Fire Monitoring System (LFFMS), delivering near-real-time alerts and dynamic burned-area maps (ISFR, 2023). Despite improved detection capabilities, however, NAPFF's implementation remains technology-heavy and largely reactive; investments in community-centric prevention, ecosystem restoration, and devolved decision-making are comparatively limited (Ministry of Environment & World Bank, 2018).

Table 2. 3 Evolution of Forest Governance and Fire Management Frameworks in India, *(Source: Based on author's understanding)*

Policy / Legal Instrument	Period / Enactment	Primary Objectives	Approach to Fire Management	Key Institutions / Mechanisms	Major Limitations / Challenges
Indian Forest Acts (1865, 1878, 1927)	Colonial period	Establish state control over forests; promote timber extraction;	Complete fire suppression; criminalization of local burning practices.	Imperial Forest Department; centralized bureaucracy.	Exclusionary approach; alienation of Indigenous communities; limited

		regulate access.			ecological understanding of fire.
National Forest Policy (1952)	Post-independence	Forests for national development and industrial use; aim to increase forest area to 33%.	Fire seen as destructive; focus on prevention and quick suppression.	State Forest Departments; Forest Research Institute (FRI).	Continued colonial management ethos; very constrained role for local communities.
National Commission on Agriculture (1976) & Social Forestry Programmes	1970s–1980s	Promote plantations and meet local needs for fuelwood and fodder; reduce pressure on natural forests.	Fire is treated as a technical problem; awareness and fire-line creation recommended.	State social forestry divisions; local panchayats.	Weak community engagement: commercial plantations replaced native forests.
Forest Conservation Act (1980)	1980	Restrict diversion of forest land for non-forest use; ensure central approval.	Indirect approach: emphasized conservation but not fire ecology.	MoEFCC (then MoE); State Forest Departments.	Focused on land conversion, not ecological fire management.
National Forest Policy (1988)	1988	Ecological stability, biodiversity conservation, and people's participation.	Recognized people's role in protection but lacked operational fire management focus.	MoEFCC; Forest Departments; local committees (later under JFM).	Inadequate implementation; lack of integration with local burning practices.
Joint Forest Management (JFM)	1990 onwards	Collaborative forest management with community participation and benefit sharing.	Fire suppression through community patrols; no recognition of traditional fire use.	Village Forest Committees (VFCs); Forest Departments.	Limited autonomy; top-down implementation; short-term incentives.
Panchayats (Extension to Scheduled Areas) Act (PESA)	1996	Empower local self-governance in tribal areas; recognize customary rights.	Potential for local fire control through Gram Sabhas; rarely operationalized.	Panchayats and tribal councils.	Poor coordination with forest bureaucracy; jurisdictional overlaps.
Forest Rights Act (FRA)	2006	Recognize community	Legal authority for community-	Gram Sabha; Community	Implementation gaps; limited

		forest rights and traditional governance systems.	led fire management under Gram Sabha.	Forest Resource (CFR) committees.	integration with state fire plans.
National Action Plan on Forest Fires (NAPFF)	2018	Reduce fire incidence through prevention, early warning, detection, and response.	Technology-driven suppression; use of MODIS/VIIRS alerts; limited local role.	MoEFCC; Forest Survey of India (FSI); State Forest Departments.	Reactive rather than preventive; minimal community involvement; low funding for restoration.

Remote sensing and GIS have improved fire danger rating and vulnerability mapping using indices such as NBR, Fire Radiative Power (FRP), and Land Surface Temperature (LST) and institutional actors like FSI, NRSC and IIRS produce periodic vulnerability maps (Babu et al., 2018; Gupta et al., 2023; ISFR, 2023; Mamgain et al., 2023; P. Roy et al., 2012). However, a persistent lack exists between national-scale geospatial monitoring and local operational use: processed products often remain confined to central portals, and local managers and communities lack accessibility (due to their lack of technological access and connectivity), interpretable outputs for planning and response. Bridging this scale gap requires systematic linkages between satellite alerts, ground validation, and community planning processes.

2.5.2.1 Contemporary Challenges in Indian Fire Governance

Despite policy advances, several persistent challenges hinder effective and inclusive fire governance in India:

- Institutional Centralization: Forest departments continue to monopolize decision-making. Local institutions (Gram Sabhas, JFM committees) have limited roles in planning or monitoring fire management (CFR, 2016).
- Fragmented Policy Frameworks: Multiple overlapping laws including *Indian Forest Act (1927)*, *Forest Conservation Act (1980)*, *FRA (2006)*, *PESA (1996)*, create ambiguity in responsibilities and coordination among agencies.
- Underfunding and Capacity Constraints: Fire management budgets remain low, often confined to contingency allocations for firefighting equipment rather than long-term prevention or restoration (Ministry of Environment & World Bank, 2018).
- Neglect of Traditional Knowledge: Indigenous fire management practices are still regarded as "illegal burning" rather than adaptive strategies. This alienates local communities from formal management and reduces the effectiveness of suppression efforts (Yadav, 2025).

- Climate Change and Fuel Accumulation: Rising temperatures, irregular rainfall, and long dry seasons are increasing fire risk, and the lack of proactive fuel management further intensifies the severity of fires (Firoz et al., 2018; Verma et al., 2019).

These challenges collectively indicate that India remains stuck between the fire suppression and fire management phases, as discussed in global paradigms, without nonetheless transitioning to adaptive and participatory governance.

2.5.2.2 Toward Adaptive and Inclusive Fire Governance

Transitioning toward adaptive, inclusive governance calls for three strategic pivots. *First,* an ecological reframing: acknowledge fire as a managed ecological process in appropriate systems and support controlled early-season burning where scientifically and socially justified. *Second,* technological integration: repurpose geospatial tools from alerting to anticipatory risk modelling by linking remote sensing, climate forecasts, and socio-economic vulnerability mapping into decision-support systems accessible at the forest division and Gram Sabha levels. *Third,* community-centred co-management: institutionalize Gram Sabhas and VFCs in fire planning, prevention, and restoration through training, incentives, and devolved budgets, transforming JFM and NAPFF into genuine co-management frameworks. Hybrid approaches that combine local fire calendars with scientific danger indices (as practiced in Australia and parts of Africa) can anchor culturally grounded, evidence-informed practice.

In summation, India's trajectory shows both constraint and opportunity. The legacy of exclusionary, technocratic forestry has left fire governance trapped between suppression and adaptive management. Nevertheless, legal innovations (FRA, PESA), expanding geospatial capacities, and increasing recognition of Indigenous knowledge provide fertile ground for reform. Achieving inclusive, resilient fire governance will require aligning technological innovation with institutional decentralization and community governance, an integrated approach particularly vital for fire-prone regions such as Central India, where livelihoods and ecological dynamics are strongly interlinked.

2.6 Technological (Remote Sensing & GIS) frameworks for Fire Analysis

RS and GIS have transformed wildfire research by enabling synoptic, repeated, and quantitative assessment of fire dynamics across diverse landscapes. Their ability to detect active fires, map burned areas and monitor ecological recovery has made them indispensable to contemporary fire science and management (Roy, 2003; Chung et al., 2019; Widya & Lee, 2024; Crowley et al., 2023). Satellite imagery, aerial photography, LiDAR, and multi-sensor integration now constitute the technological backbone of fire monitoring systems worldwide (Kinaneva et al., 2019; Kurbanov et al., 2022; Payra et al., 2023). Through spectral, thermal, hyper spectral, and structural measurements, these tools capture shifts in vegetation condition, fuel moisture, and land surface temperature - major determinants of fire susceptibility and behaviour (Aragoneses & Chuvieco, 2021; Meddens et al., 2018). A primary advantage of RS is its capacity to deliver rapid and spatially extensive information in regions where ground surveys are impractical or unsafe. Multispectral and hyperspectral imagery supports detailed mapping of fire scars, estimation of burn severity, and monitoring of post-fire vegetation trajectories (Mitchell & Yuan, 2010; Güney et al., 2023). Thermal sensors, particularly MODIS and VIIRS, offer near-real-time detection and tracking of fire progression, making them crucial for operational response (Justice et al., 2003; Bastarrika et al., 2024). As climate change intensifies drought and heat extremes (Flannigan et al., 2009; UNEP, 2022), RS-based early warning and fire danger assessment have become increasingly vital for mitigation and preparedness.

The evolution of geospatial fire monitoring reflects both technological innovation and conceptual shifts in fire governance. NOAA's AVHRR sensors in the 1980s initiated satellite-based fire detection and coarse burned-area inventory (Justice et al., 2003). The introduction of MODIS on Terra (1999) and Aqua (2002) significantly enhanced global fire monitoring through high-frequency acquisition. From the 2000s onward, multi-sensor integration enabled assessments of fire severity, emissions, and fuel conditions. Since the 2010s, advances in GIS modelling, climate datasets, machine learning, and deep learning have supported more sophisticated spatio-temporal forecasting and risk assessment. This path mirrors the shift from reactive fire suppression to proactive prediction and resilience-building. A temporal overview of sensor and method evolution is provided in the below Fig 2.3.

Remote sensing datasets for fire detection and burned-area assessment includes multispectral, thermal, hyperspectral, radar, and LiDAR systems. Multispectral sensors such as Landsat MSS/TM/ETM+ and Sentinel-2 MSI provide moderate-to-high resolution data for burnt patch delineation and post-fire recovery monitoring (Atasever & Tercan, 2024). Thermal sensors like MODIS and VIIRS enable rapid, near-real-time detection of active fires and small fire fronts (Ba et al., 2019; Bastarrika et al., 2024). Hyperspectral sensors offer detailed spectral signatures for discriminating vegetation and soil conditions, enabling precise burn-severity mapping and ecological impact assessment (Dahiya & Rathi, 2024). Active sensors such as Sentinel-1 and ALOS-2 SAR penetrate cloud and smoke to provide reliable surface information and the airborne and spaceborne LiDAR quantify canopy structure and biomass loss (McCarthy et al., 2019; Urbazaev et al., 2022). UAVs increasingly complement satellite platforms by producing flexible, high-resolution imagery for local-scale mapping, validation, and rapid assessment (Seydi et al., 2021; Cho et al., 2022). Detailed specifications for major satellites and sensors appear in *Appendix 2A*.

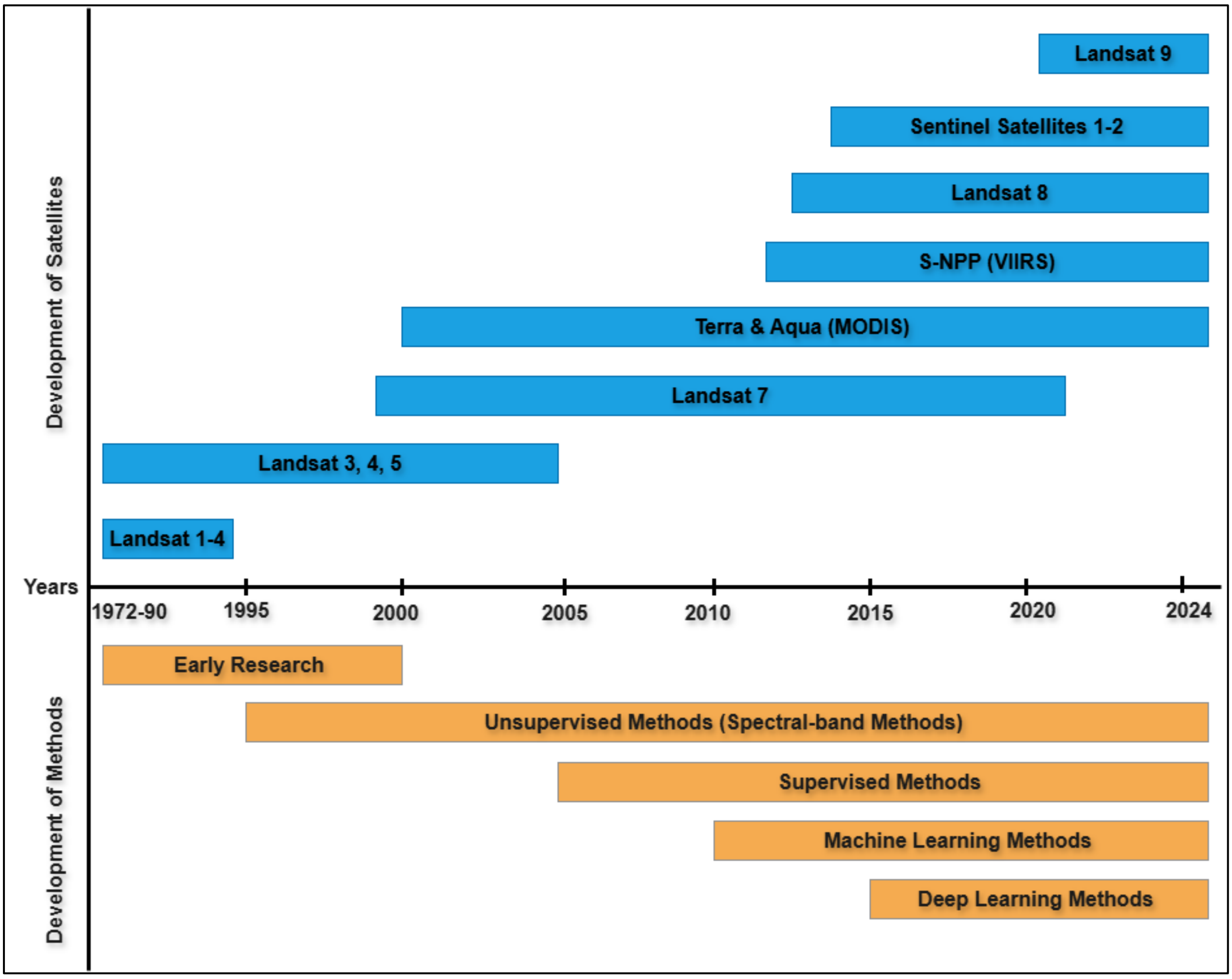


Fig. 2. 3 Temporal evolution in the emergence of different Remote Sensing satellites and wildfire assessment methods. Source: Prepared by author based on available data.

Parallel to sensor development, methodological advances have broadened analytical approaches in fire studies. Burned-area detection commonly relies on unsupervised, supervised, and deep learning techniques. Unsupervised methods such as K-means, ISODATA, PCA, and fuzzy clustering classify pixels based on spectral similarity, making them particularly valuable where ground truth is limited (Chaturvedi et al., 2001; Holden & Evans, 2010; Munshi, 2021). Threshold-based spectral indices including NDVI, NBR, dNBR, RdNBR, and NBR+, remain central for mapping fire-induced spectral change and burn severity (Rouse et al., 1974; Key & Benson, 1999; Konkathi & Shetty, 2019; Alcaras et al., 2022; Mamgain et al., 2023). These indices exploit NIR and SWIR reflectance shifts, although performance may vary in heterogeneous or low-severity burns (Kurbanov et al., 2022). A summary of spectral indices is presented in *Appendix 2B*.

Supervised classification methods depend on labelled datasets to differentiate burnt and unburnt areas. Algorithms such as Maximum Likelihood Classification (MLC), Support Vector Machines (SVM), Random Forest (RF), and K-Nearest Neighbours (KNN) offer varying strengths depending on data complexity and landscape heterogeneity (Chen et al., 2016; Petropoulos et al., 2010; Breiman, 2011; Razaque et al., 2021). SVM and RF frequently outperform classical pixel-based classifiers, as Object-Based Image Analysis (OBIA) enhances accuracy by integrating shape, texture, and contextual attributes (Polychronaki & Gitas, 2012). Algorithmic comparisons appear in *Appendix 2C*.

Recent deep learning methods have advanced spatial and temporal modelling of wildfire dynamics. Convolutional Neural Networks (CNNs) such as VGG, ResNet, and EfficientNet support high-resolution segmentation and fire-pixel detection (Majid et al., 2022; Tan & Bakır, 2024). Architectures like U-Net and DeepLab improve multi-scale segmentation in both optical and SAR data (Knopp et al., 2020; Zhang et al., 2023). Transformer-based models enhance generalization in heterogeneous environments (Gonçalves et al., 2023), and GANs augment training datasets and RNN/LSTM networks capture temporal evolution, enabling fire spread prediction and post-fire recovery assessment (Sherstinsky, 2020; Kadir et al., 2023). Their computational demands, however, remain substantial. Model workflows are summarized in *Appendix 2D.*

GIS further strengthens RS applications by integrating environmental, climatic, and socio-economic variables to model fire risk and vulnerability. Multi-criteria decision tools such as AHP and Fuzzy-AHP enable weighted analysis of temperature, slope, vegetation type, proximity to settlements, and historical fire occurrence (Kant Sharma et al., 2012; Kayet et al., 2020; Khan, Gupta, et al., 2024). In Central India, such models consistently identify dry deciduous forests, open forest edges, and densely populated forest fringes as high-risk zones, with vulnerability further shaped by livelihood dependence and institutional capacity (Jain et al., 2021; Kumari & Pandey, 2020; Saha, 2002; Sahu et al., 2024)

The integration of geospatial, climatic, and socio-economic data imitates a broader methodological shift toward socio-ecological fire analysis. Spatial overlays of fire hotspots with village boundaries, governance institutions, and NTFP collection areas help reveal how ecological processes intersect with human practices and governance arrangements (Reddy et al., 2019). This integrated approach is particularly pertinent in Central India, where fires are closely linked to seasonal livelihood practices such as mahua and tendu collection and where governance gaps shape both fire occurrence and response. Despite considerable progress, challenges persist. Coarse-resolution sensors often miss small or short-lived fires typical of tropical dry forests; processed datasets remain difficult for local agencies to access; and geospatial insights are not consistently integrated into operational decision-making. Socio-economic drivers also remain insufficiently represented in many fire-risk models. Future work should prioritise multi-sensor data fusion, participatory GIS[12], AI-driven fire forecasting tailored to monsoonal climates, and inserting geospatial intelligence into policy frameworks such as NAPFF and state-level fire action plans.

Overall, technological (RS & GIS) frameworks offer unparalleled capacity to understand forest fires as spatially dynamic and socially mediated phenomena. Integrating these technological tools with community knowledge and institutional reform is essential for advancing adaptive, data-informed, and socially inclusive fire governance in India's forest landscapes.

2.7 Synthesis and Research Gaps

The literature reviewed across global and Indian contexts reveals several converging understandings and persistent conceptual gaps that frame the rationale for the present study. While progress has been made in scientific fire monitoring, community participation, and policy reform, the social, spatial, and institutional dimensions of fire remain unevenly addressed. The following synthesis distills the major themes and identifies areas requiring further empirical and theoretical engagement:

[12] It stands for the employment of GIS with active participation of local communities to collect, map, and analyze spatial data, integrating local knowledge with formal geospatial techniques for more inclusive and democratic decision-making.

1. Fire as a socio-ecological process and no longer understood only as a destructive event but as an innate ecological regulator shaped by human activity, climate, and governance. However, in India, the institutional discourse remains largely hazard-centric, lacking recognition of fire's ecological and livelihood functions.
2. ***Technological advances vs. institutional gaps:*** Remote sensing and GIS have revolutionized fire detection and monitoring, yet their integration into local governance remains limited. Data accessibility, interpretation, and institutional responsiveness remain key bottlenecks in translating technological capacity into management efficacy.
3. ***Global Lessons, Local Realities:*** The global paradigms highlight adaptive and inclusive governance; however, India's policies continue to prioritize suppression over prevention and local agency. Learning from Australian bio-cultural models and African participatory systems bids pathways for policy re-calibration.
4. ***Central India as a Critical Interface:*** Central India represents the intersection of ecological flammability, socio-economic dependence, and governance complexity. Despite being a fire hotspot, it remains underrepresented in both Indian and global fire literature, especially in studies combining geospatial and socio-cultural dimensions.
5. ***Governance Fragmentation:*** Multiple overlapping legislations including the Indian Forest Act (1927), Forest Conservation Act (1980), FRA (2006), and NAPFF (2018), create jurisdictional ambiguity (CFR, 2016). Coherence across these frameworks, particularly regarding community authority and data-driven management, remains weak.

2.7.1 Conceptual and Research Gaps

- **Under representation of socio-cultural dimensions:** The majority of Indian fire studies focus on biophysical risk mapping, fire detection, and direct economic property damage overlooking how communities *perceive*, *adapt to*, and *utilize* fire. The cultural logic and livelihood embeddedness of fire in tribal and forest-dependent societies especially in Central India which remain poorly documented.
- **Limited integration of geospatial and ethnographic data:** As remote sensing provides macro-level insights; it rarely intersects with ground-level socio-economic surveys or ethnographic narratives. Bridging this divide is crucial for a multi-scalar understanding of fire that connects spatial patterns with human behavior and governance practices.
- **Absence of contextualized governance frameworks:** Existing models often transplant global strategies without accounting for India's local tenure systems, informal institutions,

and livelihood dependencies. There is a pressing need for region-specific governance models that balance ecological conservation with social equity.

- **Data–policy disconnect:** Despite sophisticated monitoring (FSI's FAST 3.0, NRSC datasets), the translation of spatial data into local decision-making and budget allocation remains minimal (CFR, 2016).
- **Inadequate focus on post-fire recovery and resilience:** Majority of the Indian studies end with burned-area assessment, neglecting the socio-ecological processes of recovery, regeneration, and livelihood reconstruction. Understanding post-fire trajectories is essential for designing adaptive management strategies and long-term resilience planning.
- **Less exploration of central Indian forests in comparative fire research:** Central India's unique ecological transition zone, covering tropical moist to dry deciduous forests but remains minimal in comparative fire discourse. Research has focused more on Himalayan or Western Ghats ecosystems, leaving a critical gap in understanding dry deciduous fire dynamics and community adaptation.

2.7.2 Conceptual Framework for Future Research

To address these gaps, future studies including this thesis should adopt a multi-scalar, integrative research framework that bridges ecological, technological, and social perspectives. The proposed conceptual orientation involves:

- **Macro-level (Spatial-Environmental):** Use of remote sensing and GIS for spatio-temporal analysis of fire frequency, intensity, and risk zones.
- **Meso-level (Governance-Institutional):** Examination of institutional structures, policy coherence, and governance responses to fire alerts and risk assessments.
- **Micro-level (Socio-Cultural):** Investigation of community perceptions, indigenous knowledge systems, and adaptive strategies related to fire and forest resource management.

By combining quantitative geospatial analysis with qualitative field inquiry, the research aims to generate an empirically grounded, context-sensitive understanding of forest fire dynamics in Central India, bridging the epistemological divide between technological measurement and human experience.

2.7.3 Concluding Remark

The review establishes that fire governance in India is at a crossroads, armed with technological erudition but constrained by institutional inertia and social disconnection. To move forward, it must embrace a triadic approach built on three things-a) scientific and geospatial precision, b) local knowledge and community partnership, and c) adaptive, decentralized policy mechanisms. Such an approach would not only enhance ecological resilience but also advance the livelihood security and cultural continuity of forest-dependent communities.

Through locating Central India (HFD) at the center of this inquiry, the present research contributes towards filling both thematic and geographical gaps in fire studies by establishing a conceptual foundation for examining how geospatial technologies, local practices, and governance frameworks coalesce in shaping the lived realities of fire in India's forests.

CHAPTER-3

Forest Fire Dynamics in the Hoshangabad Forest Division

A Spatio-Temporal Analysis Using RS and Statistical Methods

3.1 Introduction

Forest fires are recurring and dreadful natural disasters that devastate landscapes and ecosystems worldwide (Mamuji & Rozdilsky, 2019). The increasing frequency and intensity of forest fires in tropical and sub-tropical regions are impacting forest ecology and human settlements by reducing forest cover, degrading ecosystem services, diminishing biodiversity, causing carbon emissions, and disrupting socio-economic and cultural lives (Fan et al., 2023; Goldammer, 1987). In recent decades, anthropogenic activities have caused substantial environmental changes, leading to climate change. These climatic changes have created favorable conditions for forest fires, primarily driven by extreme weather patterns such as rising temperatures, reduced rainfall, strong winds, and decreased soil moisture. These conditions collectively create an ideal setting for the availability of fuel, which facilitates the initiation and spread of forest fires (Huang et al., 2015). Consequently, these climatic changes have also increased forest fire events in temperate regions, causing significant loss of forest cover in countries like Russia, Canada, and the USA (Tyukavina et al., 2022).

Moreover, the rising pattern of forest fires has also been observed in India (Mohd et al., 2024; Shaik et al., 2023), primarily occurring during the summer season from February to June (Bahuguna & Singh, 2002; Srivastava & Garg, 2013). According to Mohanty et al. (2022), fire incidents have surged by 52% over the last two decades, from 2000 to 2020. This trend is attributed to hot and dry weather conditions intensified by anthropogenic activities (ISFR, 2021). The tropical forests of the central Indian region are major forest fire hotspots (Jain et al., 2021; Saha et al., 2023). The HFD is a significant area within these tropical forests, known for its rich flora, fauna, and biodiversity. In recent years, the HFD has experienced an increase in forest fire incidents, cause to the destruction of forest cover, loss of forest resources, NTFPs, livelihoods, and wildlife habitats (Mohanty & Mithal, 2022). Key human-induced practices contributing to forest fires in Hoshangabad region include burning debris and litter for agricultural purposes, clearing grazing land for fresh grass, collecting fuelwood, and gathering NTFPs such as Tendu (Diospyros melanoxylon) leaves and mahua (Madhuca longifolia) flowers, especially during March and April (Khan et al., 2024). Therefore, it is essential to consider both environmental and human factors in the occurrence of fire incidents, as human activities often disrupt the natural environment. Conducting a thorough examination of the spatial and temporal aspects of fires, along with the scale of fire intensity, is imperative for a more comprehensive understanding of these forest fire occurrences.

Various studies have assessed forest fires and burnt areas using remote sensing and geographical information sciences (GIS) (Babu K.V. et al., 2016; Hafni et al., 2018; Konkathi & Shetty, 2019; Roy, 2003). The accessibility of freely available temporal satellite data, time-efficient analysis, and high result accuracy have made remote sensing and GIS prevalent techniques over traditional methods like visual observation-based assessment, watchtowers, and field surveys (Adab et al., 2013; Pandey & Arellano, 2022; Roy, 2003). Data from sources such as the Moderate Resolution Imaging Spectroradiometer (MODIS), Visible Infrared Imaging Radiometer Suite (VIIRS) (Schroeder et al., 2014), Landsat series (Hafni et al., 2018), and Sentinel satellite images are widely used for monitoring forest fires and assessing burnt areas. Furthermore, GIS, integrated with Google Earth Engine (GEE), machine learning, and artificial intelligence, provides effective platforms for forest fire mapping, burn severity analysis, and quantitative investigation of burnt areas at different scales (Salma et al., 2023). This study implements remote sensing and GIS techniques with use of MODIS fire points data. Despite the fact that previous studies have made significant contribution to the extent and severity of forest cover loss caused by fires. However, there is a paucity of comprehensive studies quantifying the rate, degree, and magnitude of fire occurrence and intensity in a spatio-temporal framework for the tropical forests of central India.

This gap makes this chapter significant, as it stands out for its integrated approach in quantifying spatio-temporal trend, fire intensity, forest type vulnerability to fire, and causal factors with greater comprehensiveness and accuracy. Its novelty lies in tackling real-world environmental challenges through an integrated approach, with potential applicability to similar geographic areas and broader regions. By using MODIS fire point data and forest cover map, this chapter investigate three primary objectives: (a) To assess and identify the spatio-temporal patterns, distribution, and trends of forest fires in the HFD of central India. (b) To quantify the rate and degree of fire intensity and exposure of forest types to forest fire. (c) To explore the associations between causal factors and forest fire using proximity regression analysis.

The importance of contextualizing research findings within broader national or global contexts is well-recognized. However, our rationale for focusing on the HFD was to provide a micro-level understanding of forest fire phenomena in the central Indian region. Using openly available data sources, this study intends to provide valuable insights into the rate and degree of forest fire patterns and causal association in the central Indian region (HFD). The aim is to extend a framework that could be applied to study the fire in other forest divisions, national parks, or similar ecosystems within India or globally in future. The findings can contribute to forest management strategies, fire prevention measures, and conservation policies, and add value to more specialized research in this direction.

3.2 Methodology

3.2.1 Satellite data description

This study used the freely available MODIS fire incidents data for the study area from 2001 to 2022. Further, forest type data has been taken from the Biodiversity Characterization Map of Indian Institute of Remote Sensing, Dehradun, India (Roy et al., 2012). The archives of fire points data (MODIS) have been accessed from NASA's Fire Information for Resource Management System (FIRMS) at https://firms.modaps.eosdis.nasa.gov.

The study area map of the HFD obtained from the Forest Department of Madhya Pradesh Government, India (https://www.mpforest.gov.in) (see Fig 3.1). Road data came from OpenStreetMap's dataset-2021 (www.openstreetmap.org) and the details about agricultural land and settlements were sourced from the Bhuvan LULC map-2016 (https://bhuvan-app1.nrsc.gov.in). All the map layers processed in Arc-GIS software (10.8 version). A detailed description of data has been given in Table 1.

Table 3. 1 Details of satellite data used.

SR.	Dataset	Spatial resolution (m)	Temporal resolution	Time-period
1	Fire points (MODIS)	1000m	2 days	2001-2022
4	Forest Type Map (IRS LISS-III)	24m	24 Days	2012
5	Road Network shapefile	-	-	2021
6	Agricultural land shapefile	-	-	2016
7	Settlements shapefile	-	-	2016

3.2.2 Methods

3.2.2.1 Temporal pattern analysis

To examine the temporal behaviour of forest fires in the HFD, descriptive statistics were computed for MODIS-detected fire events recorded between 2001 and 2022. Seasonal variation was assessed using MODIS fire points for the full study period and VIIRS fire points for the years 2012–2022, the latter being used solely to validate seasonal concentration due to its shorter time span. Fire Radiative Power (FRP) values associated with MODIS fire detections were used to quantify annual fire intensity. To avoid false detections, only fire points falling within forested areas and occurring during the primary fire season (February–June) were included in the analysis. Temporal trend detection was performed using the non-parametric Mann–Kendall (MK) test and Sen's Slope (SS) estimator to evaluate monotonic trends in fire frequency and intensity over the 22-year period (Mamgain et al., 2023; Rodrigues et al., 2016). The detailed formulation with equations has been provided in the next chapter for the MK & SS tests. These computations were carried out in MATLAB R-2023. Together, descriptive statistics, FRP-based intensity analysis, seasonal assessment, and non-parametric trend testing provided a comprehensive temporal characterization of the fire regime in the HFD.

3.2.2.2 Spatial fire distribution analysis:

To analyze the spatial dynamics of fire occurrence in the HFD, both short-term and long-term spatial assessments were conducted using Kernel Density Estimation (KDE) and Enhanced Hot Spot Analysis (EHSA), respectively.

Short-term spatial variation was examined by applying Kernel Density Estimation to MODIS fire points grouped into four temporal intervals: 2001–2005, 2006–2010, 2011–2015, and 2016–2022. These sub-decadal segments were selected to capture shifts in fire density and the spatial spread of ignition clusters over time. KDE surfaces allowed comparison of changing fire concentrations across different periods, thereby illustrating spatial expansion, contraction, or relocation of fire-prone zones.

Long-term spatial clustering was assessed using the Enhanced Hot Spot Analysis tool in ArcGIS Pro. EHSA extends the Getis-Ord Gi* statistic by incorporating temporal information, enabling detection of persistent, intensifying, diminishing, emerging, and sporadic hotspots over the full 22-year period (2001–2022). Using the complete MODIS fire dataset, EHSA generated a composite spatio-temporal hotspot map identifying zones with statistically significant fire recurrence and long-term susceptibility.

Integrating the KDE and EHSA outputs provided a comprehensive picture of spatial fire behaviour. KDE highlighted short-term spatial shifts and emerging ignition patterns, while EHSA identified long-term stable hotspots and fire-prone landscapes. Together, these methods facilitated a nuanced understanding of evolving fire dynamics in the region and supported the identification of priority areas for fire management and planning.

3.2.2.3 Forest type exposure to fire:

To examine the relationship between vegetation type and fire occurrence, MODIS fire points (2001–2022) were overlaid on the HFD forest type map. Using the *Extract Multi Values to Points*[13] tool in ArcGIS software, each fire point was assigned to a corresponding forest type. This enabled computation of fire frequency across different vegetation classes and identification of forest types most susceptible to fire.

3.2.2.4 Proximity analysis:

A proximity analysis was conducted concerning roads, agricultural land, and settlements within the study area to trace the causal factors of forest fires and its association with the human environment (Verma et al., 2015). Using an enhanced dataset consisting of MODIS fire points covering a 22-year period, a regression study was conducted to ascertain the connection between the total fire count (n=745) and distance increments. This study adopted a simple linear regression framework similar to that of Verma et al. (2015), wherein we conducted separate regressions for each factor (Road, Settlement, and Agriculture) due to the variability of distance interval classes among the proximity factors. The simple linear regression model was performed in MS Excel (Appendix 3A), and map of the proximity analysis was prepared in the Arc-GIS software (Appendix 3C).

The complete methodological workflow, covering all analytical components from temporal assessment to causal evaluation, is summarized in Figure 3.1.

[13] *Extract Multi Values to Points* is a geoprocessing tool in ArcGIS that assigns the values of one or more raster datasets to point features based on their spatial location. For each point, the tool extracts the pixel value from every selected raster layer and appends these values to the point attribute table.

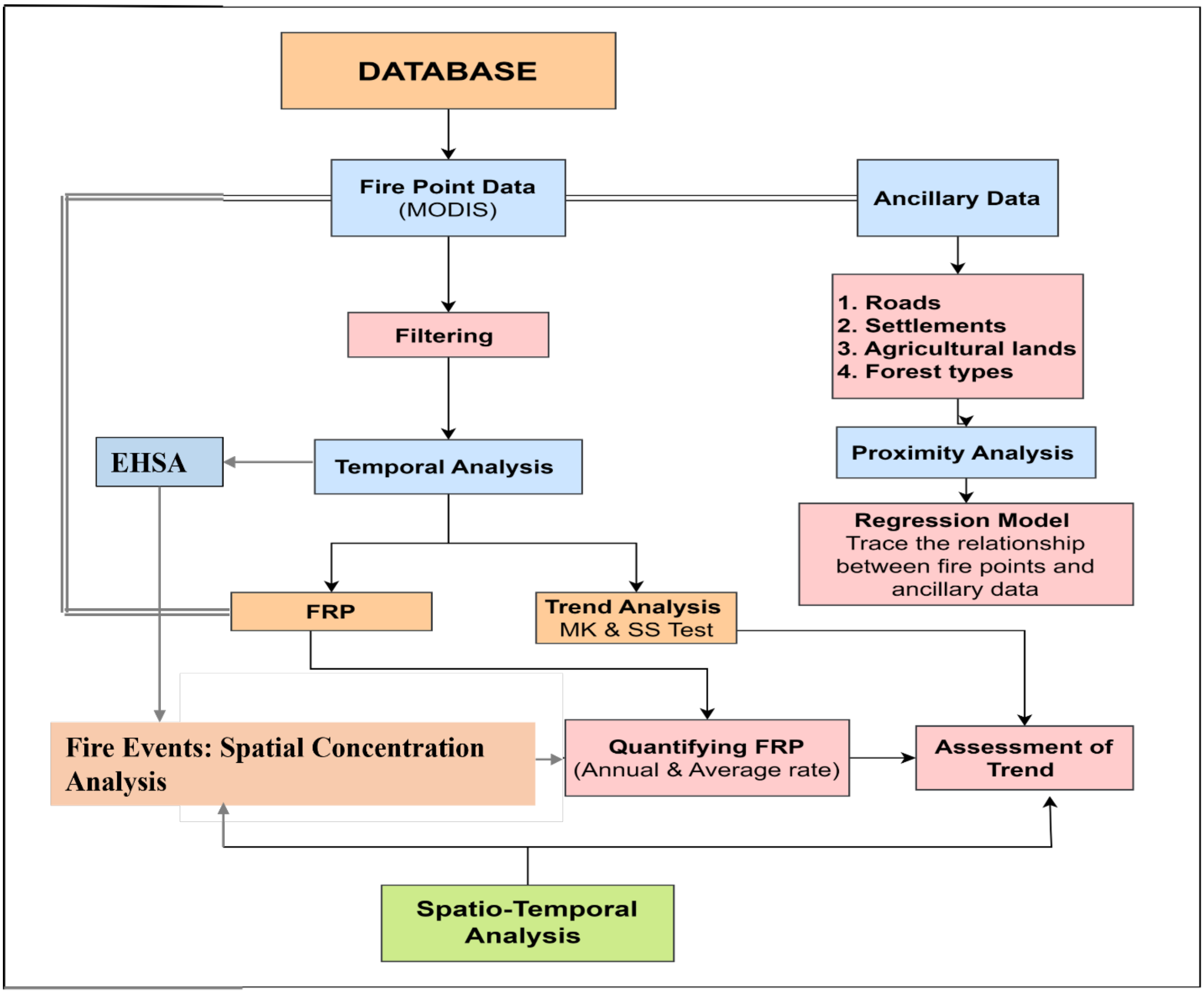


Fig. 3. 1 A detailed methodological framework *(Source: Author)*.

3.3 Results

The results present the temporal and spatial characteristics of fire activity in the HFD primarily based on MODIS satellite observations. The analyses include descriptive statistics of fire occurrences, seasonal dynamics, fire radiative power (FRP) characteristics for fire intensity assessment, trend detection using non-parametric tests, spatial distribution analysis using Enhanced Hot Spot Analysis (EHSA), Kernel Density Estimation (KDE) for short-term spatial shifts, vegetation–fire interactions, and regression-based associations with anthropogenic variables such as roads, settlements, and agricultural land.

3.3.1 Temporal and Seasonal Dynamics of Fire Occurrence

3.3.1.1 Seasonal Distribution of Fire Events

The MODIS-derived fire event data for 2001–2022 reveal marked inter-annual variability, with fire occurrences concentrated predominantly in the summer months [14]. VIIRS fire point data from 2012 to 2022 were also examined to understand seasonal distribution of fire events; however, because VIIRS observations are unavailable prior to 2012, thereby they were used only to confirm seasonal concentration and not included in the long-term temporal analysis. Both sensors consistently indicate that fire activity peaks between February and the first week of June (Fig. 3.2).

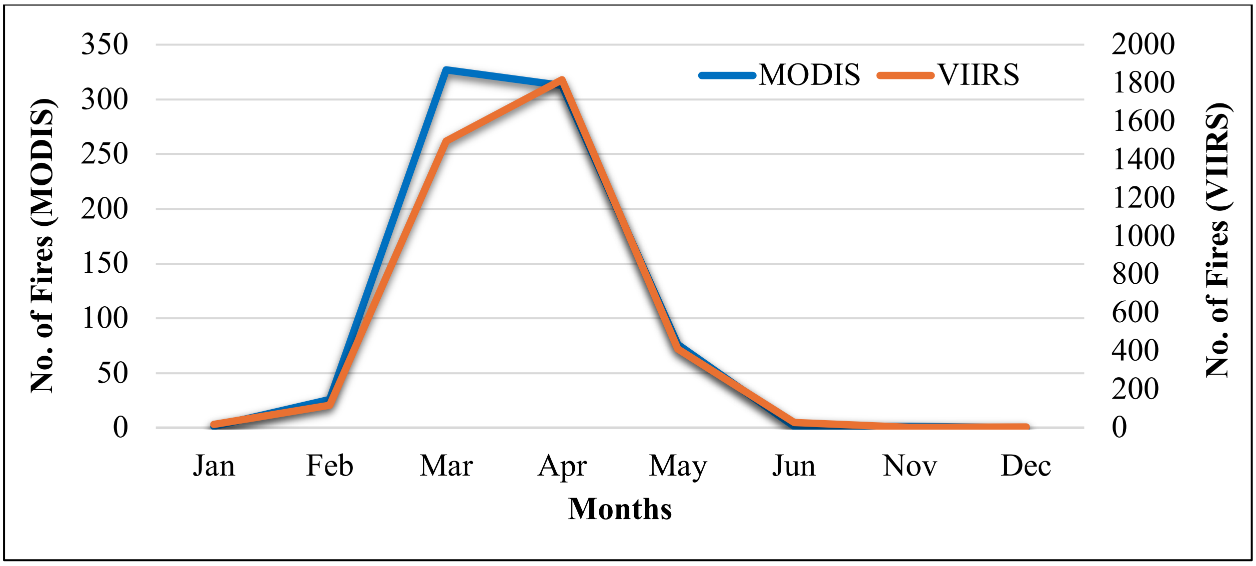


Fig. 3. 2 Seasonal distribution of fire events in HFD

3.3.1.2 Interannual Variability (Descriptive Statistics)

During the initial years of the record, fire activity remained relatively low, reaching a minimum of seven recorded incidents in 2003 (Table 3.2). Subsequent years reveal intermittent spikes in fire activity, most particularly in 2004 and 2008, which registered 42 and 44 incidents, respectively. A major escalation occurred in 2011 and 2012, each documenting 77 fire points,

[14] The type of fire that occurs in the study area is surface fire. The majority of the vegetation cover is Teak and Degraded Forest, which shed their leaves in bulk amounts before the advent of the summer season, providing sufficient fuel for fires. This vegetation type is featured by its rich biodiversity, and it takes < 2 years for the fuel to be replenished (Khan, 2013). However, in the central Indian region, more than 90% of fires are caused by human actions. According to Khan (2013), the prominent cause of fires in the HFD is the practice of Mahua flower and Tendu leave collection. When the mahua flower yield is abundant, fire incidents increase significantly because individuals set fires to clear the ground, making it easier to collect the falling mahua flowers. The mahua flowering season is in March and April, which corresponds with the highest fire incidents in this region. Therefore, predicting the average return interval of fires is not feasible in places where human actions are the primary cause.

marking a sustained phase of elevated fire occurrence. This was followed by a sharp decline in 2013 and 2014, when only two events were recorded in each year. The temporal trajectory again shows a strong resurgence in 2018 with 93 fire incidents, and the highest annual count appears in 2021 with 102 recorded fires. Although fire activity moderated in 2022 to 40 incidents, this level remains above that of several earlier years. These oscillations highlight a pattern driven by episodic peaks rather than a consistent upward progression.

Across the 22-year period, the mean annual fire count is 33.86 events. The average year-to-year change (0.714) is close to zero, reflecting the highly erratic nature of the series rather than indicating a linear trend (Fig. 3.3). The fire count in 2022 is higher than in 2001, yielding a compound annual growth rate (CAGR)[15] of 2.263 percent, this value should be interpreted with caution because CAGR assumes steady growth, which is not characteristic of this dataset. Instead, the temporal behaviour of fire occurrence in the HFD is best described as **sporadic but punctuated by distinct surge years** (2011–12, 2018, 2021), suggesting that fire regime fluctuations are episodic and influenced by short-term climatic or anthropogenic drivers rather than long-term systemic intensification.

Table 3. 2 Descriptive statistics of MODIS fire events (2001-2022)

Years	No. of Fire Incidents	Annual change	Annual Growth Rate (%)
2001	25		
2002	23	-2	-8.0
2003	7	-16	-69.6
2004	42	35	500.0
2005	22	-20	-47.6
2006	14	-8	-36.4
2007	17	3	21.4
2008	44	27	158.8
2009	48	4	9.1
2010	11	-37	-77.1
2011	77	66	600.0
2012	77	0	0.0
2013	2	-75	-97.4
2014	2	0	0.0
2015	8	6	300.0
2016	41	33	412.5

[15] ***CAGR*** reflects the smoothed average annual increase in fire incidents over the full 22-year period ("on average, how much did fires grow per year?"), whereas the Annual Growth Rate captures the year-to-year percentage change ("how much did fires change compared to the previous year?").

2017	22	-19	-46.3
2018	93	71	322.7
2019	21	-72	-77.4
2020	7	-14	-66.7
2021	102	95	1357.1
2022	40	-62	-60.8
Annual Average	**33.863**	**0.714**	**147.4**
Compound Annual Growth Rate (2001–2022)			**2.263%**

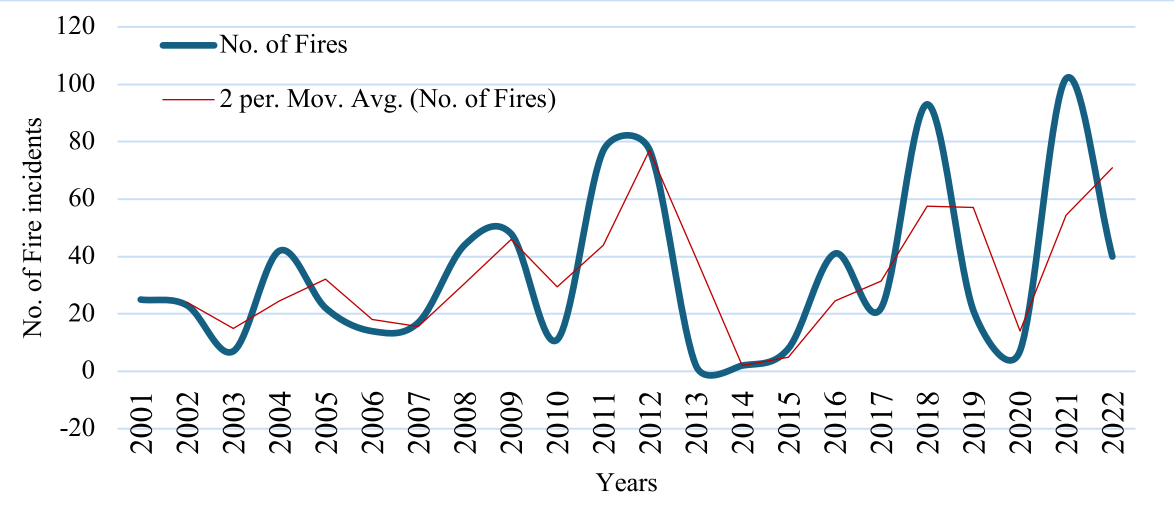


Fig. 3. 3 Number of fires recorded by MODIS sensors from 2001- 2022.

3.3.1.3 Fire Intensity (FRP Statistics):

Fire Radiative Power, derived from MODIS fire event data, provides an important indicator of fire intensity and the amount of energy released during burning events. The temporal analysis of FRP values from 2001 to 2022 reveals a general upward tendency in fire intensity, despite substantial year-to-year fluctuations. The cumulative FRP values show an average annual increase of **26.82 megawatts**, whereas the mean annual growth rate of **148 percent** reflects the strongly volatile nature of fire intensity in the study area (Table 3.3). Years with high fire counts including 2004, 2008, 2011–2012, 2016, 2018, and 2021, correspond to periods of markedly elevated FRP, indicating that both fire frequency and fire energy release surged simultaneously during these episodes.

Although the dataset is depicted by extreme variability, the long-term curve suggests a gradual intensification of fires in the HFD. The compound annual growth rate of **4.94 percent** over the 22-year period indicates that, on average, FRP increased at a moderate but consistent rate when evaluated from the first to the last year of observation. However, this metric should be interpreted cautiously, as CAGR smooths over substantial interannual oscillations, including years with exceptionally low FRP (e.g., 2013, 2014, 2020) and years with dramatic spikes (e.g., 2011, 2018, 2021). Overall, the FRP analysis demonstrates that fire intensity in the HFD has increased gradually over the long term, with pronounced year-to-year variability and episodic high-FRP years contributing substantially to this upward trajectory. These surges in FRP likely reflect interactions among fuel availability, seasonal climatic conditions, and anthropogenic ignition patterns (Fig. 3.4).

Table 3. 3 Descriptive statistics and annual growth metrics of MODIS-derived FRP in the HFD (2001–2022)

Years	**No. of Modis Fire Points**	**MODIS Fire point's FRP value (sum)**	**Annual change in FRP values**	**Annual Growth Rate (Percent)**
2001	25	301.9		
2002	23	403.3	101.4	34%
2003	7	102.5	-300.8	-75%
2004	42	773.9	671.4	655%
2005	22	290.4	-483.5	-62%
2006	14	244.1	-46.3	-16%
2007	17	338.7	94.6	39%
2008	44	1015.1	676.4	200%
2009	48	1096.7	81.6	8%
2010	11	166.6	-930.1	-85%
2011	77	1424.5	1257.9	755%
2012	77	1488.8	64.3	5%
2013	2	30.3	-1458.5	-98%
2014	2	29.8	-0.5	-2%
2015	8	132.9	103.1	346%
2016	41	708.4	575.5	433%
2017	22	265.4	-443	-63%
2018	93	1767.7	1502.3	566%
2019	21	284.2	-1483.5	-84%
2020	7	264.5	-19.7	-7%
2021	102	1909.5	1645	622%
2022	40	865.3	-1044.2	-55%
Annual average	**33.863**	**632.02**	**26.82**	**148%**
CAGR of MODIS FRP (2001–2022)				**4.94%**

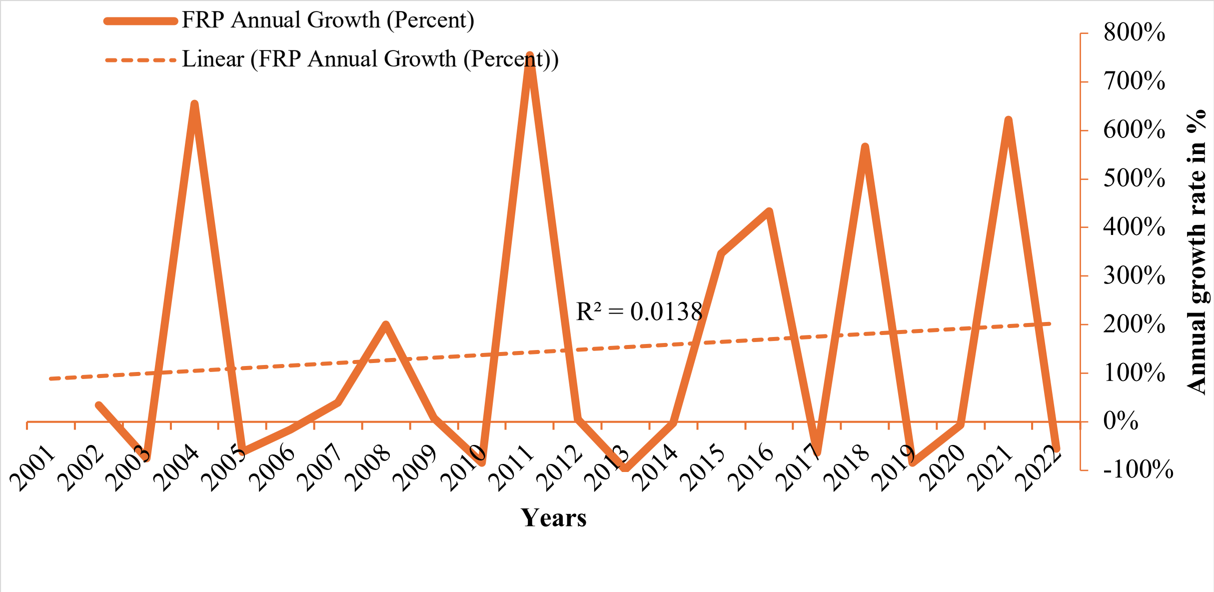


Fig. 3. 4 Annual variation and long-term trend of FRP in the HFD (2001-2022)

The figure shows substantial interannual fluctuations in total FRP values, including prominent high-intensity fire years (e.g., 2004, 2008, 2011–12, 2018, 2021). Despite this volatility, the overall trajectory indicates a gradual increase in fire intensity over the 22-year period.

3.3.1.4 Trend Analysis (MK Test and Sen's Slope)

In the present study Mann-Kendall Test and Sen's Slope Estimator have been utilized to analyze the trend of fire incidents over time in the specified study area. The results of MK Test indicated a calculated z-value of 0.451, accompanied by a significance level (p-value) of 0.651. The positive value represents the increasing trend of forest fire incidents. Thus, it suggests a noticeable upward pattern in the temporal progression of fire occurrences in the studied region with non-significant trend. Besides, we included Sen's Slope Estimator, which gives a computed Qi value of 0.714. Likewise, MK test, if the value of the Sen slope (Qi) is positive, then the magnitude will increase, and if the values in negative, then they will decline. Thus, both the Mann-Kendall Test and Sen's Slope Estimator align to confirm the non-statistically significant progress in fire events within HFD. However, there is currently no significant trend in fire frequency, although a trend may emerge as we get more data in the next few years (Fig. 3.5).

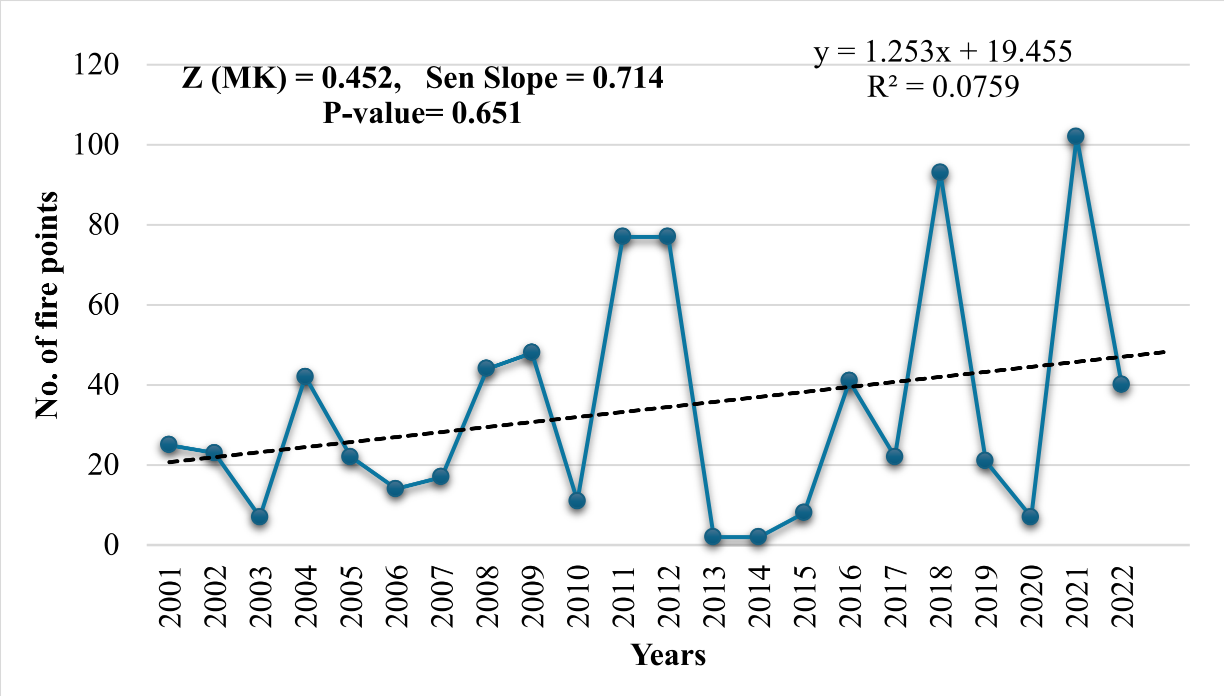


Fig. 3. 5 Mann Kendal and Sen Slope analysis of MODIS fire points data (2001-2022)

3.3.3 Spatial Dynamics of Fire Distribution

3.3.3.1 Short-term Spatial Shifts (KDE)

The KDE was applied to fire points across four temporal intervals (2001–2005, 2006–2010, 2011–2015, and 2016–2022) to assess short-term spatial changes in fire distribution within the HFD. The KDE outputs indicate a progressive spatial expansion of fire-prone zones concurrent with the temporal increase in fire activity (Fig. 6).

During the first interval (2001–2005), fire occurrence was concentrated primarily in the western portion of the division (circle **c** in Fig. 6), with only one dominant hotspot. In the second interval (2006–2010), fire density expanded more in westward, accompanied by a minor increase in the central–western areas. By 2011–2015, multiple zones including the high concentration in western, slight increase in central–northwestern, and high increase in far eastern sections—became more prominent fire concentration areas, reflecting a broader distribution of ignition activity. The final interval (2016–2022) shows the most extensive spatial spread, with high-density clusters clearly emerging in the eastern region, central–northwestern areas (circle **e,** ***Fig 3.6***), and the easternmost zone corresponding to the Bankhedi Range (circles **b**, **d**, **f**). These changes are visually highlighted using red and blue circles in Fig. 3.6 to denote evolving hotspot locations.

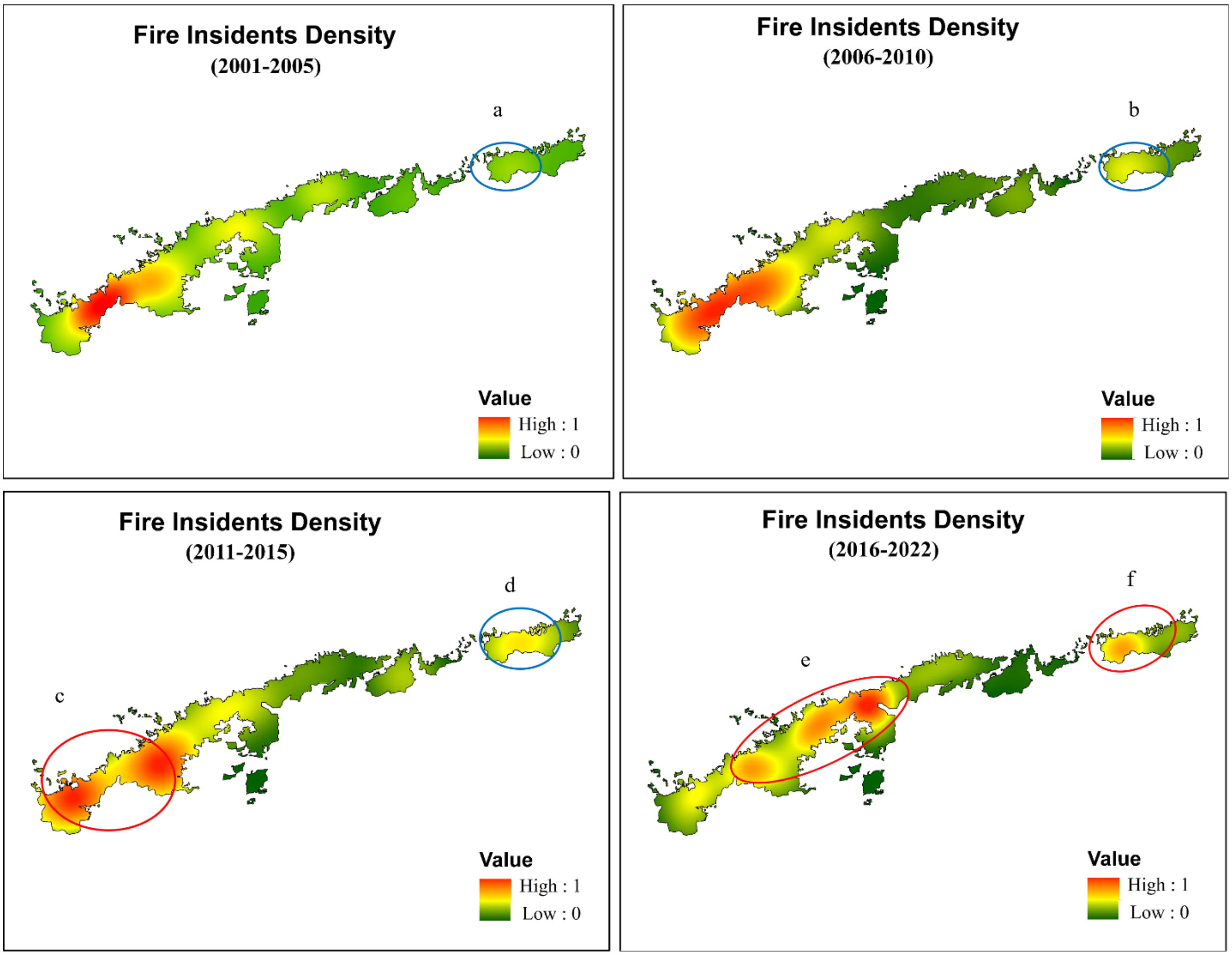


Fig. 3. 6 Short-term spatial shifts in fire density based on Kernel Density Estimation across four temporal intervals (2001–2005, 2006–2010, 2011–2015, and 2016–2022).

Across the four KDE periods, the western, central–northern, and eastern ranges consistently demonstrate elevated fire density, indicating persistent susceptibility. Among the forest ranges, Banapur, Bankhedi, Itarsi, Seoni, and Hoshangabad show the highest concentrations of fire activity, with gradual intensification between 2001 and 2022. Overall, the KDE results clearly illustrate a short-term spatial shift in fire distribution, characterized by westward and central expansion from an initially eastern-dominant fire landscape.

3.3.3.2 Long-Term Spatial Distribution and Clustering (EHSA)

To identify statistically significant fire hotspots and assess long-term spatio-temporal clustering, the Enhanced Hot Spot Analysis tool in ArcGIS Pro was used to fire events recorded during the primary fire season (February–June) to minimize the influence of false alarms. The EHSA results corroborate the KDE findings, revealing consistent fire hotspot concentrations in the western, northern–central, and eastern ranges of the HFD across the 22-year period (Fig. 3.7). EHSA's ability to integrate spatial and temporal dimensions demonstrates that fire occurrences in HFD are highly sporadic, aligning with the interannual variability observed in the descriptive statistics. Nonetheless, despite this variability, the emerging hotspot patterns confirm that specific regions repeatedly experience high fire frequency. The three major hotspot clusters, corresponding to the western, central–northern, and easternmost areas, indicate persistent fire pressure and increased vulnerability across these landscapes.

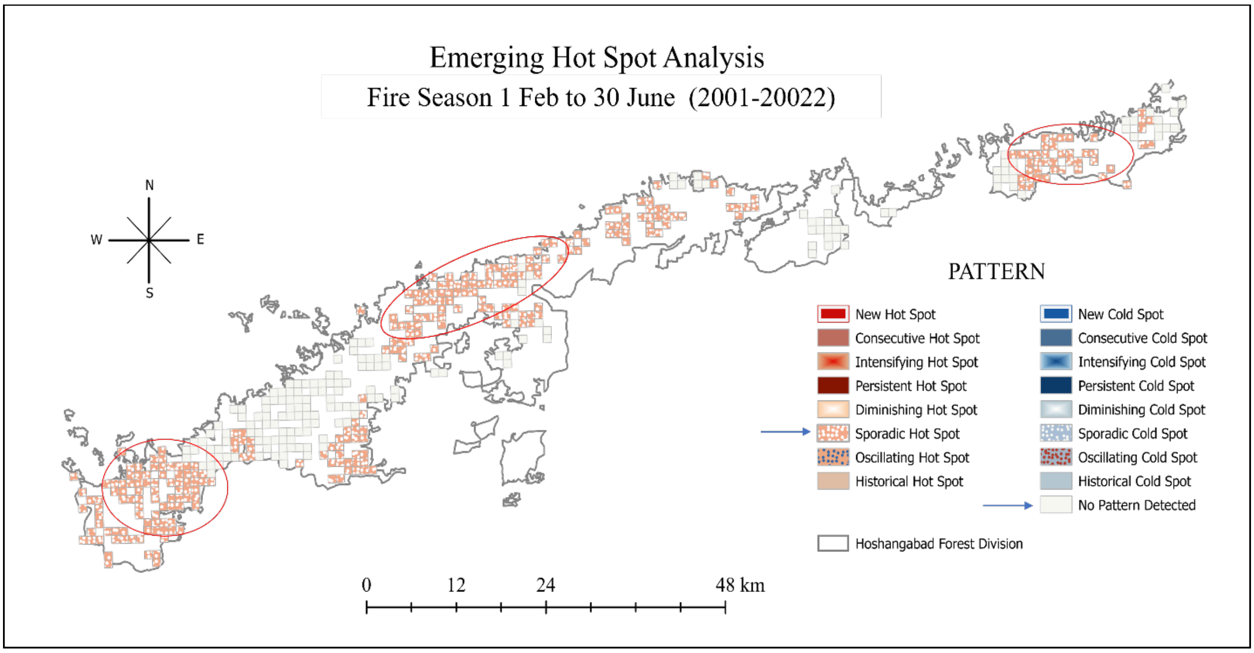


Fig. 3. 7 Long-term spatial distribution and clustering of fire occurrences using EHSA for the fire season (February–June), HFD (2001–2022).

The spatial concentration of fires in these zones is driven by a combination of natural and anthropogenic factors. The natural causes such as lightning may contribute marginally, existing research shows that more than 90 percent of fires in central India are human caused (Bahuguna & Singh, 2002). In HFD, major anthropogenic drivers include the burning of ground litter to aid mahua flower collection and the preparation of forest floors for tendu leaf harvesting (Date et al., 2023; Chandra & Bhardwaj, 2015). These practices, particularly when conducted carelessly, frequently result in escaped fires that engulf large areas of forest (Khan, 2013). The spatial heterogeneity observed in fire patterns across the division also reflects variations in topography, vegetation structure, fuel load, weather conditions, and human access (Ahmad et al., 2018).

Taken together, the EHSA results emphasize the need for targeted fire management and mitigation strategies in the high-risk zones. Areas identified as persistent or emerging hotspots (2001–2022) may warrant increased monitoring, community engagement, and fuel reduction interventions such as prescribed burning, whereas zones experiencing repeated burns may require ecological restoration to recover forest structure and socio-economic values.

3.3.4 Fire Occurrence and Vegetation Types

In addition to other fire-influencing factors, forest types play a critical role in the propagation of forest fires, as found by Srivastava & Garg (2013) in their study. In line with their findings, this study also identified a significant pattern: over 91% of fires have occurred in teak and degraded forests due to their large areal coverage (nearly 76%) in the study region (Table 3.4 & Appendix 3B). Therefore, from the perspective of forest conservation and fire suppression activities, particularly during the summer season (mainly in March and April), teak and degraded forests are more critical and exposed. However, in terms of frequency and vulnerability, degraded forest is the most fire-prone vegetation cover in the study area.

Table 3. 4 Natural vegetation and fire in HFD of Central India from 2001-2022

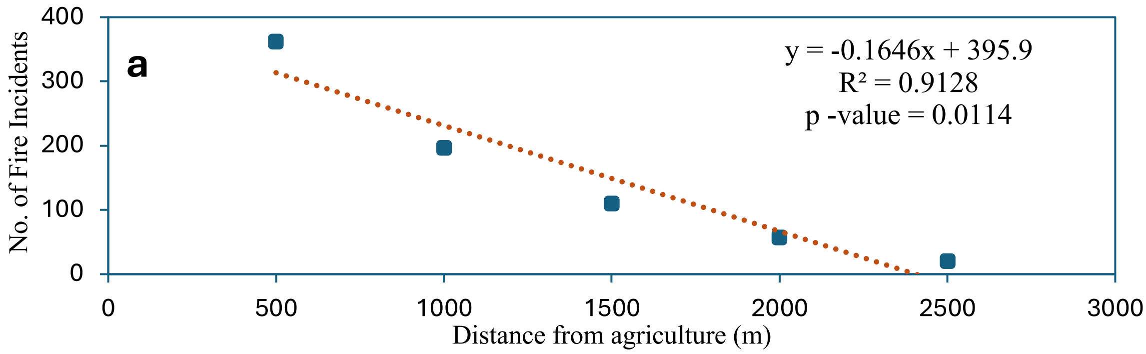
Forest Type	**Area (sq. km)**	**Area (%)**	**No. of fire incidents recorded by MODIS (2001-2022)**	**% of Fire Incidents**
Teak	470	49.58	418	56.11
Degraded forest	263	27.74	261	35.03
Dry deciduous	99	10.44	28	3.76
Scrub	83	8.76	12	1.61
Bamboo	28	2.95	23	3.09
Teak mixed moist deciduous	5	0.53	3	0.40
Total	**948**	**100**	**745**	**100.00**

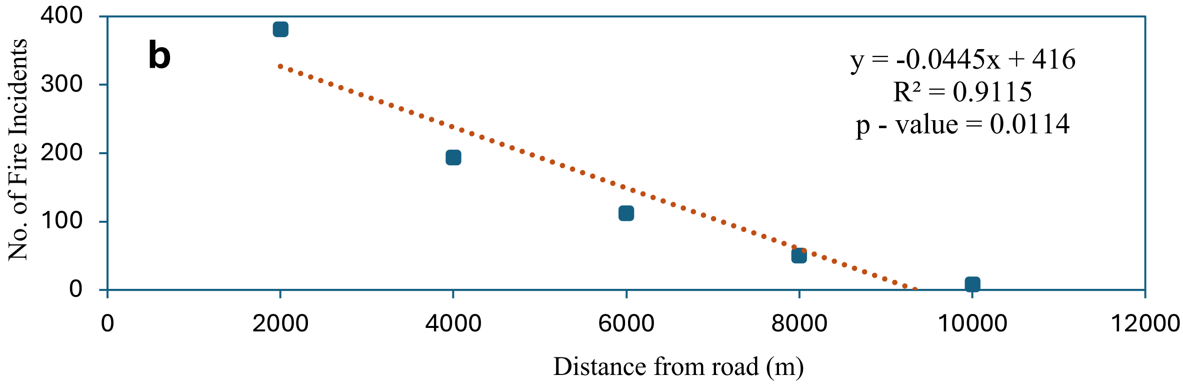
3.3.5 Human–Environment Interactions and Fire

3.3.5.1 Regression Associations with Roads, Settlements, and Agriculture

The analysis of the relationship between spatial proximity to distinct features (such as roads, agricultural land, and settlements) and the frequency of fire incidents, as identified by MODIS data, revealed significant patterns. The roads (R^2 = 0.911, p - value = 0.011) and agricultural land (R^2 = 0.912, p -value = 0.011) reveals strong negative association with fires. While the settlements (R^2 = 0.44660, p- value = 0.217558) represents the weak negative association with fire incidences compared to roads and agriculture features (Fig. 3.8). Concerning the distance from agricultural lands, it was observed that fire incidents were most frequent when situated at a proximity of less than 500 meters (n=362), gradually decreasing as the distance increased: 500 - 1000 meters (n=196), 1000 - 1500 meters (n=110), 1500 - 2000 meters (n=57), and beyond 2000 meters (n=20), with an aggregated total of 745 incidents. Similarly, the proximity to roads shown a trend wherein the highest occurrence of fire incidents transpired within a distance of less than 2000 meters (n=381), diminishing as the distance interval expanded: 2000 - 4000 meters (n=194), 4000 - 6000 meters (n=112), 6000 - 8000 meters (n=50), and surpassing 8000 meters (n=8).

Meanwhile, in relation to settlements, the data indicated elevated fire incident frequencies in close vicinity, i.e., below 2000 meters (n=143), followed by a significant increase in incidents within the range of 2000 - 4000 meters (n=359). Fire occurrences subsequently dwindled as distance escalated: 4000 - 6000 meters (n=214), 6000 - 8000 meters (n=29), and a complete absence of incidents beyond 8000 meters, yielding a combined total of 745 incidents. Several factors contribute to the hump-shaped pattern observed between settlement and fire: (a) People avoid setting fire in the forest nearby their settlement because it has high chances to affect their settlement but at some distance, they will not be responsible and affected directly. (b) The limited availability of Mahua flowers within a radius of less than 2 km from their settlement motivates individuals to travel further into the forests, typically up to distances of 4 to 6 km. Consequently, the number of fire incidents is particularly higher within the range of 2 to 6 km. This correlation can be attributed to the close association between Mahua collection activity and fire occurrence. As a result, areas located within less than 2 km from settlements, as well as those beyond 6 km, have reported relatively few fire incidents (see Appendix 3A & B).





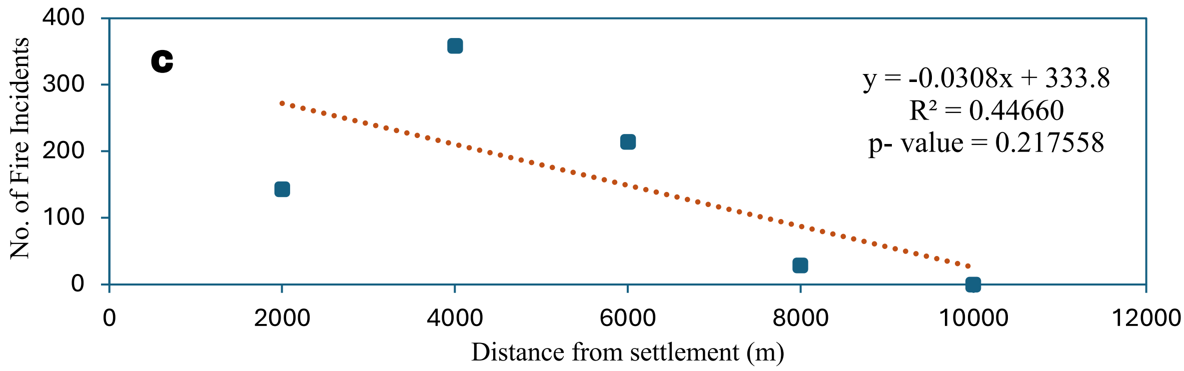


Fig. 3. 8 Fire incident-based proximity analysis using simple linear regression model (a) Distance from agricultural land, (b) Distance from roads, and (c) Distance from settlements.

3.3.6 Integrated Fire-Prone Area Assessment

The combined temporal, spatial, ecological, and anthropogenic analyses demonstrate that significant portions of the HFD are persistently fire prone. Temporal assessments reveal strong interannual variability with episodic surge years (2011–12, 2018, 2021) and a gradual rise in fire intensity, seasonal patterns show consistent fire concentration between February and early June. Spatially, KDE surfaces indicate a progressive expansion of fire densities since 2001, and EHSA results corroborate this by identifying persistent and emerging hotspots in the western, central–northern, and eastern ranges, highlighting stable long-term fire clusters despite year-to-year fluctuations. Vegetation analysis shows that teak and degraded forests, which dominate the landscape, account for over 91 percent of fires, with degraded forests being the most vulnerable cover type due to rapid fuel accumulation. Regression findings confirm strong anthropogenic influence, with fire likelihood increasing near roads, agriculture, and settlement interfaces, particularly in areas associated with mahua flower and tendu leaf collection. Collectively, these results indicate that fire occurrence in HFD is shaped by the interaction of seasonal fuel dryness, vegetation structure, and human activity, creating recurrent ignition zones that require priority attention for fire management, prevention, and ecological restoration.

3.4 Discussion

The temporal assessment of fire activity in the HFD reveals a generally increasing tendency in both fire occurrence and intensity, although marked by pronounced year-to-year fluctuations. Consistent with studies from central India (Bahuguna & Singh, 2002; Jain et al., 2021; Roy, 2003), fires are concentrated almost entirely within the summer months. This seasonal confinement underscores the need for intensified monitoring, patrolling, and community engagement during February–June. As the Mann–Kendall and Sen's Slope analyses indicate a positive but statistically non-significant trend in annual fire frequency, the gradual rise in FRP, episodic surge years, and expansion of burned areas suggest emerging pressures that warrant proactive management. The presence of persistent socio-economic drivers—such as NTFP collection, expanding agricultural interfaces, urbanizing forest margins, and unregulated anthropogenic interventions—further strengthens the need for sustained vigilance by forest authorities (Saha et al., 2023). Future studies should incorporate longer time series and additional climatic, socio-economic, and biophysical variables to refine trend detection and strengthen predictive understanding.

Spatially, both KDE and EHSA outputs converge to reveal that western, central–northern, and eastern zones of HFD consistently experience higher fire density and recurrent hotspot formation. These spatial concentrations align strongly with human accessibility gradients. Higher road density and larger settlement footprints in the central–northern corridors facilitate greater human entry, thereby elevating ignition likelihood. Similarly, the eastern region—including the Bankhedi range—experiences substantial fire activity due to its proximity to agricultural fields and dispersed rural settlements, which are associated with routine burning of ground litter for mahua flower and tendu leaf collection. Proximity-based statistical analyses and linear regression models confirm that distance to agriculture, roads, and settlements is inversely associated with fire occurrence, supporting earlier findings on the dominant influence of anthropogenic access on forest fires in India[16](Singh & Jeganathan, 2024; ISFR, 2021; Roy, 2003; Verma et al., 2015). Although diagnostic tests are not presented due to scope limitations, the consistently high R^2 values across models provide confidence in these relationships. These

[16] The difference in trends between global wildfire causes and those in India can be attributed to various factors. According to the WWF report-2020 titled *"Fires, Forests and the Future,"* over 75% of wildfires globally are caused by human activities, which vary regionally, including shifting cultivation, developmental activities, grazing, agricultural expansion, tourism, and road networks. These factors, along with regional land use practices, socio-economic conditions, and environmental policies, lead to diverse wildfire causation patterns. Proximity to settlements and roads significantly influences wildfire occurrence, increasing the risk of accidental ignition and fire spread. In India, over 90% of wildfires are human-induced, highlighting the dominant role of human activities and the unique socio-environmental context driving wildfire dynamics in the country (Bahuguna & Singh, 2002).

results reinforce the principle that spatial planning and fire management in human-dominated forest landscapes must explicitly integrate accessibility and livelihood-linked fire use.

Vegetation structure further shapes fire patterns, with teak and degraded forests accounting for more than 91 percent of all fire incidents over the 22-year period. This finding is consistent with Srivastava & Garg (2013), who highlight the high flammability of dry deciduous systems and the substantial fire susceptibility of degraded stands. In HFD, leaf shedding during March–April creates abundant fine fuels, which, when combined with intense human activity for mahua and tendu collection, amplifies ignition rates. Degraded forests, in particular, display the highest per-unit fire incidence, indicating heightened vulnerability and diminished ecological resistance. Consequently, fire prevention and suppression efforts must prioritize teak and degraded forest patches during the critical summer months, with targeted fuel management, rapid-response mechanisms, and enhanced community sensitization.

Overall, the findings of this study contribute essential insights for fire management and conservation within the central Indian landscape. They emphasize the necessity of season-focused monitoring, spatially targeted interventions, and community-informed prevention strategies. The clustering of fire-prone zones near roads, agricultural edges, and settlements indicates that mitigating human-driven ignitions is fundamental to reducing fire frequency and associated ecological loss. Further research should explore long-term spatial dependencies, integrate socio-economic drivers at finer scales, and evaluate climate–fire interactions to support more predictive and adaptive management frameworks. While broader-scale studies provide important context, meso- and micro-level analyses such as this are indispensable for designing operationally effective and socio-ecologically grounded fire management strategies tailored to the HFD and similar forested regions in central India. Additionally, this study recognizes the potential for future research to expand upon its findings by integrating them into broader national or global forest fire studies, thus enhancing the overall understanding of fire dynamics and informing more comprehensive management approaches.

3.5 Conclusion

This study conducted a comprehensive assessment of fire dynamics in the HFD using multi-year MODIS satellite observations and complementary spatial and statistical techniques. Through descriptive, trend, intensity, spatial, and regression analyses, the study examined temporal variations, fire intensity patterns, spatial heterogeneity, and the principal drivers of forest fires from 2001 to 2022. The findings indicate that the frequency, intensity, and spatial extent of fires in HFD have increased over the past two decades. FRP values show a gradual long-term rise in fire intensity, supported by statistical indicators of an upward tendency. Spatial analyses (KDE and EHSA) consistently identify the western, central–northern, and eastern regions of the division, dominated by teak and degraded forests—as the most vulnerable fire-prone zones. Regression results further demonstrate strong negative associations between fire occurrence and distance to roads, agricultural lands, and settlements, underscoring the dominant role of anthropogenic accessibility and forest-dependent livelihood practices in shaping ignition patterns.

The study also acknowledges certain limitations, particularly in the form of the unavailability of cloud free satellite data in the open domain for the HFD. This constraint limited the ability to conduct pixel-based burnt-area trend analysis and reduced the precision of fire severity and recovery assessments. Despite these constraints, the research provides valuable insights into the spatio-temporal structure of forest fires, quantifies fire intensity dynamics, and elucidates both ecological and anthropogenic determinants of fire occurrence. These findings offer an empirical foundation for developing targeted fire management interventions, strengthening community-based prevention strategies, and designing forest-type–specific mitigation measures.

Future research should integrate the applications of more advanced tools and techniques of remote sensing with cloud free long-term high resolution satellite images, data science, machine learning, and artificial intelligence to study the fire phenomena and its aftermaths (burnt areas) at various scales. Expanding this work across comparable forested landscapes will further enhance understanding of fire regimes in central India and contribute to the development of more robust, science-based fire management and conservation frameworks.

CHAPTER-4

Forest Fire Risk Assessment

Developing Integrated Geospatial Framework Using Open-Source Data

4.1 Introduction

Forest fire have emerged as one of the most formidable natural disasters worldwide, resulting in significant damage to lives, property, and the environment (Davis et al., 2014; Mamuji & Rozdilsky, 2019; Stephenson et al., 2013). In recent years, forest fire activities have shown an upward trend in tropical and subtropical areas of South Asia, attributed in part to changing climatic conditions and human interventions to forest ecosystems (Ertugrul et al., 2019; K. P. Vadrevu et al., 2019; van der Werf et al., 2008; Zeren Cetin, Varol, Ozel, et al., 2023). As a result, the world is experiencing unprecedented loss of forest cover, an unceasing decrease in soil fertility, water and air quality, deteriorating human health, and disruption of socio-economic and cultural settings (Doerr & Santín, 2016; Paveglio et al., 2016; Santín & Doerr, 2016). As these devastating events are likely to become more widespread in the near future, it is crucial to implement proactive measures for forest fire prevention and mitigation. According to recent few studies, significantly large forest regions in South Asia is undergoing fragmentation due to the extensive urbanization, agricultural expansion, industrialization, illegal encroachment and climate change impacts in the past few decades (Cetin et al., 2023; Ertugrul et al., 2021).

Studies also reported concerning forest fire vulnerability in India due to increasing frequency across different geographical regions (Mohanty & Mithal, 2022; Mohd et al., 2024; Reddy et al., 2019). According to Forest survey of India, out of 24.6% of the geographical area (80.9 million hectares) in India covered by natural vegetation (forest and tree cover), approximately 60% of are deciduous type, which sheds its leaves in the spring season and provides a substantial source of fuel to forest fires (ISFR, 2021). During the pre-monsoon season (from late February to early June), elevated air temperature, lower moisture availability in the air and soil, very less rainfall, wind along the dry hillslope areas attributes to a heightened risk of forest fire during pre-monsoon summer days in India (Gupta et al., 2023; Kale et al., 2017a; Kodandapani et al., 2008; K. P. Vadrevu et al., 2013). Alongside, anthropogenic factors create a conducive environment for rapid fire spread during dry and hot months (Gupta, Bhatt, et al., 2020; Narayanaraj & Wimberly, 2012; Sari, 2023; Schmerbeck & Fiener, 2015). Consequently, these fire incidents embark their imprints on Indian forest ecosystems on a larger scale which affecting the spatial cover of the forest, biodiversity richness, and associated livelihood practices of the forest dependent local households (Babu K.V. et al., 2016; K. Vadrevu et al., 2009).

Since human impact on forest fire risk varies region-wise and mostly concentrated along the fragmented forest area (Lasslop & Kloster, 2017), local or micro-level management and protection policies become crucial to implement. Thus, identifying forest fire risk zones in a specific region plays a pivotal role in this effort, offering valued insights into the spatial distribution and potential severity of fire-prone areas. Researchers and policymakers can collaboratively assess the various factors contributing to forest fire risk by employing advanced geospatial analysis and remote sensing techniques (Cetin et al., 2024; Ozenen Kavlak et al., 2021; Zeren Cetin et al., 2020). Adhering to a similar context, the current work explores integrated approach an expert-based method to identify forest fire risk zones in the HFD of Central Indian highland region. This region was selected due to its prominence as a major hotspot for forest fire, primarily attributed to various human activities such as agricultural practices, residual burning, burning of grazing lands for new fodder, clearing forest surface by fire for picking Mahua (Madhuca longifolia) flowers, burning forest cover for better tendu (Diospyros melanoxylon) leaves collections in next season, and collection of other NTFPs (Mohanty & Mithal, 2022). The intent of conducting a comprehensive fire risk assessment in this region is to develop more effective fire management strategies aimed at protecting communities and ecosystems from the ravaging impact of these destructive fires.

The accessibility, openness, and pertinency of the geospatial data to deal with the small to large scale fire and associated losses is an instrumental factor to study and mitigate the catastrophic effects of fire. For instance, by using active fire points from MODIS (Zhang et al., 2017) and VIIRS (Sofan et al., 2020), widespread forest fire become easily detectable on a daily scale, whereas using burnt area algorithm (Mamgain et al., 2023) using LANDSAT (Sunar & Özkan, 2001) or SENTINEL-2 (Tariq et al., 2023) data, the impact of small-scale fires can identify at 6-8 days interval. However, small-scale fire preventive measures are challenging and complex in nature. Large scale fires are often triggered by localized ignition and later amplified depending on the fuel availability, weather conditions and topographic conditions (Liu et al., 2012). Therefore, it is essential to identify the areas with the risk of small to large-scale forest fire and have a regional impact in order to mitigate potential losses.

Numerous studies employed different methods to assess the regional fire risk. Among them, regression approach such as logistic regression (Jafari Goldarag et al., 2016; Mohammadi et al., 2014), machine learning and deep learning based methods such as artificial neural network (Kantarcioglu et al., 2023; Satir et al., 2016), multi-criteria decision analysis (MCDA) methods such as Analytical Hierarchy Process (AHP), Fuzzy AHP, weighted-overlay methods (Adab et al., 2013; Cetin et al., 2023; Costa-Saura et al., 2022; Gabban et al., 2008; Ghosh & Kar, 2018; Kayet et al., 2020; Kumari & Pandey, 2020; Nikhil et al., 2021; Nuthammachot & Stratoulias, 2021; Roshani et al., 2022; Salavati et al., 2022; S. M. B. dos Santos et al., 2020; K. Vadrevu et al., 2009) are often used. Upon reviewing the literature on existing methods and approaches, the current study adopts an integrated approach that involves two broader aspect – one, assessing the spatial and temporal pattern of fire incidents, and second, assessing its risk at a local scale. A spatial autocorrelation of fire incidents were studied before identifying fire hotspots in this region in order to assess the contemporary situation. After that, an expert knowledge-based MCDA method, i.e., AHP was integrated into a Geographic Information System (GIS) environment to assess the local fire risk. This integrated approach uses readily available data and does not necessitate extensive modeling. These features make this study unique, and novel compared to the previous investigations. Consequently, this adopted methodology can be easily applied to similar geographical areas ranging from micro (forest division or national parks) to macro regions to assess fire risk effectively, develop mitigation strategies, and minimize future losses due to fires.

Thus, with the employment of integrated approach, this study possesses to investigate three major objectives:

a) To trace the spatial-temporal pattern of fires in the increased areal coverage of a 10 km buffer zone around the HFD.
b) To produce a fire risk map to identify the highly vulnerable areas and associated spatial dependencies for targeted fire mitigation plans.
c) To create a GIS-integrated methodological framework for fire risk and pattern assessment at a geospatial-level over any small- (such as forest divisions or national parks) using freely available data and without necessitating extensive modeling or data analysis expertise.

To achieve these goals, MODIS active fire records during the last two decades were used to comprehend the fire scenario in this study. Several environmental proxies (temperature, rainfall, wind, topography) and socio-economic datasets (cropland, settlement, transport networks, population) were incorporated to assess fire risk.

4.2 Methodological Foundation

This chapter develops an integrated geospatial methodology to assess forest-fire risk in the HFD and its immediate landscape. The methodological framework combines spatial–temporal analysis of historical fire occurrences with an expert-based multi-criteria decision analysis (AHP) implemented in a GIS environment. The framework is designed to be repeatable using open-source data and applicable at micro-scales (forest divisions, protected areas) as well as larger forested landscapes.

4.2.1 Rationale for the 10-km buffer

A 10-kilometre buffer around the administrative boundary of the HFD was created to capture the broader landscape influences on fire behaviour and incidence. Fires and ignition sources are not constrained by administrative boundaries; they propagate across adjacent land uses and are driven by neighborhood conditions (e.g., fuel continuity, agricultural burning, transport corridors, settlement proximity). Mohanty and Mithal (2022) identify the Hoshangabad district as one of the national hotspots for extreme forest fires, and local practices (residual agricultural burning, grazing-land fires, NTFP collection such as tendu and mahua harvesting) frequently involve landscape-scale interactions. The 10-km buffer thus ensures that cross-boundary drivers and potential source areas are included in the analysis, improving the ecological and management relevance of the resulting risk map (see Fig. 1(e), Chapter 1).

4.2.2 Data Preparation

Forest fires are governed by several factors, which can be categorized into two parts: the first is natural factors (Geographical and environmental variables) and the second, socio-economic factors (road network, rail tracks, agricultural practices, settlement, and population density) (Kayet et al. 2020; Sivrikaya et al., 2022). Based on the literature review, eight physical and six socio-economic factors are identified to assess the fire risk in the study region. All layers were projected to a common coordinate system and resampled to a uniform analysis resolution prior to overlay and modelling. The data used for the present study is presented in Table 4.1.

Table 4. 1 Details of the data used in this study.

Variables	**Data Type**	**Year of Acquisition**	**Source**	**Purpose**	**Spatial Resolution**
Forest Type	Vector	2012	Biodiversity Characterization Map, prepared by ISRO https://bis.iirs.gov.in/pdf/biodiversitcharacterization.pdf	Forest fuel type map	1:50,000
Temperature	Raster	2021	Terra MODIS satellite (downloaded from Google Earth Engine GEE) (https://developers.google.com/earthengine/datasets/catalog/MODIS06MOD11A1)	Surface-level Air Temperature map	1000 m
Rainfall	Raster	2021	Climate Hazards Group InfraRed Precipitation with Station Data (accessed from GEE) (https://developers.google.com/earthengine/datasets/catalog/UCSB-CHGCHIRPSDAILY)	Rainfall map	5566 m
Elevation	Raster	--------	NASA's Shuttle Radar Topography Mission (SRTM) – Digital Elevation Model (DEM) data with the spatial resolution of 1 arc-second for global coverage, accessed from GEE (https://developers.google.com/earthengine/datasets/catalog/USGS_SRTMGL1003)	Elevation map	30 m
Slope	Raster	--------		Slope Map	30 m
Aspect	Raster	--------		Aspect map	30 m
TWI	Raster	--------		TWI map	30 m
Wind	Raster	2021	NASA's Giovanni (https://giovanni.gsfc.nasa.gov/giovanni)	Wind speed map	27000 m (0.25^0)
Road Network	Vector	2021	OpenStreetMap (www.openstreetmap.org)	Road network buffer map	1:50,000
Rail Network	Vector	2021	OpenStreetMap (www.openstreetmap.org)	Rail network buffer map	1:50,000
Agriculture Land	Vector	2016	Agricultural land data extracted from the LULC map of Bhuvan (https://bhuvan-app1.nrsc.gov.in)	Agricultural land buffer map	1:50,000

Water Bodies	Vector	2016	Water bodies data extracted from the LULC map of Bhuvan (https://bhuvan-app1.nrsc.gov.in)	Water bodies buffer map	1:50,000
Population Density	Raster	2020	NASA's Socio-economic Data and Applications Center (SEDAC) (https://sedac.ciesin.columbia.edu)	Population density map	1000 m (30 arc-second)
Settlement	Vector	2016	Settlement extracted from the LULC map of Bhuvan (https://bhuvan-app1.nrsc.gov.in)	Human settlement buffer map	1:50,000
Active Fire points	Point	2001-2022	MODIS Fire points data, downloaded from NASA's Fire Information for Resource Management System (FIRMS) (https://firms.modaps.eosdis.nasa.gov/)	Fire inventory mapping and trend analysis	1000 m

4.2.3 Analytical workflow for Integrated Geospatial Framework

To develop a GIS-integrated methodological framework for fire risk and spatial–temporal pattern assessment at a geospatial-level over any small forest landscape. The methodological workflow comprises four sequential and interlinked modules. Each module stage builds upon the outputs of the previous one, ensuring both methodological coherence and analytical transparency.

a) ***Spatial–temporal characterization of fire history***: First, the analysis begins with the detection of Trend using MODIS active fires to spot temporal patterns and existing trends. Subsequently, it engaged with the spatial autocorrelation (e.g., Moran's I) calculation, to quantify clustering prior to hotspot detection. Receiving information on whether clustering of fire exists or not if exits then proceeds with the Hotspot identification based on Getis-Ord Gi*, to locate statistically significant high-incidence areas.

b) ***Factor preparation and standardization:*** After the spatio-temporal assessment of fire , this framework moves towards preparing the data for major fire influencing factor layer (selection of factors layers are based on the previous literature while considering the geography of the area and potential fire controlling factors). After that, the GIS layer of each controlling factor was prepared. The Euclidian distance function in the ArcGIS 10.8 software was employed to calculate the distance to roads, railways, agriculture, settlements, and waterbodies. The slope, aspect, and topographic wetness index (TWI) layers were prepared based on the SRTM DEM. The population density data for the study area was reclassified into five classes using the image reclassification tool of ArcGIS. Later, all the selected layers have been standardized to a common numerical scale suitable for MCDA (ranked or normalized values). The selected variables (layers) including continuations (e.g., slope, TWI, distance surfaces) were reclassified into ordinal categories based on literature thresholds and local expert judgement.

c) ***Multi-criteria risk assessment (AHP integrated with GIS):*** On the third module, it moves toward the construction of AHP model embedded into GIS environment. An expert panel provided pairwise comparisons for the selected factors. Pairwise comparison matrices were constructed and normalized to obtain factor weights. Consistency of expert judgements was assessed using the Consistency Ratio (CR); matrices with CR > 0.10 were revisited and adjusted. Weighted overlay (through the raster calculator tool) in GIS combined standardized factor layers using AHP-derived weights to produce a continuous forest fire-risk surface and then categorical risk map using natural break method of classification (e.g., low, moderate, high, very high).
d) ***Post-processing and validation***: The final risk map was cross-validated against independent space-based fire observations (MODIS points) to evaluate predictive performance. The validation metrics included spatial hit-rate (proportion of observed fires falling within high-risk categories), confusion-matrix derived statistics, and spatial overlap measures. Where appropriate, Receiver Operating Characteristic (ROC) analysis and Area Under the Curve (AUC) were used to quantify discrimination ability.

The study documents sources of uncertainty (remote sensing detection limits for small fires, temporal sampling gaps, expert weight variability) and applies sensitivity analysis to assess how changes in factor weights affect risk classification. All scripts, processing steps, and parameter choices are recorded to ensure reproducibility and facilitate application to other forest divisions and protected areas.

4.2.4 Spatial analysis –

This study assessed the spatial pattern of fire records regarding spatial autocorrelation and hotspot analysis. Since the study area is limited to a forest division, for that reason it avoided the clustering method. Instead, it looked into whether fire occurrences over an area is influenced by its neighboring area.

a) **Spatial autocorrelation**

To assess if any spatial autocorrelation (SA) exists in the pattern of fire occurrences in the present study area, this study calculated Moran's I (Moran, 1950) with 95% confidence interval using all the fire records. This method provides whether the fire occurrence locations are clustered, randomly distributed, or scattered (Memisoglu Baykal, 2023). The equation of Moran's I is as follows:

$$I = (N / W) * \Sigma_i \Sigma_j w_{ij} * (x_i - \bar{x})(x_j - \bar{x}) / \Sigma_i (x_i - \bar{x})^2 \quad (1)$$

where, I represent the Moran's I statistic, N is the total number of fire points, W represents spatial weights, w_{ij} represents the spatial weight between spatial units i and j, x_i and x_j represent the values of the variable of interest at spatial units i and j, $\bar{x}$ represents the mean of all the x values.

The range of Moran's I is between 1 (perfect spatial correlation) and - 1 (total spatial dispersion). A value of 0 denotes random distribution.

b) **Getis-Ord Gi– based spatial hotspot analysis**

With a considerable assumption that fire locations will not homogenously occur in the study area, the analysis looked to see if there are any hot spots (areas with a very high concentration of fire points' locations) present in this region. To identify these hotspots, this study used the Getis-Ord Gi* statistic (Getis & Ord, 1992) using mapping cluster tool in the ArcGIS 10.8 software. The Gi* statistic is a spatial analytical technique that calculates significant spatial grids with high values surrounded by multiple other grids with high values. It is important to note that while high-fire incidence grids are deemed relevant, they might not necessarily constitute statistically significant hotspots. Thus, the analysis aimed to assess the aggregated values of the attribute of interest in the surrounding environment by considering the sum of all attributes in the vicinity. It is mathematically expressed by the equation as follows (Getis & Ord, 1992) :

$$G_i^* = \frac{\sum_{j=1}^{1} W_{ij}\, x_j}{\sum_{j=1}^{1} x_j} \quad (2)$$

whereas:

Gi * is the spatial subordination statistics of fire occurrence i over n incidents.

xj describes the scale of the variable x at incident j over every n

wij describes the load value of the incidence ***i*** and ***j,*** which characterize their spatial inter-association.

The result of the ***Gi **** statistic provides a z-score of every character in the dataset. The higher positive z-score indicates a more powerful grouping of high values (hot spot), and statistically negative lower z-scores indicate a stronger grouping of small.

4.2.5 Temporal pattern analysis –

This study assessed the temporal pattern of fire activities using non-parametric statistical tests - Maan-Kendal (MK) test and Sen's slope (SS) (Mamgain et al., 2023; Rodrigues et al., 2016). Both tests were performed in MATLAB. For this purpose, space-based fire records for 22 years (2001 to 2022) were used. This analysis aimed to determine whether any alterations occurred in the temporal fire pattern in HFD.

a) Mann-Kendall Test

The Mann-Kendall Test (Kendall, 1975; Mann, 1945) was used to detect the trends of fire incidents in the study region. It analyses whether an upward or downward temporal pattern exists in fire incidents. It is widely used in temporal investigations of several climate and environmental variables, including forest fire studies (Aftergood & Flannigan, 2022; Gupta et al., 2020; Kumar & Kumar, 2022; Mallick et al., 2021; Reddy et al., 2019). The mathematical representation of the test is mentioned below.

$$S = \sum_{f=1}^{T-1} \sum_{g=k+1}^{T} \text{sign}(x_g - x_k) \qquad (3)$$

$$\text{sign}(x_g - x_k) = \begin{cases} +1 & if\ (x_g - x_k) > 0 \\ 0 & if\ (x_g - x_k) = 0 \\ -1 & if\ (x_g - x_k) < 0 \end{cases} \qquad (4)$$

$$\text{var (S)} = \frac{1}{18}\left[T(T-1)(2T+5) - \sum_{p=1}^{q} t_p\, p(p-1)(2p+5)\right] \qquad (5)$$

$$Z = \begin{cases} (S-1)/\sqrt{VAR(S)} & if\ S > 0 \\ 0 & if\ S = 0 \\ (S+1)/\sqrt{VAR(S)} & if\ S < 0 \end{cases} \qquad (6)$$

While x_k and x_g represent the cumulative forest fire points in two consecutive years, ***T*** stands for the length of the time series. t_p corresponds to the count of connections for the ***p***th value. Positive ***Z*** values indicate a rising pattern, whereas negative ***Z*** values indicate a declining pattern.

b) Sen's Slope Estimator

Sen's slope estimator test (Sen, 1968) was used to estimate the slope of the trend of forest fire incidents. It calculates the median of all possible slopes between pairs of data points, making it robust against outliers. This estimator is commonly applied in forest fire-related studies and other fields to analyze trends and monotonic patterns in time series data (Dennison et al., 2014; Ionita et al., 2022; P. Jain et al., 2017; Jiménez-Ruano et al., 2019; Maffei et al., 2021; Mamgain et al., 2023; Mohammad et al., 2022). The mathematical formulation of this test, as elucidated by Sen in 1968, is represented below:

$$d_i = Median\left[\frac{x_j - x_k}{j-k}\right] \text{ for all j } > \text{ k}, \quad (7)$$

In this context, ***d*** signifies the slope, while $\boldsymbol{x_j}$ and $\boldsymbol{x_k}$ denote the respective data values at times ***j*** and ***k***, with the constraint that ($1 \leq k < j \leq n$), where ***n*** stands for the total number of variables.

$$Q_i = \begin{cases} d_{\frac{n+1}{2}} & \text{if } n \text{ is odd} \\ \frac{1}{2}\left(d_{\frac{n}{2}} + d_{(n+2)/2)}\right)\frac{1}{2}\left(d_{\frac{n}{2}} + d_{(n+2)/2)}\right) & \text{if } n \text{ is even} \end{cases} \quad (8)$$

A Q_i value in the positive range indicates a rising trend, while a Q_i value in the negative range indicates a declining trend.

4.2.6 AHP construction

AHP is a robust and adaptable theory of decision-making developed by Saaty 1980. It is a hierarchical decision-making procedure that illustrates the associations between objectives and potential options (Saaty, 2003; Sivrikaya & Küçük, 2022). One of the significant benefits of using AHP is its easy implementation, reasonable and organized confinement of expert-based knowledge (Donegan et al., 1992), and scope to include personal experience-based opinion and other subjective inclinations. AHP has been widely applied in several geospatial studies and performed significantly among different multi-criteria decision analysis (MCDA) methods (Kumari & Pandey, 2020; Lamat et al., 2021; Nikhil et al., 2021; Nuthammachot & Stratoulias, 2021; Suryabhagavan et al., 2016). This method provides the liberty to incorporate geographical and socio-economic attributes simultaneously and integrate with GIS-based analysis. Thus, AHP is extensively used for assessing geographical vulnerability to natural hazards, such as forest fire (Lamat et al., 2021; Nikhil et al., 2021), earthquakes (Erden & Karaman, 2012), flood and drought (Ghosh & Kar, 2018). Thus, the present study used this approach to produce a forest fire vulnerability map over HFD. To analyze any spatial model, a few criteria and its subsequent sub-criteria are usually set based on the problem statements and expert opinions. AHP follows a similar process for giving weights to the parameters (Roshani et al., 2022). However, not every criterion is assigned the same weight; instead, weights are assigned based on the relative importance of each criterion and sub-criterion by a scale from 1 to 9 (Appendix 4B) (Saaty, 1980). Relative importance was decided on existing literature which exploited similar approaches for various locations (Table 4.3) (Kayet et al., 2020; Kumari & Pandey, 2020; Nasiri et al., 2022; Nuthammachot & Stratoulias, 2021; Salma et al., 2023; Van Hoang et al., 2020; Whitman et al., 2015).

The utilization of pair-based comparisons allows for creating a matrix that evaluates the vulnerability of each criterion for forest fire vulnerability through systematic comparisons made between pairs (Table 4.2). It has been shown in the below equation (Abdo et al., 2022):

$$\begin{matrix} D1 \\ D2 \\ D3 \\ . \\ . \\ . \\ Dn \end{matrix} \begin{bmatrix} Fk1/Fk2 & Fk1/Fk2 & \cdot & \cdot & \cdot & Fk1/Fkn \\ Fk2/Fk1 & Fk2/Fk2 & \cdot & \cdot & \cdot & Fk2/Fkn \\ Fk3/Fk2 & Fk3/Fk2 & \cdot & \cdot & \cdot & Fk3/Fkn \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ Fkn/Fk1 & Fkn/Fk2 & \cdot & \cdot & \cdot & Fkn/Fkn \end{bmatrix} \qquad (9)$$

whereas **D** is the selected criteria and **F** is the priority value assigned to each criterion

Once the definitive weights have been chosen for each criterion, a pivotal subsequent stage involves calculating the consistency ratio (CR) to assess the coherence of the expert opinions. The accuracy of the outcome depends on the consistency of the pairwise comparison of the criteria and sub-criteria. The CR allows testing of one-to-one comparisons between criteria that need to be calculated to ensure consistency. If the CR is 0.10 or lower, the AHP continues; otherwise, the comparison matrix must be revised and improved to avoid inconsistency (Saaty, 1980). To examine the consistency ratio of the comparison matrix, the following equation (2) has been used:

$$CR = \frac{CI}{RI} \qquad (10)$$

where RI is the random index (random inconsistency), CR is the consistency ratio (CR is used to calculate the probability value), CI is the consistency index (CI depends on the order of the matrix established by Saaty), and CR is the consistency ratio (Bhuyan et al., 2024; Bhuyan &

Deka, 2022; Saaty, 2003). This analysis adopted Saaty (1980)'s conventional RI values. (Appendix 4C). CI is calculated by applying the below equation:

$$\boldsymbol{CI} = \frac{\boldsymbol{\lambda_{max} - n}}{\boldsymbol{n+1}} \tag{11}$$

where $\boldsymbol{CI}$ is the consistency index, $\boldsymbol{\lambda max}$ is the largest eigenvalue, and $\boldsymbol{n}$ is the number of criteria.

As a result, the following equation presents the final weights obtained using the AHP method:

$$\boldsymbol{Fire\ Risk} = (FT \times 0.20) + (DR \times 0.18) + (DS \times 0.13) + (DA \times 0.12) + (ST \times 0.8) + (RF \times 0.7) + (WS \times 0.5) + (EL \times 0.4) + (PD \times 0.3) + (DRT \times 0.3) + (TWI \times 0.2) + (DW \times 0.2) + (Slope \times 0.1) + (Aspect \times 0.1) \tag{12}$$

where the acronyms stand as below –

FT: Forest types; ***DR:*** Distance from Road; ***DS:*** Distance from Settlement; ***DA:*** Distance from Agriculture; ***ST:*** Surface Temperature; ***RF***: Rainfall; ***WS:*** Wind Speed; ***EL***: Elevation; ***PD:*** Population Density; ***DRT:*** Distance from Rail track line; ***TWI:*** Topographical Wetness Index; ***DW:*** Distance from Waterbodies.

Table 4. 2 AHP pair-wise comparison matrix and computation of priority weights

Factors	**FT**	**DR**	**DS**	**DA**	**ST**	**RF**	**WS**	**EL**	**PD**	**DRT**	**TWI**	**DW**	**Slope**	**Aspect**	**Priority**	**Rank**
FT	1.00	2.00	2.00	3.00	3.00	4.00	4.00	5.00	5.00	6.00	6.00	7.00	8.00	9.00	0.21	1
DR	0.50	1.00	2.00	3.00	3.00	4.00	4.00	5.00	5.00	6.00	6.00	7.00	8.00	9.00	0.18	2
DS	0.50	0.50	1.00	2.00	2.00	3.00	3.00	4.00	4.00	5.00	5.00	5.00	6.00	7.00	0.13	3
DA	0.33	0.33	0.50	1.00	2.00	3.00	3.00	5.00	5.00	6.00	6.00	6.00	7.00	8.00	0.12	4
ST	0.33	0.33	0.50	0.50	1.00	2.00	2.00	3.00	3.00	4.00	4.00	4.00	5.00	6.00	0.08	5
RF	0.25	0.25	0.33	0.33	0.50	1.00	2.00	3.00	3.00	4.00	4.00	4.00	5.00	6.00	0.07	6
WS	0.25	0.25	0.33	0.33	0.50	0.50	1.00	2.00	2.00	3.00	3.00	3.00	4.00	5.00	0.05	7
EL	0.20	0.20	0.25	0.20	0.33	0.33	0.50	1.00	2.00	3.00	3.00	3.00	4.00	5.00	0.04	8
PD	0.20	0.20	0.25	0.20	0.33	0.33	0.50	0.50	1.00	2.00	2.00	2.00	3.00	4.00	0.03	9

DRT	0.17	0.17	0.20	0.17	0.25	0.25	0.33	0.33	0.50	1.00	2.00	2.00	3.00	4.00	0.03	10
TWI	0.17	0.17	0.20	0.17	0.25	0.25	0.33	0.33	0.50	0.50	1.00	2.00	3.00	4.00	0.02	11
DW	0.14	0.14	0.20	0.17	0.25	0.25	0.33	0.33	0.50	0.50	0.50	1.00	2.00	3.00	0.02	12
Slope	0.13	0.13	0.17	0.14	0.20	0.20	0.25	0.25	0.33	0.33	0.33	0.50	1.00	2.00	0.01	13
Aspect	0.11	0.11	0.14	0.13	0.17	0.17	0.20	0.20	0.25	0.25	0.25	0.33	0.50	1.00	0.01	14

Number of comparisons = **91**, Principal eigen value = **14.924**, Consistency Ratio (CR) = **4.5%**

Table 4. 3 Weights of the criteria and scores of the sub-criteria

SR.	Layers	Sub-Classes	Categories	Rank	Weight	Weights (%)
1	**Forest Type**	A. Teak, Mixed Teak	Very High	5	0.21	20
		B. Degraded Forest	High	4		
		C. Grassland, Scrub	Medium	3		
		D. Dry Deciduous, Bamboo	Low	2		
		E. Others	Very Low	1		
2	**Distance from Road**	A. < 3 km	Very High	5	0.18	18
		B. 3 - 7 km	High	4		
		C. 7 - 10 km	Medium	3		
		D. 10 - 14	Low	2		
		E. > 14 km	Very Low	1		
3	**Distance from Settlement**	A. < 3 km	Very High	5	0.13	13
		B. 3 - 6 km	High	4		
		C. 6 - 9 km	Medium	3		
		D. 9 - 13 km	Low	2		
		E. > 13 km	Very Low	1		
4	**Distance from Agriculture**	A. < 1 km	Very High	5	0.12	12
		B. 1 - 2 km	High	4		
		C. 2 - 3 km	Medium	3		
		D. 3 - 4 km	Low	2		
		E. > 4 km	Very Low	1		
5	**Surface Temperature**	A. 27.52 - 30.50 C	Very Low	1	0.08	8
		B. 30.50 - 33.48 C	Low	2		
		C. 33.48 - 36.46 C	Medium	3		
		D. 36.46 - 39.44 C	High	4		
		E. 39.44 - 42.43 C	Very High	5		
6	**Rainfall**	A. 1135 - 1287 mm	Very High	5	0.07	7
		B. 1287 - 1439 mm	High	4		
		C. 1439 - 1591 mm	Medium	3		
		D. 1591 - 1743 mm	Low	2		

		E. 1743 - 1896 mm	Very Low	1		
7	**Wind Speed**	A. 2.15 - 2.37 m/s	Very Low	1	0.05	5
		B. 2.37 - 2.58 m/s	Low	2		
		C. 2.58 - 2.80 m/s	Medium	3		
		D. 2.80 - 3.01 m/s	High	4		
		E. 3.01 - 3.23 m/s	Very High	5		
8	**Elevation**	A. 278 - 448 m	High	4	0.04	4
		B. 448 - 618 m	Very High	5		
		C. 618 - 788 m	Medium	3		
		D. 788 - 958 m	Low	2		
		E. 958 - 1129 m	Very Low	1		
9	**Population Density**	A. < 0.47 (person/sq km)	Very Low	1	0.03	3
		B. 0.47 - 3.10	Low	2		
		C. 3.10 – 17.60	Medium	3		
		D. 17.60 – 97.68	High	4		
		E. > 97.68	Very High	5		
10	**Distance from Rail Track line**	A. < 7 km	Very High	5	0.03	3
		B. 7 - 14 km	High	4		
		C. 14 -21 km	Medium	3		
		D. 21 - 28 km	Low	2		
		E. > 28 km	Very Low	1		
11	**Topographical Wetness Index (TWI)**	A. 2.01 - 6.56	Very High	5	0.02	2
		B. 6.56 - 11.12	High	4		
		C. 11.12 - 15.67	Medium	3		
		D. 15.67 - 20.22	Low	2		
		E. 20.22 - 24.78	Very Low	1		
12	**Distance from Water Bodies**	A. < 2 km	Very High	5	0.02	2
		B. 2 - 4 km	High	4		
		C. 4 - 6 km	Medium	3		
		D. 6 - 8 km	Low	2		
		E. > 8 km	Very Low	1		
13	**Slope**	A. 0 - 15◦	Very Low	1	0.01	1
		B. 15 - 30 ◦	Low	2		
		C. 30 - 45 ◦	Medium	3		
		D. 45 - 60 ◦	High	4		
		E. 60 -75◦	Very High	5		
14	**Aspect**	A. flat	Very Low	1	0.01	1
		B. N, NE	Low	2		
		C. NW, W	Medium	3		
		D. S, SW	High	4		
		E. SE, E	Very High	5		

a) Validation of forest fire risk map

To validate the robustness of the AHP-based fire risk model, this analysis used the receiver operating characteristics (ROC) area under the curve (AUC) method. The ROC curve is a graphical representation of the model's performance across different thresholds and plays a significant role in evaluating quality, calculating probability, and forecasting (Roshani et al. 2022; Silva et al. 2020; Sivrikaya et al. 2022). The curve shows the trade-off between the true positive rate (sensitivity) and the false positive rate (specificity) w.r.t. adjustment of the classification threshold. The AUC curve provides a value range from 0 to 1, where a higher value indicates the higher efficiency of the model and vice versa. For convenience, the AUC values have been categorized into five classes - poor prediction (0.5 to 0.6), average prediction (0.6 to 0.7), reliable prediction (0.7 to 0.8), very good prediction (0.8 to 0.9), and outstanding prediction (0.9 to 1) (Abedi Gheshlaghi, 2019). The AUC has been calculated using the following equation:

$$\boldsymbol{AUC} = \frac{(\sum \boldsymbol{RT} + \sum \boldsymbol{TR})}{(\mathbf{A}+\mathbf{B})} \qquad \textit{(13)}$$

where,

$\boldsymbol{RT}$ represents those pixels that have been classified correctly,

$\boldsymbol{TR}$ represents those pixels that have been classified incorrectly,

$\boldsymbol{A}$ means the sum of fire-affected forest pixels and

$\boldsymbol{B}$ represents the sum of non-fire forest pixels.

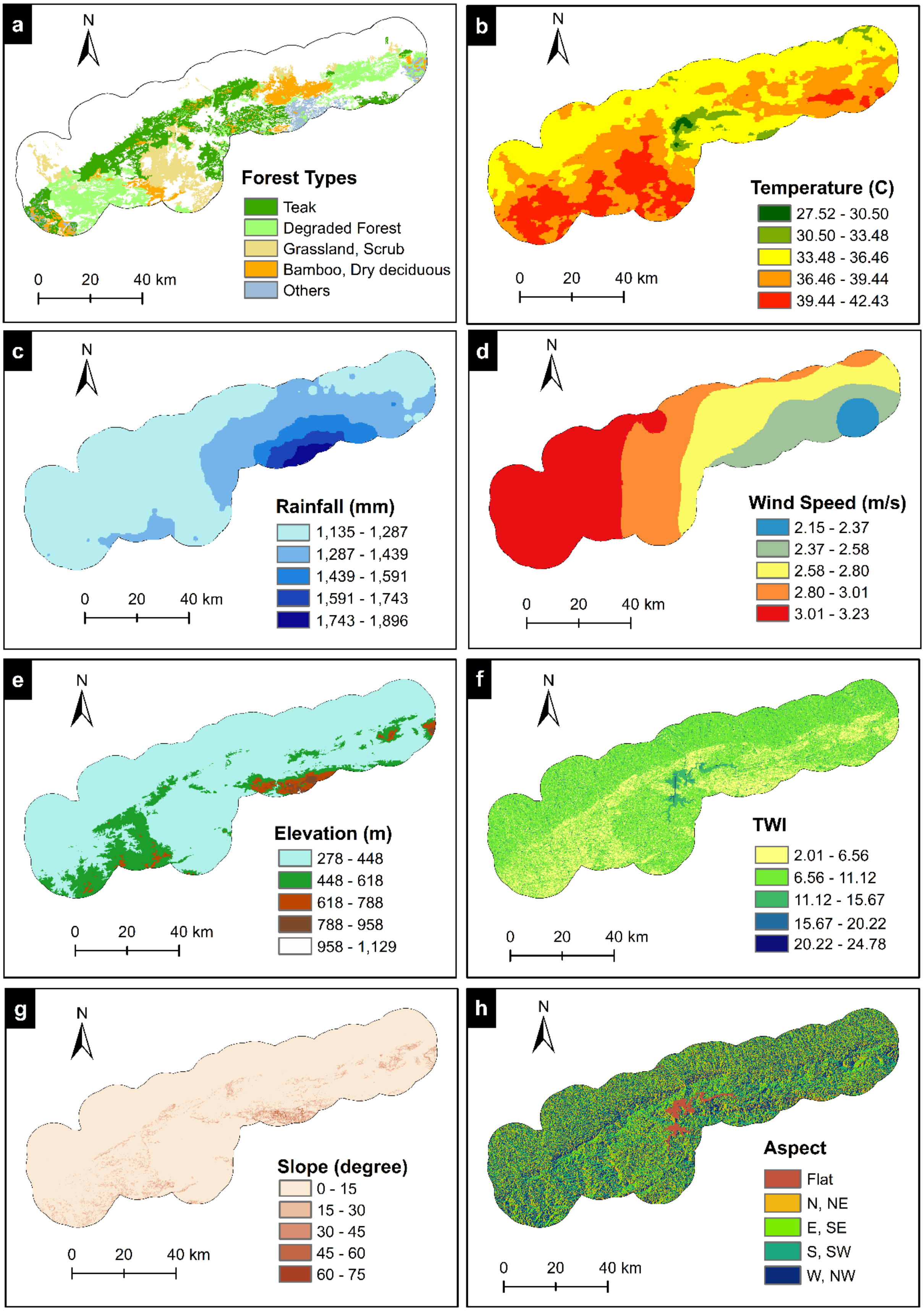
4.2.7 Forest fire controlling factors –

Understanding the features that govern fire risk are essential to comprehend beforehand in order to effectively implement management actions and mitigation strategies (Jaiswal et al., 2002). Based on extensive literature review, this study identified the critical environmental and socio-economic factors that influence the risk associate with fire occurrences (Kant Sharma et al., 2012; Lamat et al., 2021; Nikhil et al., 2021; Nuthammachot & Stratoulias, 2021; Parajuli et al., 2020; Povak et al., 2018; Sivrikaya & Küçük, 2022; Tiwari et al., 2021). These factors are briefly outlined in Table 4.4. It is noteworthy that the spatial heterogeneity of these controlling factors acts as the linchpins for the spatial variations in risk assessment of an environmental hazard (Flannigan et al., 2016; Nezval et al., 2022; Roshani et al., 2022; Salma et al., 2023; Satendra & Kaushik, 2014). The spatial distribution of these controlling factors is shown in Figure 4.1.

Table 4. 4 Factors influencing forest fire

SR	Factors	Impact on Forest fire	References
1	Forest Fuel Type	Regulates fire intensity and likelihood of fire ignition and rapid spread; thus, dry deciduous forests more susceptible than moist deciduous and evergreen types	(Behera et al., 2023; Kant Sharma et al., 2012; Roy, 2003)
2	Surface-level Air Temperature	Positive anomalies ignite and also help in fire spreading; thus, fire susceptibility increases with higher air temperatures at surface-level	(Flannigan et al., 2016; Sivrikaya & Küçük, 2022; Tiwari et al., 2021; Zeren Cetin, Varol, & Ozel, 2023)
3	Precipitation	Inverse relationship with fire risk; higher precipitation increases the soil moistness, reduces the surface temperature, and restricts the drying of fuel contents	(Aragão et al., 2018; Babu et al., 2018; K. Vadrevu et al., 2009)
4	Wind	moisture is transported to downwind region through high wind, thus accelerate the evapotranspiration over upwind regions and increase the dry downs in soil moisture, which aids rapid fire spread	(Flannigan et al., 2016; Lamat et al., 2021; Povak et al., 2018)
5	Elevation	Radiation heat flux decrease with increasing altitude, resulting higher altitude to be less susceptible for fire activities	(S. Kumar et al., 2015; Suryabhagavan et al., 2016)
6	Slope	Greater slope increases the rate of heat transfer between the fire flame and fuel in the uphill areas	(Ajin et al., 2016; Nikhil et al., 2021)
7	Topographical Wetness Index (TWI)	Inverse relationship with fire activities; Higher topographic wetness reduces fire risk by increasing surface moisture, while lower wetness decreases soil moisture and elevated fire risk	(Abdo et al., 2022; Tiwari et al., 2021)
8	Aspect	Determines the exposure to direct and prolonged insolation and often influences the surface air temperature and humidity	(Lamat et al., 2021; Nuthammachot & Stratoulias, 2021)

9	Distance from Roads	Roadside fringe areas more vulnerable due to frequent chances of human interventions (intentional or unintended causes that ignite the roadside fire spread towards the jungle (forest)	(Babu et al., 2018; Nikhil et al., 2021; Parajuli et al., 2020; Roshani et al., 2022)
10	Distance from Settlement	Area near to settlement are more vulnerable because human activities (cooking, vehicle sparks, recreational activities) increase fire risk	(Kale et al., 2017b; Nikhil et al., 2021)
11	Distance from Agriculture Land	Crop residue burning increases fire risk; farmland activities contribute to forest fire	(Chas-Amil et al., 2013; Tyukavina et al., 2022)
12	Distance from Rail Network	Proximity to railway tracks increases fire risk; frictions and sparks from tracks ignite fires	(Belikova et al., 2022; Nezval et al., 2022)
13	Distance from Water Bodies	As observed that the areas far from water bodies safer; human activities near water bodies increase fire risk	(Hussin et al., 2008; Sivrikaya & Küçük, 2022)
14	Population Density	Densely populated areas more prone to fires; human-caused forest fire	(ISFR, 2021; Satendra & Kaushik, 2014)


a
N
Forest Types
Teak
Degraded Forest
Grassland, Scrub
Bamboo, Dry deciduous
Others
0 20 40 km
b
N
Temperature (C)
27.52 - 30.50
30.50 - 33.48
33.48 - 36.46
36.46 - 39.44
39.44 - 42.43
0 20 40 km
c
N
Rainfall (mm)
1,135 - 1,287
1,287 - 1,439
1,439 - 1,591
1,591 - 1,743
1,743 - 1,896
0 20 40 km
d
N
Wind Speed (m/s)
2.15 - 2.37
2.37 - 2.58
2.58 - 2.80
2.80 - 3.01
3.01 - 3.23
0 20 40 km
e
N
Elevation (m)
278 - 448
448 - 618
618 - 788
788 - 958
958 - 1,129
0 20 40 km
f
N
TWI
2.01 - 6.56
6.56 - 11.12
11.12 - 15.67
15.67 - 20.22
20.22 - 24.78
0 20 40 km
g
N
Slope (degree)
0 - 15
15 - 30
30 - 45
45 - 60
60 - 75
0 20 40 km
h
N
Aspect
Flat
N, NE
E, SE
S, SW
W, NW
0 20 40 km

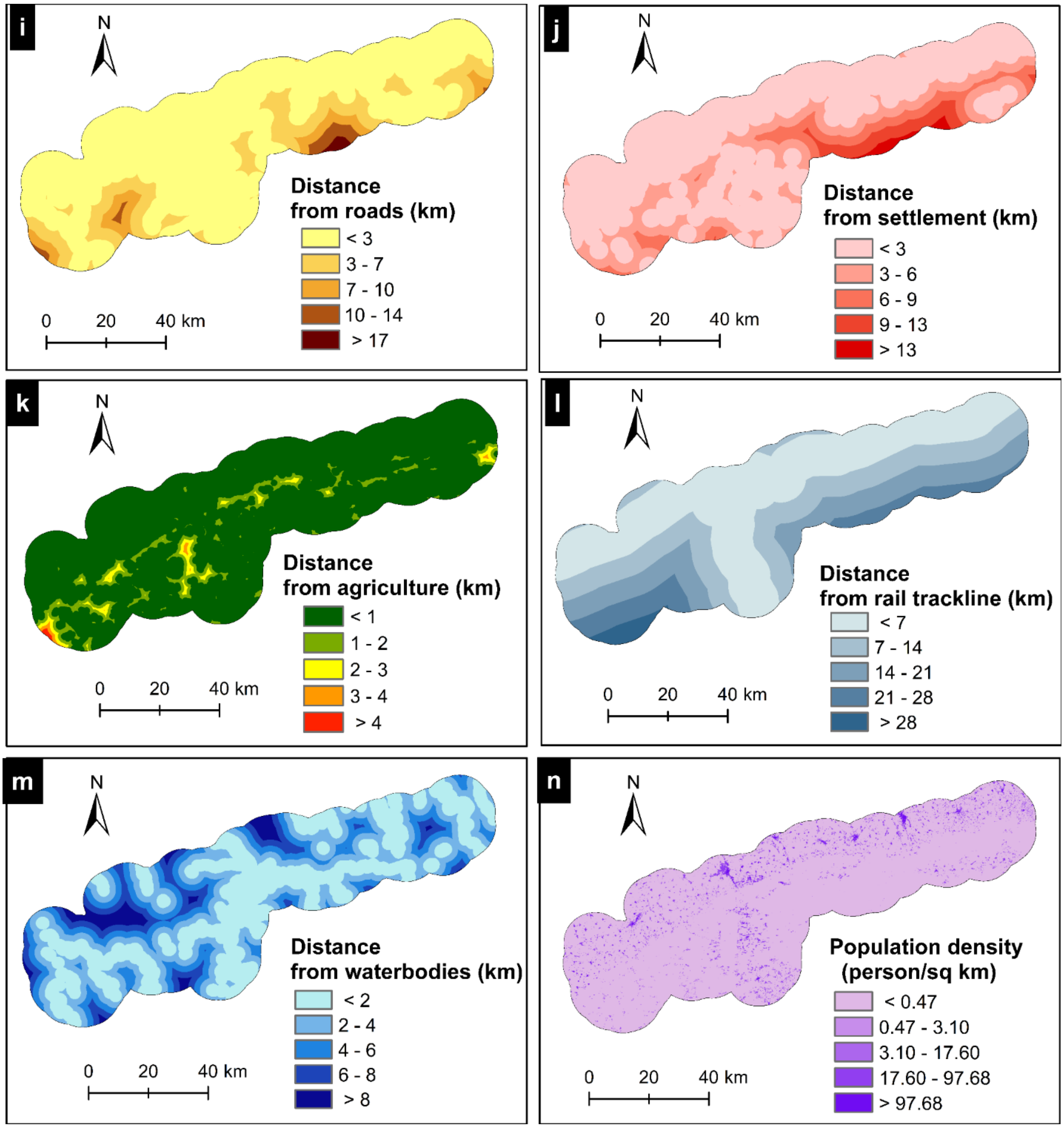


Fig. 4. 1 *Spatial distribution of fire controlling factors:* (a) Forest type, (b) Surface Temperature, (c) Rainfall, (d) Wind speed, (e) Elevation, (f) TWI, (g) Slope, (h) Aspect (i) Distance from road (j) Distance from settlement, (k) Distance from agriculture lands, (l) Distance from rail network, (m) Distance from waterbodies, (n) Population density

4.3 Results

4.3.1 Trends of Fire

The temporal analysis conducted in this study using the Mann-Kendall (MK) Test and Sen's Slope estimator aimed to identify trends in fire occurrences within the HFD area over a 22-year period from 2001 to 2022. The results of the MK test revealed a non-significant increasing trend in fire occurrences, with a z-value of 1.550 and a corresponding p-value of 0.12. Similarly, the application of Sen's Slope estimator identified a non-significant increasing slope of approximately one event per year over the 22-year period from 2001 to 2022 (see Fig. 4.2). Both statistical tests collectively suggest that there is no strong, statistically significant monotonic trend in fire occurrences within the HFD. Though the results do not demonstrate a clear and significant trend at the standard confidence level of 0.05, there could potentially be a weak trend that the tests were not able to detect with high confidence given the available data.

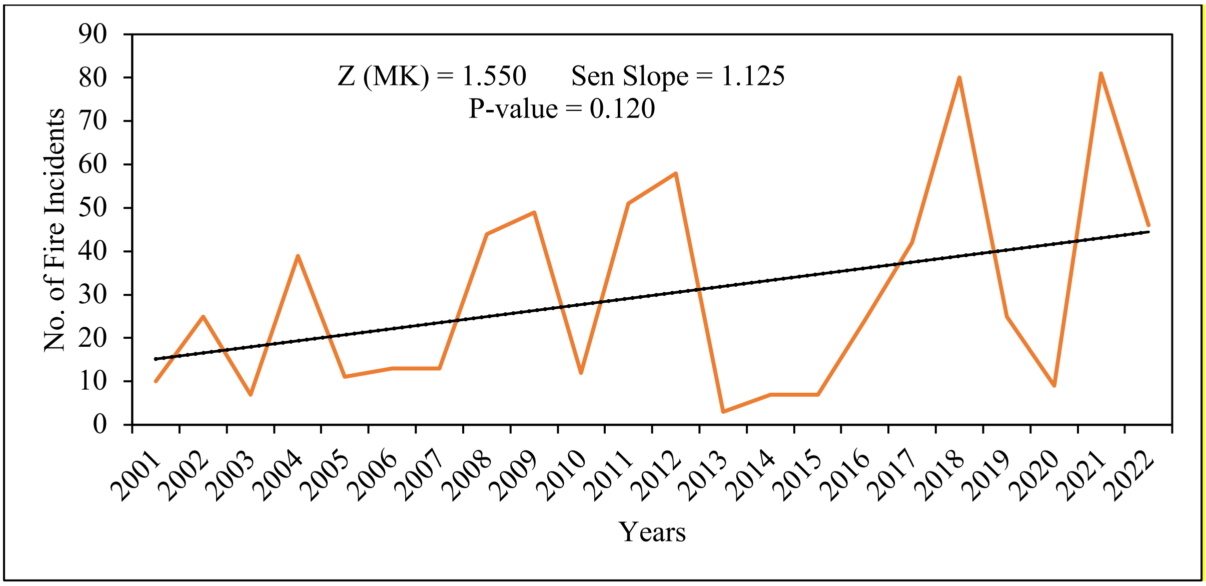


Fig. 4. 2 Temporal Analysis of Fire by using MK and Sen's slope estimator test

There may be a need for further investigation or consideration of broader regional factors and additional data sources. It is possible that additional data or a longer time series may reveal a more pronounced trend in fire occurrences. Alternatively, other factors not accounted for in this analysis could influence the observed patterns.

4.3.2 Spatial Autocorrelation

To begin the spatial investigation, this study examined the spatial autocorrelation (SA) among fire events that occurred within the HFD area from 2001 to 2022. Spatial autocorrelation refers to the degree to which similar values (in this case, fire occurrences) are clustered or dispersed across space. The analysis revealed a Moran's I value of 0.107 with a z-score of 6.336 and a very low p-value (<0.001). These statistical measures indicate a strong presence of spatial autocorrelation in the distribution of forest fire within the study area (Appendix 4A).

By analyzing these results, the study designates that forest fires in the HFD area are not randomly distributed but tend to occur in clusters or hotspots. When a fire ignites in one location, it is more likely to spread and affect nearby areas. This pattern suggests that certain regions within the forest division are more susceptible to forest fire due to factors such as vegetation type, terrain, or human activities.

The significant Moran's I value, and z-score confirm that the observed spatial autocorrelation is not due to random chance but reflects underlying patterns in the distribution of fire occurrences. Identifying these hotspot areas of fire occurrence is imperative for developing effective fire management and prevention strategies within the HFD (Forest Division) area. By understanding where forest fire tends to cluster or occur more frequently, resources and efforts can be strategically allocated to prioritize these high-risk areas or hotspots.

4.3.3 Fire Hotspots

The analysis of fire patterns revealed distinct spatial clusters within the study area, characterized by two hotspots (areas with higher fire occurrence) and two cold spots (areas with lower fire occurrence). These clusters were identified using circular demarcations labeled with small letters ('a', 'b', 'c', 'd') in Fig. 4.3A. The identified cold spots were represented by circles 'a' and 'd', indicating areas with relatively fewer instances of fire. In contrast, circles 'b' and 'c' denote hotspots, representing areas with a notably higher concentration of fire incidents. Among these spatial clusters, Zone 'b' exhibited the highest concentration of fire points, accounting for approximately 36% of all recorded fire incidents over the 22-year study period. Zones 'd' and 'c' each contributed 3% to the total fire incidents, while Zone 'a' accounted for 5%.

Several factors are likely to contribute to the formation of these hotspots. Zone 'b', with the highest concentration of fire incidents, may be influenced by proximity to transport networks, agricultural fields, or areas dominated by teak forests. Additionally, degraded forest areas characterized by high temperatures and low rainfall could contribute to increased fire susceptibility in Zone 'b'. Similarly, Zone 'c' may share similar characteristics with Zone 'b', explaining its designation as a hotspot with a concentration of fire incidents. On the other hand, Zones 'a' and 'd', identified as cold spots, may exhibit different environmental conditions or land use patterns that contribute to lower fire occurrence.

The observed hotspot dynamics highlight a higher vulnerability to forest fire in the south-western part of the study region based on historical records and spatial analysis. However, to gain deeper insights into these hotspot phenomena, it is crucial to consider various physical and socio-economic variables. Factors such as vegetation type, topography, human activities (like agricultural practices or transport infrastructure), climate conditions (temperature, rainfall, wind), and land management practices can all influence fire occurrence and intensity. Integrating these variables into the analysis using the Analytic Hierarchy Process (AHP) will provide a more comprehensive understanding of fire vulnerability in specific areas. By understanding the complex interactions of these factors, we can develop targeted fire prevention and management strategies tailored to the unique characteristics of each hotspot and cold spots within the study area. This knowledge-based approach is essential for effective fire mitigation and reducing the impact of forest fire on local ecosystems and communities.

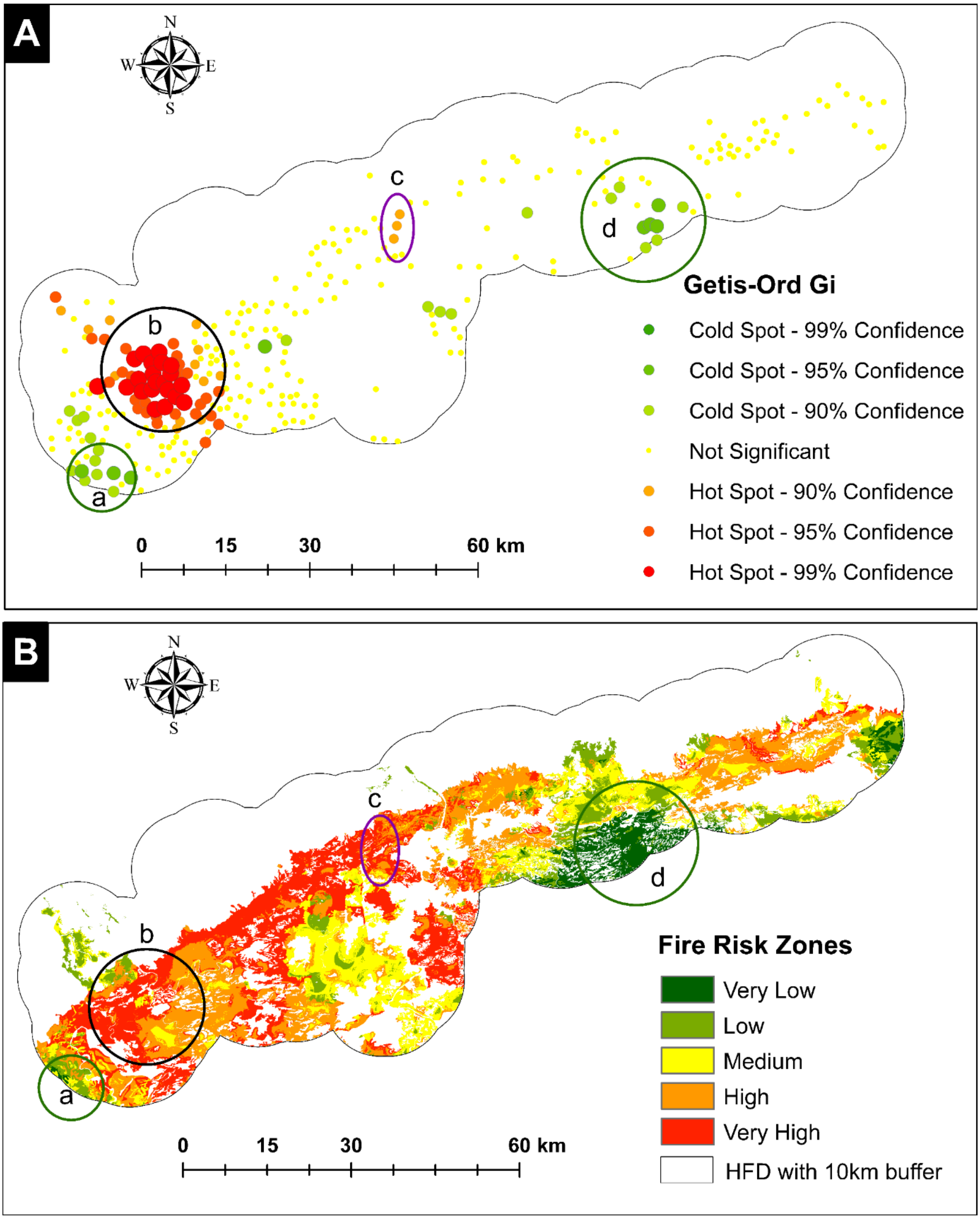


Fig. 4. 3 *(A) Hotspot analysis map with (**B**) Fire risk map (AHP)*

4.3.4 Forest Fire Risk Mapping

To assess the risk of forest fires, a comprehensive analysis was conducted using a pair-wise comparison matrix considering several factors to evaluate their relative impact on fire probability. The final weights derived from this assessment are presented in Tables 4.2 and 4.3, alongside scores for different factor classes. It was important to evaluate the consistency of expert opinions for fourteen driving criteria. The consistency ratio of the selected variables in the AHP comparison matrix is **4.5%,** which supports the expert opinion and inculcates that the evaluations were consistent and appropriate for forest fire risk mapping.

Based on the assessment, the study area has been divided into five classes as per the degree of the fire risk, namely very low (155 sq km), low (300 sq km), moderate (592 sq km), high (816 sq km), and very high forest fire risk (724 sq km). The forest fire risk map demonstrates that around 60% of forest cover comes under the high to very high-risk zones. Thus, a large portion of the HFD and its buffer peripheral areas comes under the areal hegemony of the fire regime, and nearly 32% of the forest covers the core and the periphery of the forest division facing a high chance of fire (Table. 4.5).

Among the several agents impeding the risk, the transportation network and regular human activities to collect forest resources by local people are affecting the most (Khan 2013). Among the nine forest ranges in this forest division, five are highly vulnerable to fire risk. These are Seoni Malwa, Banapur, Itarsi, Hoshangabad, and Bankhedi range, coming under high to very high-risk zones as assessed by this current geospatial model (Fig. 4.4). The rest of the forest ranges -Pipariya, Bhagpur, Sukhtawa, and Bagara, were also affected by forest fire; however, they fall in the low to medium forest fire risk category in the AHP Model, with limited extent and intensity. It also to be noted that the peripheral areas, dominated by the teak forest cover, are highly vulnerable to fire and fall under the high to very high category of ignition risk. Other vegetation types like moist deciduous and green moist are less prone to fire.

This comprehensive fire risk asseesment highlights the urgent necessity for targeted interventions and forest management strategies, particularly in the highly vulnerable regions (Seoni Malwa, Banapur, Itarsi, Hoshangabad, and Bankhedi ranges) where frequent fire incidents pose significant threats to the forests and forest-depndent communities. Hence, the AHP result provides critical insights into the spatial distribution of fire hazards within the HFD. By identifying high-risk areas and understanding contributing factors, effective mitigation strategies can be implemented to maintain biodiversity, forest ecosystem integrity, and human livelihoods in these vulnerable regions.

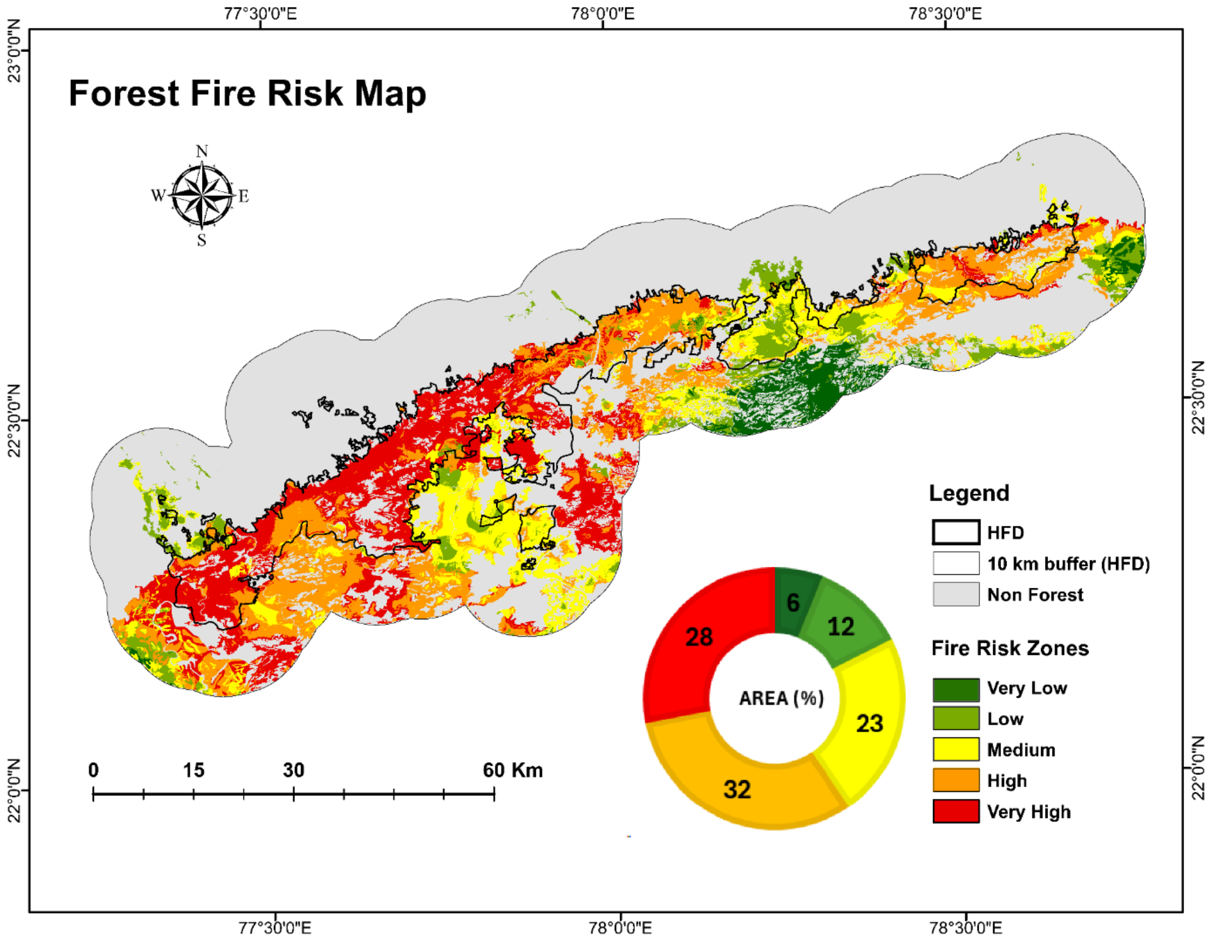


Fig. 4. 4 Forest fire risk map

Table 4. 5 Forest fire risk area with fire points

SR.	Vulnerability to Fire	Area (sq km)	Area (%)	Fire Points (2001-22)	% of Fire Points
1	Very Low	155	6	7	1
2	Low	300	12	50	8
3	Medium	592	23	87	13
4	High	816	32	274	42
5	Very High	724	28	239	36
	Total	**2587**	**100**	**657**	**100**

4.3.5 Validation (ROC-AUC)

The prepared fire risk map of the HFD was validated with 81 forest fire incidents occurred in 2021. From the temporal pattern, the analysis found that the HFD region had experienced an unprecedented surge in forest fire events during 2021. Thus, the findings of AHP model validated in the context of this specific year. The graphical plot of the ROC curve is positioned closer to the upper-left corner (true positive values), indicating a reliable and good-performing model. Along with the ROC plot, an AUC value of 0.762 is considered a rationally high value, indicating that your AHP model is operative in distinguishing between different levels of forest fire risk. It suggests that the prescribed model had satisfactorily decent discriminative efficiency (Fig. 4.5).

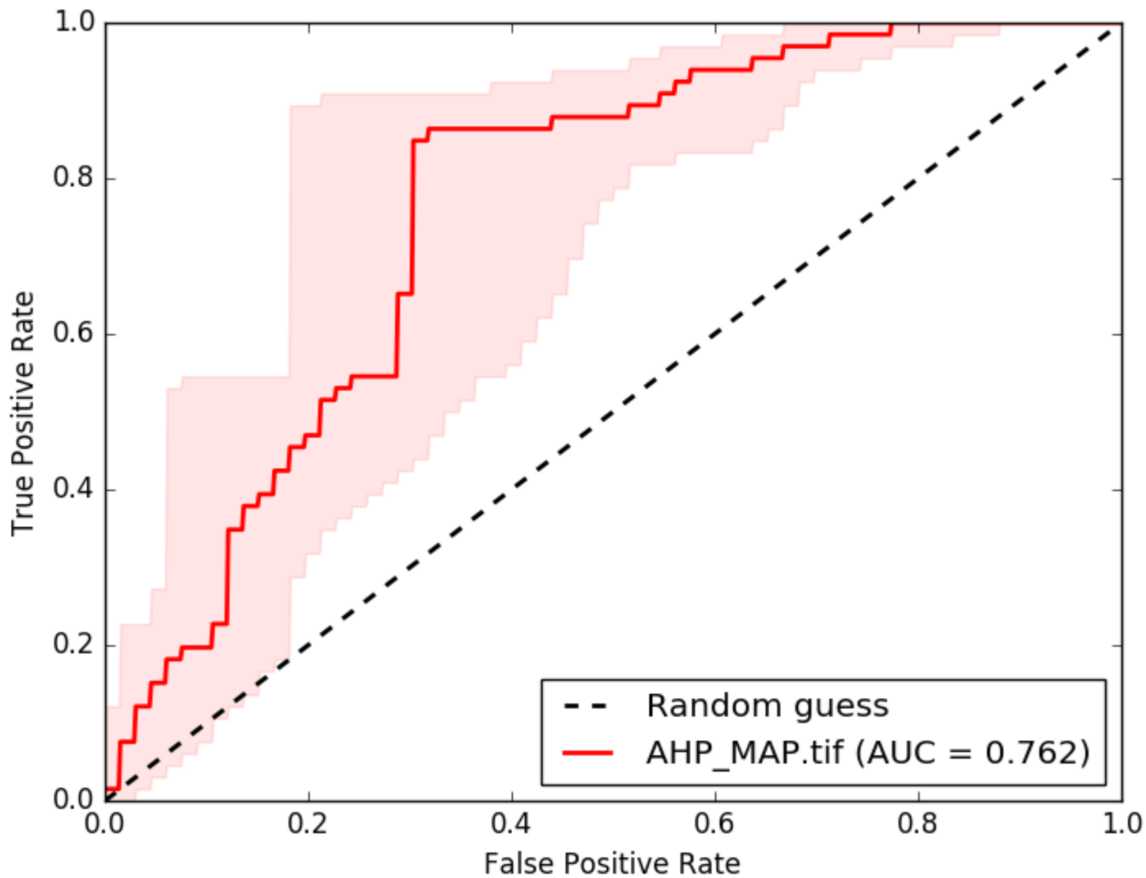


Fig. 4. 5 ROC -AUC Curve

4.4 Discussion

4.4.1 Spatial analysis of forest fire:

The spatial distribution of forest fire in the HFD exhibits a significant positive spatial autocorrelation, implying that fire occurrences are not randomly distributed but tend to cluster in specific geographical areas. This spatial clustering suggests that neighboring locations influence the likelihood of forest fire due to various factors such as vegetation type, topography characteristics, human activities, and weather patterns. For example, areas with teak & degraded vegetation and proximity to human settlements or transportation routes may experience higher fire occurrence due to increased ignition sources or accessibility for fire spread.

The observed positive spatial autocorrelation underscores the importance of considering spatial dependencies in fire mitigation techniques. Instead of treating each forest fire incident in isolation, understanding the spatial relationships and clustering of fire occurrences can guide more targeted and efficient utilization of resources and interventions (S. Kumar & Kumar, 2022a; Reddy et al., 2019; K. P. Vadrevu et al., 2013). For instance, focusing fire prevention efforts in areas surrounding known hotspots or where spatial clusters of fire occurrences are identified can help mitigate future fire risks more effectively.

Furthermore, hotspot analysis conducted in the study revealed distinct spatial patterns in the HFD. Zone 'b', characterized by concentrated fire prevalence (hotspots), likely corresponds to areas with high fuel loads, conducive weather conditions, or increased human activities leading to frequent fire ignition and spread. On the other hand, Zones 'a' and 'd', identified as cold spots with minimal fire incidents, may have lower concentration of teak and degraded vegetation, natural barriers, or effective fire management practices in place. These findings highlight the spatial heterogeneity of forest fire risk within the study area, indicating that not all parts of the HFD face equal fire threats. Effective fire management strategies should acknowledge and address this variability by tailoring interventions to specific spatial contexts. For instance, implementing prescribed burning or fuel reduction treatments in identified hotspot zones can help reduce fuel accumulation and mitigate fire risks (F. L. M. Santos et al., 2021). Conversely, areas identified as cold spots may benefit from continued monitoring and preventive measures to maintain their low fire occurrence status.

The inclusion of spatial analysis into forest fire management strategies allows optimized resource allocation and response planning based on identified spatial patterns and risk levels. This approach leads towards a more proactive and targeted framework to forest fire prevention and mitigation, ultimately reducing the impact of forest fire on forest and surrounding communities. In line with recommendations by Kumari and Pandey (2020), integrating spatial analysis techniques into fire management practices enables a comprehensive understanding of fire dynamics and informs evidence-based decision-making to enhance resilience and sustainability in forest management.

4.4.2 Importance of environmental and socio-economic factors:

The observed factors influencing fire occurrence in the study area highlight a complex interplay of environmental and human-related elements. A key environmental factor identified is the type of forest fuel, with dry deciduous forests being more susceptible to forest fire due to the abundance of easily ignitable materials such as dry leaves (Behera et al., 2023; ISFR, 2021; Saha, 2002). Additionally, various environmental conditions significantly influence fire incidents, including elevation, rainfall, temperature, wind patterns, and slope characteristics (Cetin et al., 2023; Jiménez-Ruano et al., 2019; Kale et al., 2017b; Kayet et al., 2020; Nasiri et al., 2022; Sivrikaya & Küçük, 2022, 2022). It was observed that areas with elevations ranging between 450m and 700m are more exposed to fire and fall under the high-risk zone for fire. Beyond these elevation limits, fire occurrences are less frequent and rarely spread extensively. In addition, the southwest corner of the study area is closely related to steep slopes, which are primary factors contributing to the intensification of forest fires in this specific portion of the region. Steep slopes can accelerate fire propagation, making fire suppression efforts more challenging and increasing the overall fire risk. Moreover, the regions which are experiencing lower rainfall, higher temperatures, and stronger winds tend to register higher fire counts due to favorable conditions for fire ignition and spread.

Human-related factors also play a crucial role in shaping the fire landscape. Proximity to roads, settlements, agricultural lands, rail networks, water bodies, and population density increases the risk of fire ignition and spread. Human activities such as cooking, recreational pursuits, and agricultural practices further contribute to fire risk (Chas-Amil et al., 2013; Pozo et al., 2022; Rodrigues et al., 2016; Roy, 2003; Saha, 2002).

The spatial distribution of these factors, as illustrated in Figure 2, exhibits distinct variabilities across the study region. This emphasizes the importance of integrating Geographic Information System (GIS)-based analysis of multiple diverse factors to comprehensively understand fire risk. By mapping and analyzing these spatial patterns and relationships, the forest managers and stakeholders can prioritize and implement targeted fire prevention and management strategies to specific risk areas within the study region and beyond.

4.4.3 Fire Risk Mapping:

The AHP-based forest fire risk mapping conducted in the HFD offers a detailed assessment of vulnerability, revealing that a significant portion of the forest cover (around 60%) falls within high to very high-risk zones, underscoring the widespread threat of fire in the area. This outcome highlights the critical need for proactive fire management strategies to mitigate potential risks.

The mapping model identifies specific forest ranges within the study area with varying levels of vulnerability to fire. This variation can be attributed to several factors, including forest type and land cover characteristics. Forests dominated by teak and areas with degraded forest and grasslands are more susceptible to fire incidents due to higher fuel loads and flammability (Srivastava & Garg, 2013; Suryabhagavan et al., 2016). The spatial pattern of fires observed in the southern-western and western parts of the study area aligns with these findings, emphasizing the influence of forest composition on fire dynamics. Moreover, human activities and infrastructure play significant roles in shaping fire risk. Proximity to major transportation networks, such as busy roads used by commuters, tourists, and locals, increases the likelihood of fire ignition due to human-related causes such as discarded cigarettes, vehicle sparks, or accidental fires (ISFR, 2021; Roy, 2003; Sivrikaya & Küçük, 2022). Understanding these factors (natural and human-induced) is crucial for developing targeted prevention and management strategies.

The final risk map highlights specific forest ranges and their peripheries, particularly Seoni-Malwa, Banapur, Itarsi, Hoshangabad, and Bankhedi, as highly vulnerable to forest ignition. These areas require focused attention and proactive measures to reduce fire risks and minimize potential impacts. Recommended actions include enhanced monitoring and patrolling during the fire-prone summer season, installation of forest fire watch towers for early detection and rapid response, and implementation of prescribed burning practices to reduce fuel loads in teak-dominated and degraded forest areas. Prescribed burning, when conducted under controlled conditions, can effectively reduce accumulated dry vegetation, mitigating the intensity and extent of potential fires (Fernandes & Botelho, 2003; F. L. M. Santos et al., 2021; Satendra & Kaushik, 2014). This practice is particularly beneficial in areas where natural fire regimes have been disrupted due to human activities, leading to increased fuel loads and heightened fire risks (Prestemon et al., 2002). Hence, the detailed AHP-based forest fire risk mapping in the HFD provides several imperative communications for fire supervision and conservation efforts in the HFD. It highlights the implication of spatial dependencies, the spatial heterogeneity of fire risk, and the necessity for decision-based actions supported by vulnerability assessments. The insignificant increasing trend in fire events and the validated AHP model further emphasize the importance of current research and monitoring to acclimatize and progress fire managing approaches.

Thus, this GIS-based integrative approach allows for a holistic methodology to fire risk assessment by considering the spatial interactions and dependencies among various influencing factors. This comprehensive understanding enables informed decision-making and effective allocation of resources to mitigate fire risks and enhance resilience in forest management practices. By addressing both environmental and human-related factors, authorities can work towards reducing the impact of fires on ecosystems, communities, and natural resources in the study area and can be applied to other geographies and on broader regions.

4.5 Conclusion

Fires in a forest area like Hoshangabad can create a serious threat to the biodiversity and local people who depend on forest resources for their earnings and livelihoods. A thorough investigation including geospatial and non-geographic information is requisite to comprehend the sensitivity and vulnerability of fires in this region. This study employed several statistical techniques to understand the temporal tendency of fire activities over two decades (2001-2022) and spatial pattern of its occurrences. Further, it used the AHP method in a GIS environment to identify fire risk zones (very low, low, medium, high, and very high) in the area. This zonation was also being evaluated against the fire records provided by MODIS and achieved 76% accuracy. The key findings of the study are as follows:

- The positive rise in trend and magnitude of fire events are found in the study area by using the MK and SS tests over a 22-year period. Although the trend is not statistically significant, further investigation with broader region could reveal underlying trends.
- The spatial distribution of fire events in the study area was found to be attributed with significantly positive spatial autocorrelation, indicating that the majority of fires occurred in certain areas. This clustering suggests that neighboring locations influence the likelihood of fires and emphasizes the importance of considering spatial dependencies in fire mitigation techniques. Preventing fire ignition over those specific areas could potentially drop in large occurrence of fire activities in this forest division.
- Specific hotspot areas were identified based on the spatial pattern of active fire locations. The western hilly slopes in HFD region found the most vulnerable region that had been affected in the past years. Such identification would help the local forest authorities could take site-specific actions to prevent fires over this area.

- Integrating GIS to the AHP based spatial risk analysis provides risk zonation at 30m resolution in the area. It shows that the western, central west and south-western areas are prone to greater risk of fires. Regular monitoring over those particular areas during summer season (since most fire occur during summer) could avoid any man-made obtrusion and further protect the teak trees. Over those areas, fire authorities could take necessary action to reduce the dry fuel material load along the roadside areas.

The study also has some limitations such as the analysis was limited to a single forest division, potentially missing broader regional trends. The study duration (22 years) and available data may not fully capture long-term trends or factors influencing fires. The complexity of fire dynamics requires consideration of additional variables beyond those analyzed in this study. Despite the limitations, by utilizing the workflow (methodological framework) of this study can also a guideline for the management authorities in government and non-government organizations to assess fire patterns and estimate risks at a geospatial-level over any small- (Forest divisions or National Parks) or large-scale (regional-level) area in India. In future, researchers can use advanced geospatial technologies, long-term fire data, and machine learning methods to conduct similar studies. Additionally, they can compare results using multi-criteria decision-making methods to enhance the depth and accuracy of fire risk assessments.

CHAPTER-5

Perceived Economic Impacts of Fire

A Qualitative and Descriptive Analysis

5.1 Introduction

Fires represent a frequent ecological disturbance in India's forested regions, with wide-ranging consequences for biodiversity, ecosystem health, and human livelihoods (ISFR, 2023; Roy, 2003). As fires are often perceived through a biophysical or management-centric lens, their socio-economic and cultural consequences on forest-dependent communities remain underexplored, particularly in the tribal belts of central India (Manikchand et al., 2025). This chapter seeks to address this gap by offering a qualitative and descriptive synthesis of how communities in the HFD of Madhya Pradesh in central Indian region perceive and experience the economic and livelihood impacts of forest fires.

India's fires are largely surface fires, propelled by an amalgamation of anthropogenic ignition fonts and climatic variability (Satendra & Kaushik, 2014). Studies have concluded that fire incidences in central India are mounting in frequency and duration, often concurring with the dry pre-monsoon period between March and May (Jain et al., 2021; Khan, Gupta, et al., 2024; Ray, 2021; Saha, 2002; Sahu et al., 2024). In forest fire prone districts such as Hoshangabad, the temporal alignment is associated with the peak season for harvesting of major NTFPs, like tendu (Diospyros melanoxylon) and Mahua (Madhuca indica), which are essential to local livelihoods. (Khan, Sharma, et al., 2024). Thus, even when fires do not explicitly harm agricultural fields or homes, they can severely disturb livelihood cycles by upsetting the collection timing, quality, and quantity of forest-based minor produce.

Major tribes of this forest region; the Korku and Gond[17], depends on mixed livelihoods that combine seasonal NTFP collection, small-scale agriculture, wage labor, and animal husbandry

[17] The Korku and Gond are major Indigenous tribal communities of central India with a substantial presence in Madhya Pradesh. The Korku primarily inhabit the Satpura ranges, particularly in districts such as Betul, Chhindwara, and Hoshangabad, and belong linguistically to the Austroasiatic (Munda) family. The Gond, one of the largest tribal groups in India, are widely distributed across central and eastern Madhya Pradesh and speak languages of the Dravidian family. Both communities are historically forest-dependent, with livelihoods cantered on rainfed agriculture and the

(Bhattacharya & Krishna Patra, 2007; Bhattacharya et al., 2025). For the forest dependent people including Korku and Gond, forest fire acts as an aggravation that intersects with multiple economic aspects: it threatens fodder availability, extends grazing distances, affects income from NTFP markets, and introduces uncertainty into seasonal employment patterns (Manikchand et al, 2025). However, disentangling the direct impacts of fire from broader livelihood challenges is methodologically difficult (Nyamadzawo et al., 2013). In many places, forest fires are only one among several overlapping crises, including irregular rainfall, deforestation, and industrial development, which makes it imperative to explore how local people themselves perceive these changes and attribute cause.

Identifying these gaps, the purpose of present study, particularly this chapter, is to implement a perception-based and community-centered approach. Instead of building partial assumption through linear causality or relying purely on quantitative parameters, the study seeks to understand how forest-dependent households perceive the presence of fire in their socio-ecological landscape. Perception routes us to analytical lens in human-environment research since it reflects light on lived experiences, local knowledge, and social meanings that often get hinder in technocratic assessments (Adger et al., 2013; Berkes, 2012). Scholars of political ecology[18] or environmental anthropology emphasize that the communities interactions with fires are not merely on economic/financial, but also cultural, spiritual, and shaped by power dynamics (Goldammer & De Ronde, 2004; Suhardiman et al., 2026).

As the focus of this chapter is to provide a perception-based assessment, it adheres to qualitative assessment, asking the question of *What, Why and How* from the participants' narration received during the survey without overly abstracting their descriptions into theoretical constructs (Sandelowski, 2000). Consequently, this chapter explores and analyzes perceptions related to the

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collection of NTFPs including mahua and tendu patta and maintain strong cultural and spiritual relationships with forest landscapes and seasonal ecological cycles.

[18] An interdisciplinary analytical framework that examines environmental change and resource use through the lenses of power, politics, and socio-economic inequality. It focusses, how ecological outcomes are shaped not just by biophysical processes, but by historical trajectories, institutional arrangements, state policies, market forces, and unequal power relations between actors operating at multiple scales, from local communities to global regimes. By focusing on questions of access, control, knowledge production, and discourse, political ecology critically interrogates dominant environmental narratives and highlights how marginalized groups often bear blame and disproportionate costs of conservation and environmental governance (Blaikie & Brookfield, 1987; Robbins, 2012).

causes of fire, its impacts on agriculture and livestock resources, seasonal employment, cumulative and indirect effects on NTFPs (including Mahua, mushrooms, achar, tendu, and amla), causal factors of annual income disruptions, especially the effects of fire on annual family income from forest-based activities. Thus, this chapter contributes to a more grounded and community-sensitive understanding of forest fire impacts by centering local perceptions and ground realities.

5.2 Methodological Framework

This chapter adopts a qualitative interpretivist approach[19] embedded within a mixed-methods framework (Elwood, 2010), drawing on qualitative descriptive design (e.g., perception-based assessment and thematic analysis[20]) with rooted descriptive statistical analysis, to capture the multi-layered perception-driven impacts of forest fire on rural livelihoods and local economies in the HFD of central India. This approach is justified by the realization that measuring the effects of forest fires exclusively through objective indicators ignores the subjectivity involved, experience, and culturally situated knowledge systems (Creswell & Clark, 2017). The research design proceeded in two inter-linked phases:

Phase I: In this phase we assessed the spatio-temporal patterns of forest fires in the HFD region using satellite-derived geospatial data (see chapter 3), later we performed the risk zonation mapping using the Integrated MCDA framework in a GIS environment (refer to chapter 4). Our aim was to identify high-vulnerable or fire-prone zones based on fire occurrence density measurement, hotspot analysis, and AHP-based risk mapping. This assessment helped us in

[19] A qualitative interpretivist approach embedded within a mixed-methods framework, combining descriptive statistical summaries with perception-based thematic analysis. Rooted in the interpretivist tradition of social research, the approach prioritizes local knowledge, lived experiences, and culturally situated meanings over abstract generalizations. While structured survey data were analyzed using basic descriptive statistics (frequencies, percentages), the emphasis remained on thematic interpretation of open-ended narratives to understand the socio-ecological impacts of forest fires. This methodological blend is particularly suited to community forestry and indigenous environmental studies, where causal complexity, cultural embeddedness, and subjective perception shape people's interactions with ecological change (Sandelowski, 2000; Braun & Clarke, 2006; Chambers, 2002).

[20] Thematic analysis follows six iterative steps: familiarization, coding, searching for themes, reviewing themes, defining, and naming themes, and reporting. Researchers immerse themselves in data through repeated reading and memos; generate comprehensive codes manually or with software; cluster codes into candidate themes using visual maps; review themes for coherence and fit against the full dataset, merging, or discarding as needed; refine each theme's essence and select illustrative quotations; and write a transparent analytic narrative linking themes to research questions and literature. Maintain a codebook, reflexive memos, and an audit trail to ensure rigor and reproducibility (Ahmad et al, 2025).

selection of vulnerable zones to conduct in-depth field study, with a focus on villages located in or near areas of recurrent fire activity.

Phase II: In the second phase, after identifying the fire-prone villages, we conducted a pilot study in selected villages to gain an overview and preliminary understanding of whether fire influences the residents' socio-economic status. A pilot study revealed that, according to local perception, there is almost no change in economic gain/loss due to the direct effect of forest fires. It is mainly because of the spatial location of fires, most of which occurred deep in the forest, far from habitation and agricultural zones. Through a pilot survey assessment, it was found that most people collect major NTFPs, such as Mahua, Achar, Gulli, and Amla, from nearby scattered forests or from trees within their agricultural fields or close to the fields. Furthermore, the assessment reveals that fire impacts were significantly influenced by structural and environmental drivers, including occupational shifts, job opportunities in industries or urban areas (industrial job migration), temperature variability, lightning, and irregular rainfall.

The pilot study led us to change our approach from an impact quantification model, based on regression and correlation analysis, to a perception-centered, qualitative, and descriptive assessment, which is non-inferential due to the complexity of isolating fire as a standalone causal agent. Using this approach we conducted a comprehensive field survey in 48 forest-fringe villages in HFD and made interpretation of lived experiences, local meanings, and the rooted cultural knowledge surrounding fire, parallel with traditions in human geography, environmental anthropology, and political ecology (Berkes, 2012; Neumann, 2014).

5.2.1 Data Collection

The comprehensive field survey was carried out between April 2024 and December 2024, during and after the peak of forest fire season, across 48 strategically selected villages near identified fire-vulnerable zones in the HFD. The selection of villages was based on a combination of: (a) *Proximity to fire hotspots* (from fire risk maps), (b) *Population size* and socio-demographic heterogeneity, and (c) *Access to forest-dependent livelihoods* (e.g., NTFP collection, grazing, fuelwood dependence).

Using purposive and stratified sampling methods, we conduct surveys in 48 villages and collected 402 household samples through semi-structured questionnaire (Dunn, 2010), ensuring diversity in gender, age (excluding the age <18), caste, and forest dependency (see Table 5.1). Along with household interviews, key informant accounts, and in-depth discussion were also considered, majorly among them were forest guards, retired officials, Gram Panchayat members, village heads, school-teachers, elders and traditional knowledge holders, and wage laborers involved in forest-related seasonal work. We used Hindi language to take care of participants' comfortability. However, in some cases, especially elders from the Gond and Korku-speaking tribal communities, we took the help of a local field survey assistant, Mr. Vikkey Narke, who smoothed communication by translating questions and clarifications into the local dialect. He also helped in simplifying terms such as 'irregular rainfall' and 'temperature variability' in local language to ensure clarity and accurate responses. The purpose of these interviews was to discover insights on themes including fire impacts on agriculture, fuelwood, NTFP, seasonal employment impressions, overall income of family, governance mechanisms of fire, and changes in grazing practices, fire use, and community's participation in the forest fire suppression activities.

5.2.2 Data Structure and Processing

Our data consists of both structured quantitative indicators (e.g., perceived fire impact on fuelwood, NTFPs availability, income variability, grazing distance) and open-ended narratives. Following fieldwork:

- We utilize Microsoft Excel to code Quantitative responses and asses them using non-inferential- basic descriptive statistics including frequency distributions, cross-tabulations, and percentage summaries.
- Using thematically coding qualitative narratives were built such as identifying recurring patterns, quotes, metaphors, and frames of meaning like how people speak about fire's impact, whether as a seasonal incident, a sacred cleansing force, or a consequence of policy letdown. Employing this enabled us to draw parallel quantitative patterns of fire with ethnographic depth exclusively presented in chapter 6 and 7.

This chapter avoided the use of any multivariate statistical models (e.g., regression or ANOVA). It was an intentional methodological choice, driven by the nature of data which was interpretive, experience-based, and community-specific. Since regression analysis, while an essential tool for generalization and prediction, it may not well align in a context where causality is diffuse, culturally set in, and multi-factorial (Bryman, 2016). For instance, the decline in Mahua collection does not get affected exclusively due to forest fire but also get affected by changing forest access, policies, shifting gender roles, and market fluctuations, and environmental constraints (irregular rainfall, temperature variability, and dry hot winds)- none of which can be cleanly isolated in a regression model.

Hence, our approach validates with qualitative description and perception-based thematic analysis frameworks commonly used in community forestry, indigenous studies, and environmental justice research (Chambers, 1994; Sikor & Lund, 2009). By prioritizing native voices, cultural significance, and indigenous knowledge, the methodology seeks to address contextual realities rather than superficial statistical generalizations.

5.2.3 Ethical Considerations and Validity

To keep research ethics in the forefront, all participants were informed about the goal of the study beforehand, and verbal agreement was obtained before to the interviews. Respondents engaged voluntarily, and their identities were kept anonymous or pseudo. Our findings, which are based on triangulation and combine different data types (survey, interviews, and GIS data), verify the legitimacy of our research. During the interviews, we also considered gender representation, local dialects, and power disparities. The below detailed methodological framework flowchart has been specified on Figure.5.1 for immediate understanding.

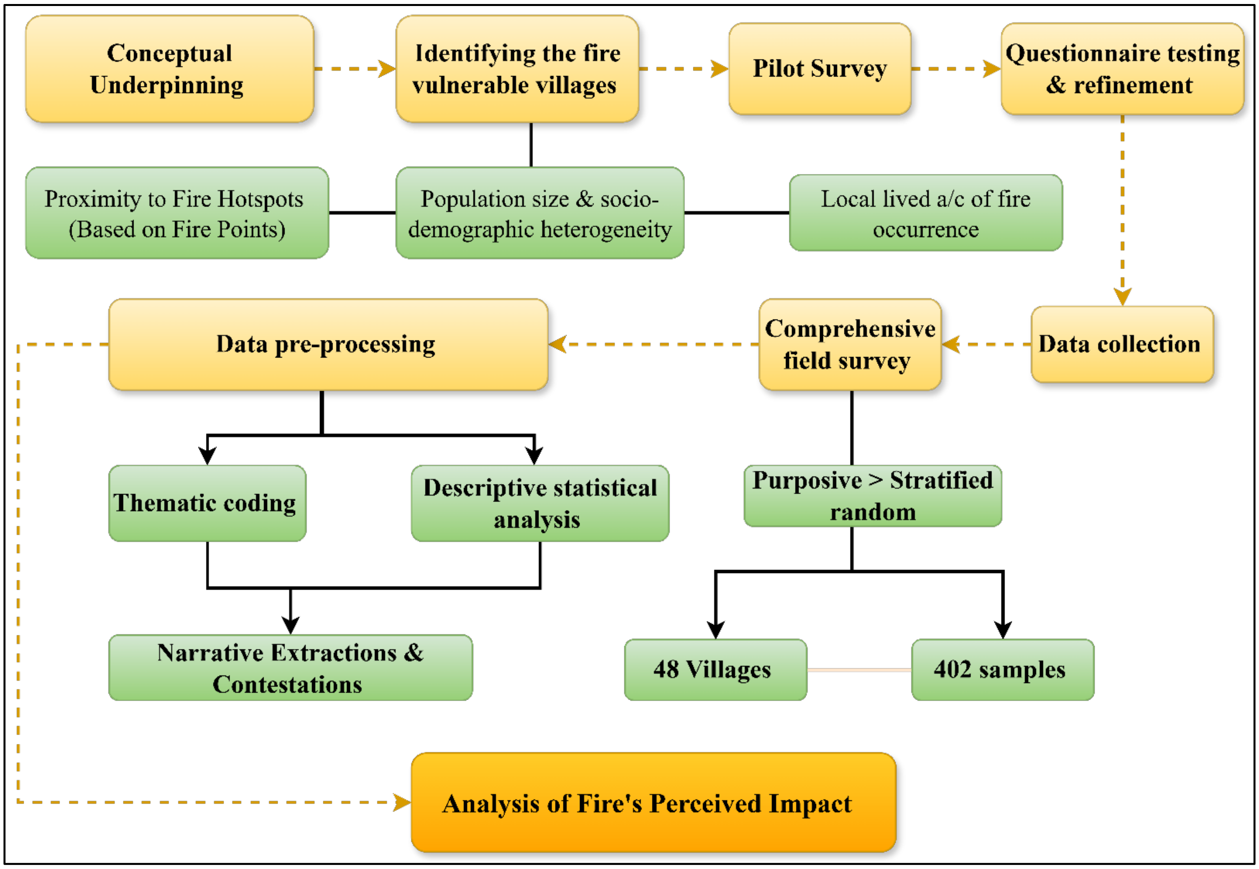


Fig. 5. 1 Comprehensive Methodology flowchart *(Source: Author)*.

Table 5. 1: List of surveyed villages and the number of household samples collected.

SR	Forest Range	Village Name	Sample Size	Range Total
1.	Bankhedi	Chhater	11	72
		Chhirpani	12	
		Deori	9	
		Fatehpur	13	
		Jhariya Jhora	12	
		Mahua Kheda	9	
		Nadipura	6	
2.	Itarsi	Amjhira	16	122
		Jaali Kheda	14	
		Jamai Kalan	14	
		Mahola	13	
		Nanupura	9	
		Pandari	17	
		Chicha Dhana	2	
		Goghra	2	

		Karkha Jamai	4	
		Lalpani	10	
		Manatekar (Pipariya Khurd)	2	
		Matapura	8	
		Parchha	4	
		Suplai	3	
		Tangana	4	
3.	Banapura	Batki	6	55
		Borkunda	9	
		Gangiya	3	
		Gotabari	11	
		Iklani	10	
		Jondhal	8	
		Sotachikli	8	
4.	Seoni Malwa	Dhaknipura	9	29
		Jhirnapura	8	
		Santai	12	
5.	Sukhtawa	Dhamai	9	43
		Mandikhoh	3	
		Morpani	11	
		Kalari pat bandi	11	
		Kasda Khurd	7	
		Kasda Ryt	2	
6.	Hoshangabad	Dobh jhirna	12	38
		Ghoghari kheda	9	
		Naya bori	12	
		Naya Jam	2	
		Naya Mallupura	3	
7.	Pipariya	Naya raikheda	5	31
		Raikheda	3	
		Sangai	15	
		Suakhapa	8	
8.	Shogpur	Char gaon	12	12
	Grand Total	***Villages: 48***	***402***	***402***

5.3 Results

5.3.1 Socio-Cultural, Demographic, and Economic Characteristics of the Respondents

Understanding the existing demography, cultural values and ethos, and economic order is critical for understanding how communities interpret the socio-economic repercussions of fires. These contextual knowledge influences - how people perceive and respond to environmental stressors, how knowledge is conveyed, decisions are formed, and vulnerabilities are reduced or increased. Based on a survey of 402 households, this section of the chapter reflects on descriptive and graphical account of the respondents' socio-cultural and economic descriptions to provide a thorough examination of fire perceptions and adaptive responses.

With 62.7% of respondents identifying as male and 37.3% as female, the sample was predominantly male (Fig 5.2a). This gender disparity, which results in a male-to-female ratio of roughly 1.7:1, could be explained by cultural conventions where men are more likely to contact with outsiders or serve as household heads. It is also consistent with the survey methodology, which emphasized replies from primary decision-makers. However, due to gender asymmetry, many results, particularly those relating to land usage, resource collection, or caregiving obligations, should be interpreted with caution, as these may be disproportionately experienced by women and hence underrepresented in the dataset.

The respondents' age distribution provides more evidence about how life stage affects resource dependency and risk perception. Early middle-aged individuals (30–39 years old) comprised the most significant portion of the sample (31.3%), followed by young adults (21–29 years old), who accounted for 18.4% of the respondents. 17.9% of older persons were 60 years of age or older, closely matched by 17.4% of those in the 50–59 age range. At 14.9%, the middle-aged group (40–49 years old) had the lowest representation. Refer to Fig. 5.2b. This age distribution shows a concentration of active, working-age people who are probably going to be primarily responsible for household management and livelihood activities.

From the social positioning stand, majority of respondents (80.3%) belonged to Scheduled Tribes (STs) of Gond and Korku tribes, whose cultural and economic lives are profoundly knotted with the forest ecosystem. Other categories include- Scheduled Castes (SCs) constituted 11.2%, Other

Backward Classes (OBCs) 7.5%, and only 1.0% were from General or other social categories (Fig 5.2c). This balanced representation of tribal groupings is consistent with the study area's focus, which is primarily made up of settlements that rely on forests. Although it also restricts the findings' applicability to non-tribal communities, the preponderance of ST respondents guarantees that the study stays rooted in indigenous experiences and perspectives. Nevertheless, the tribal-centric perspective is suitable in a situation where ecological knowledge, collective memory, and customary land usage are important factors in determining fire-related vulnerabilities.

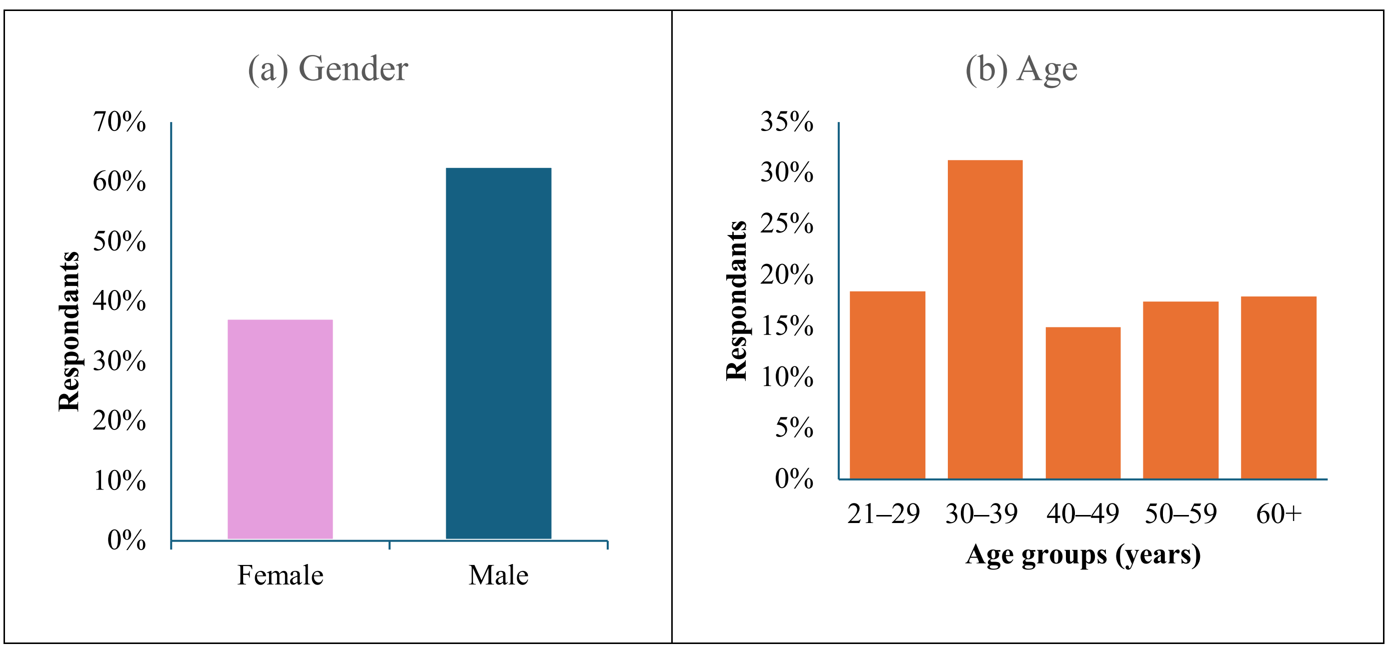
Further the religious diversification among the surveyed population reflects on interlinkage between cultural identity and environmental perception. Among them 20.6% of respondents belongs to indigenous Sarna faith, and 26.4% identified as a syncretic belief system combining indigenous and Hindu elements. Majority of them belongs to Hindu majority - 52.5% and Muslim representation was negligible at 0.5% (Fig 5.2d). In order to understand how people view fires as a larger component of spiritual cosmologies rather than only as physical phenomena, the presence of syncretic and indigenous belief systems provide us advantage. Responses to fire management tactics may be influenced by these worldviews, particularly when outside actions are thought to disrespect traditional values.

In terms of household dynamics, heads of families accounted for 60.2% of respondents, followed by spouses (28.6%) and children (10.9%) (Fig 5.2e). Prevalent social hierarchies and the methodological focus on interviewing the primary head of the household are reflected in this distribution. With 41.8% of homes having four to five members, family sizes were mostly medium. The big households (seven to nine individuals) made up 21.9%, whereas the moderately big households (six members) made up 20.6%. Just 8% of people lived in homes with one to three people (Fig. 5.2f). The pattern of nuclear and joint homes, which can affect the division of labor, group decision-making, and intra-household resilience in the face of fire disasters, is suggested by the preponderance of medium to large family structures.

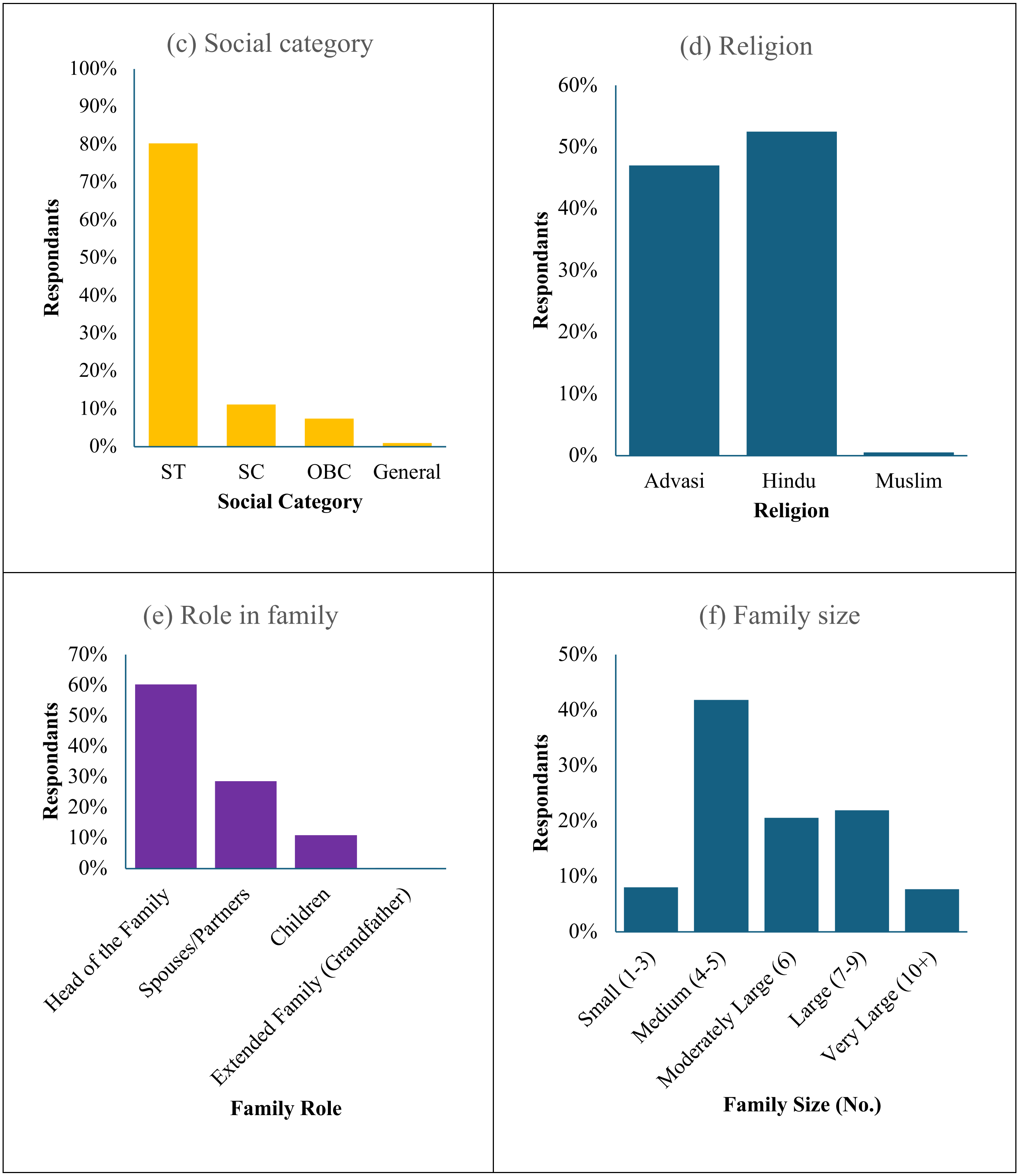
The survey revealed structural barriers in access to education and persistent inequalities in rural and tribal areas. 34.8% of respondents had only completed elementary school, and nearly half (49.5%) of all respondents said they had no formal education. Just 4% had completed any kind of higher education, while 11.7% had completed secondary school (Fig 5.2g). This educational profile points to a lack of formal communication channels and institutional expertise, which could make it difficult to participate in state-led adaptation initiatives, get early warnings, or manage post-disaster recovery procedures. Understanding fire as an ecological phenomenon and a policy concern is also impacted by low literacy, which highlights the necessity of accessible and context-sensitive information distribution techniques.

Lastly, respondents' reported dwelling types serve as a stand-in for both structural vulnerability and economic position. Thatched or kucha houses were the most prevalent (41.5%), followed by semi-pucca constructions (32.1%) and pucca, or permanent, houses (26.4%) (Fig 5.2h). Thatched or kucha [21] houses are frequently constructed using mud, bamboo, or local resources. Both low household incomes and increased vulnerability to fire-related damages are indicated by the prevalence of non-pucca housing. When combined with restricted access to insurance or fire control facilities it has been noticed that inadequate home construction raises the danger of property loss and injury in places where forest fires are frequent.

Altogether, these sociocultural, demographic, and economic traits collectively simplify the complicated web of variables that influence how communities perceive, experience, and react to fires (see Fig. 5.2). They offer the essential background for understanding perceptions as deeply associated with systems of inequality, cultural memory, and ecological dependency rather than as isolated phenomena.



[21] Kucha house means a house made up from wood and muds only.


(c) Social category
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Respondants
ST
SC
OBC
General
Social Category
(d) Religion
60%
50%
40%
30%
20%
10%
0%
Respondants
Advasi
Hindu
Muslim
Religion
(e) Role in family
70%
60%
50%
40%
30%
20%
10%
0%
Respondants
Head of the Family
Spouses/Partners
Children
Extended Family (Grandfather)
Family Role
(f) Family size
50%
40%
30%
20%
10%
0%
Respondants
Small (1-3)
Medium (4-5)
Moderately Large (6)
Large (7-9)
Very Large (10+)
Family Size (No.)

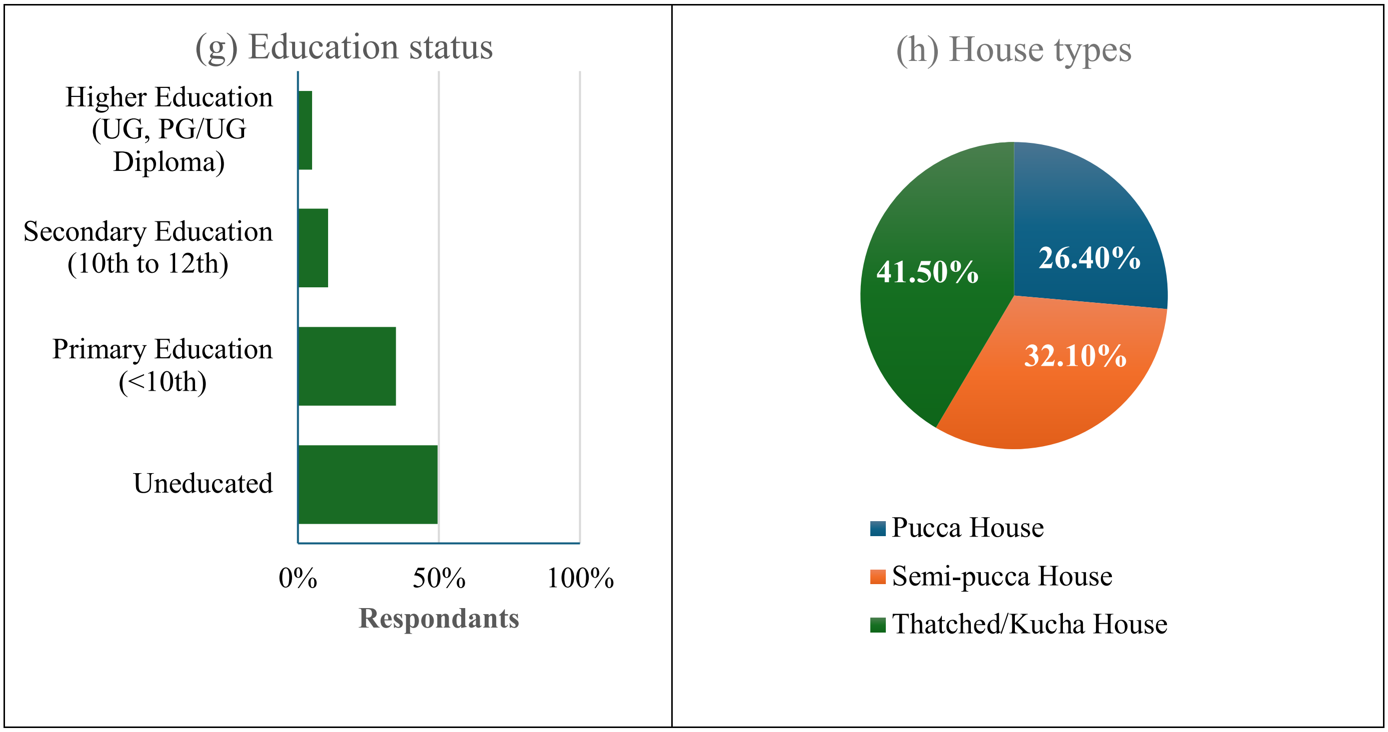


Fig. 5. 2(a-h) Socio-cultural, demographic, and economic characteristics of the respondents

5.3.1.1 Occupational characteristics of the respondents

It came to our knowledge that nearly all the respondents were engaged in more than one type of occupation for their livelihood generation and survival. The occupation includes both informal sector and NTFP or forest resource-based activities. Although agriculture/farming was the major occupation (51.5%), but its reliance declined steeply across secondary and tertiary occupations. Unskilled labor featured prominently across the first two occupation tiers, underlining economic vulnerability. With a rise to 43% in the third occupational tier, NTFPs in particular emerged as an essential means of secondary and tertiary income, demonstrating diversification strategies based on forest-based livelihoods. (See Table 5.2).

Table 5. 2 Combined occupational distribution across four tiers.

Occupation Category	1st Occupation	2nd Occupation	3rd Occupation	4th Occupation	Total HH
Farmer	207 (51.49%)	71 (17.66%)	15 (3.73%)	3 (0.75%)	296
Housewife	20 (4.98%)	9 (2.24%)	59 (14.68%)	61 (15.17%)	149
Labor	146 (36.32%)	138 (34.33%)	31 (7.71%)	4 (1.00%)	319

NTFP	6 (1.49%)	166 (41.29%)	173 (43.03%)	2 (0.50%)	347
Poultry	1 (0.25%)	4 (1.00%)	10 (2.49%)	9 (2.24%)	24
Service/Salaried *(Asha, Anganwadi, Forest Officer)*	17 (4.23%)	7 (1.74%)	5 (1.24%)	0	29
Student	5 (1.24%)	2 (0.50%)	0	1 (0.25%)	8
NA	0	5 (1.24%)	109 (27.11%)	322 (80.10%)	–
Total	***402 (100%)***	***402 (100%)***	***402 (100%)***	***402 (100%)***	**–**

This occupational multiplicity highlights both vulnerability and adaptability. During discussing about the multiple occupation with a respondent at Itarsi forest range, they collectively informed that – *"एके काम के भरोसे रहब तो दू बखत के रोटी भी नइ मिलै। खेती तो बहुतै अनिश्चित है, पूरा मानसून पे टिकी रहै। इसलिये जब खेती को टेम नइ होत, त हम शहर म जा के मजूरी कर लेत हैं, या फैक्ट्री म काम करत हैं। और महिना भर जंगल से लकड़ी-पत्ती अउर वनोंपज बटोर लेत हैं। यही सब जोड़-जाड़ के हम अपन घर-परिवार चलावत हैं अउर पेट भर खा पावत हैं।"* (English Translation: If I only do one job, I won't be able to eat two meals a day. The monsoon has a significant impact on agriculture, which is highly unpredictable. I therefore work as a laborer in the city or in industries during the agricultural off-season, and I also spend around a month gathering forest goods. This combination enables us to provide for our family and maintain our way of life).

The growing role of NTFPs may influence perceptions of fire impacts, especially where these resources are directly threatened.

5.3.1.2 Agricultural landownership

Socio-economic disparity is revealed by land distribution. A further 27% of households held marginal landholdings (one to two acres), while over 31% of households were landless. Another 31.1% were smallholders (3–5 acres). Table 5.3 shows that only 3% had more than 10 acres. The majority of households' fragile financial situation and their likely reliance on forests and other seasonal employment opportunities in the surrounding cities and industrial firms for supplemental livelihood needs are apparent in this concentration of landlessness and marginal farming. When examining risk exposure and coping mechanisms, such land-related vulnerabilities are essential, especially in communities that are close to forests that are prone to fire.

Table 5. 3 Categorized summary of the respondents' landholding information.

Land ownership category	Range (Acres)	No. of Respondents	% of Total
Landless	0	126	31.3%
Marginal	1–2	108 (40+68)	26.9%
Small	3–5	125 (59+15+51)	31.1%
Medium	6–10	31 (6+8+4+13)	7.7%
Large	>10	12 (3+1+5+1+1+1)	3.0%
Total		***402***	***100%***

5.3.1.3 Economic (livelihood) infrastructure and market access

Infrastructure accessibility and market services plays a strategic role in shaping socio-economic settings and livelihoods (Aziz, 2015). There are considerable disparities in the study area- access to basic agricultural infrastructure, transport connectivity, market proximity, storage facilities, and fair-trade opportunities, all of which adds to livelihood vulnerabilities.

A majority of respondents (79%) reported access to water in their agricultural fields, indicating a partial buffer against climate or fire-induced livelihood shocks. However, this agricultural advantage is not mirrored in transport accessibility. About 59% of respondents stated they lack easy access to transport facilities, which severely hinders mobility and limits access to markets and services. As market distance is another critical barrier: nearly 79% of respondents reside more than 5 km from the nearest local market. Communities that depend on selling seasonal or perishable NTFPs are further marginalized by this geographic remoteness. Furthermore, 94% of respondents stated that they lacked government-sponsored or private NTFP storage facilities, which compelled them to make quick sales—often under abusive circumstances. Trade connections aggravate this fundamental disadvantage. As a result, 49% of NTFP collectors sell only to private middlemen (Baniya), while another 40% deal with both intermediaries and government agents. The small institutional presence in the purchase of forest products is reflected in the fact that just 1% sell exclusively to agents authorized by the government. Furthermore, only 6% of respondents said they sold their NTFPs at the government-set Minimum Support Price (MSP), implying the inadequate effectiveness of current support systems in guaranteeing just remuneration (Table 5.4).

Table 5. 4: Infrastructure and Market Access Among Respondents

Indicator	Category	No. of HH	Percentage
Water availability in agricultural fields	Yes	229	78.7%
	No	62	21.3%
Access to transport facilities	Yes	160	41.2%
	No	228	58.8%
Distance to local market	< 2 km	3	1.0%
	2–3 km	1	0.3%
	3–5 km	58	19.2%
	5–10 km	180	**59.6%**
	> 10 km	59	**19.5%**
Availability of NTFP storage facility	Yes	21	6.1%
	No	326	93.9%
NTFP buyers (excluding tendu leaves)	Middlemen only	169	48.7%
	Van Upaj Samiti only	4	1.2%
	Both (Middlemen + Govt)	139	40.0%
Selling NTFPs at Govt. MSP	Yes	21	6.1%
	No	315	93.9%

Note: *Percentages are calculated based on total responses for each category. Blanks and missing responses are excluded.*

5.3.1.4 Annual income profile of the respondents

We analyze the income level data of 373 households out of 402, to assess the economic vulnerability of forest-dependent communities. Rest 29 households' income information was either incomplete or unavailable; therefore, we excluded them from this analysis. Income profiles provide us with interesting dynamics of material conditions that shape households' exposure, sensitivity, and adaptive capacity.

Over half of the sample's families fell within the low-income range, with 28.15% earning between ₹50,000 and ₹99,999 per year and 24.66% earning between ₹1,00,000 and ₹1,49,999 per year. Furthermore, 5.09% of respondents said their income was less than ₹50,000. Overall, 57.9% of respondents make less than ₹1.5 lakh annually, which is indicative of ongoing poverty and precarious living circumstances. Their reliance on informal, seasonal, and climate-sensitive jobs including rainfed agriculture, daily wage labor, and forest product gathering is strongly linked to their economic precariousness. The availability of forest resources is disrupted, agricultural activities are delayed, and household expenses for food, fuel, fodder, and healthcare are raised by forest fires, hot summer winds (temperature variability), and irregular rainfall all have a direct impact on these sources of income.

About 18.77% of households reported annual incomes between ₹1.5 lakh and ₹1.99 lakh, still within a range considered economically fragile, particularly for larger families. Households in this range often supplement subsistence farming with temporary migration, labor in nearby towns, or engagement in forest-based economies. Middle-income groups (₹2,00,000 to ₹4,99,999) constituted a smaller segment (approximately 12.87% of the sample) while only 8.31% reported annual incomes between ₹5,00,000 and ₹9,99,999. A mere 2.14% earned above ₹10 lakh annually (Fig.5.3). These higher-income households are relatively less dependent on forest-based livelihoods and may have access to salaried employment, small businesses, or urban migration channels. Their economic buffers allow for faster recovery from environmental risks related losses and greater access to adaptation mechanisms such as large agriculture land holding, mechanized irrigation, or crop insurance, and continuation salary received by the government and non-government organizations.

The uneven income distribution points to a high degree of livelihood vulnerability within most of the population surveyed. Households with low and unstable incomes face compounding challenges—limited education, inadequate infrastructure, and high dependence on forest resources.

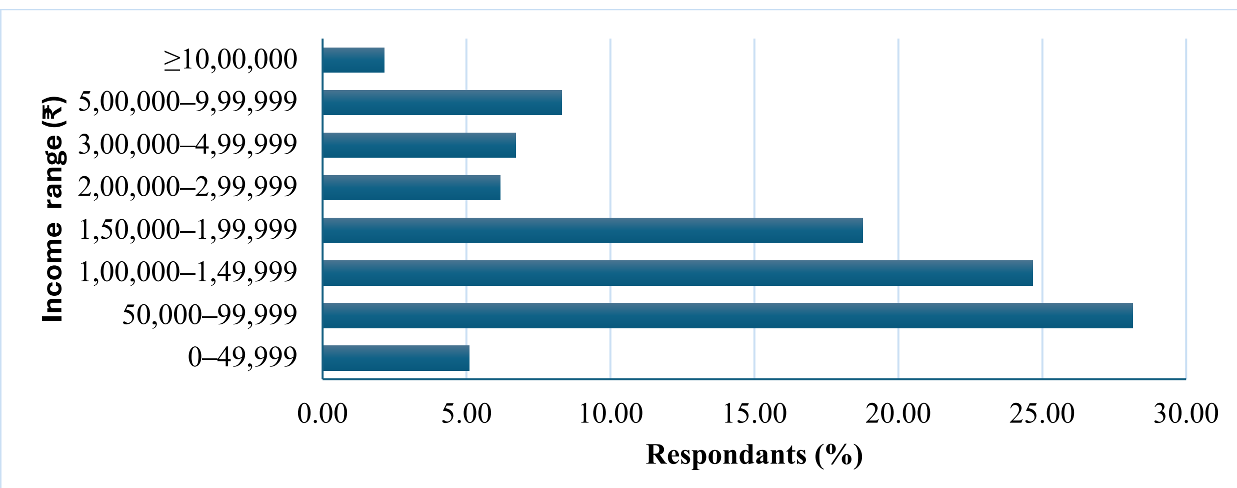


Fig. 5. 3 Annual income of the respondents from all sources

5.3.2 Causes of Forest Fire: Community Perceptions and Local Observations

Our study, which included survey data and descriptives accounts, indicated anthropogenic activity as a key source of fires in the Hoshangabad region. More over 80% of respondents, 323 out of 402, identified human activity as the primary cause of forest fires, with only 9 citing natural factors such as lightning or severe heat. A small segment (70 respondents) either left the response blank or expressed uncertainty, underlining the limited visibility of natural causes in everyday discourse.

The range of specific causes under human activities category mentioned by respondents reflects a mix of intentional and accidental fire sources, often tied to livelihood activities. The most frequently cited reason was the burning of surface vegetation to facilitate the collection of NTFPs, especially mahua and sometimes for better tendu leaves. This was followed closely by lit cigarettes or bidi[22] stubs thrown carelessly inside the forest. Multiple response combinations indicate that these two causes often co-occur with debris burning, shifting cultivation, or other agricultural clearing practices.

Quantitatively, out of the detailed responses:

- **266 respondents** (66.2%) cited a combination of NTFP collection fires and cigarette/bidi stubs (Fig. 5.4).
- A smaller group (13 respondents) mentioned both cigarette stubs and NTFP fires without including other factors.
- Only a handful (fewer than 15) mentioned more complex combinations involving prescribed burning, power line malfunctions, tourism, or unattended campfires.

[22] A local form of cigarette made from the tendu leaves. The tobacco being wrapped into dry Tendu leave and give the cylindrical shape just like cigarette but thin in width and size.

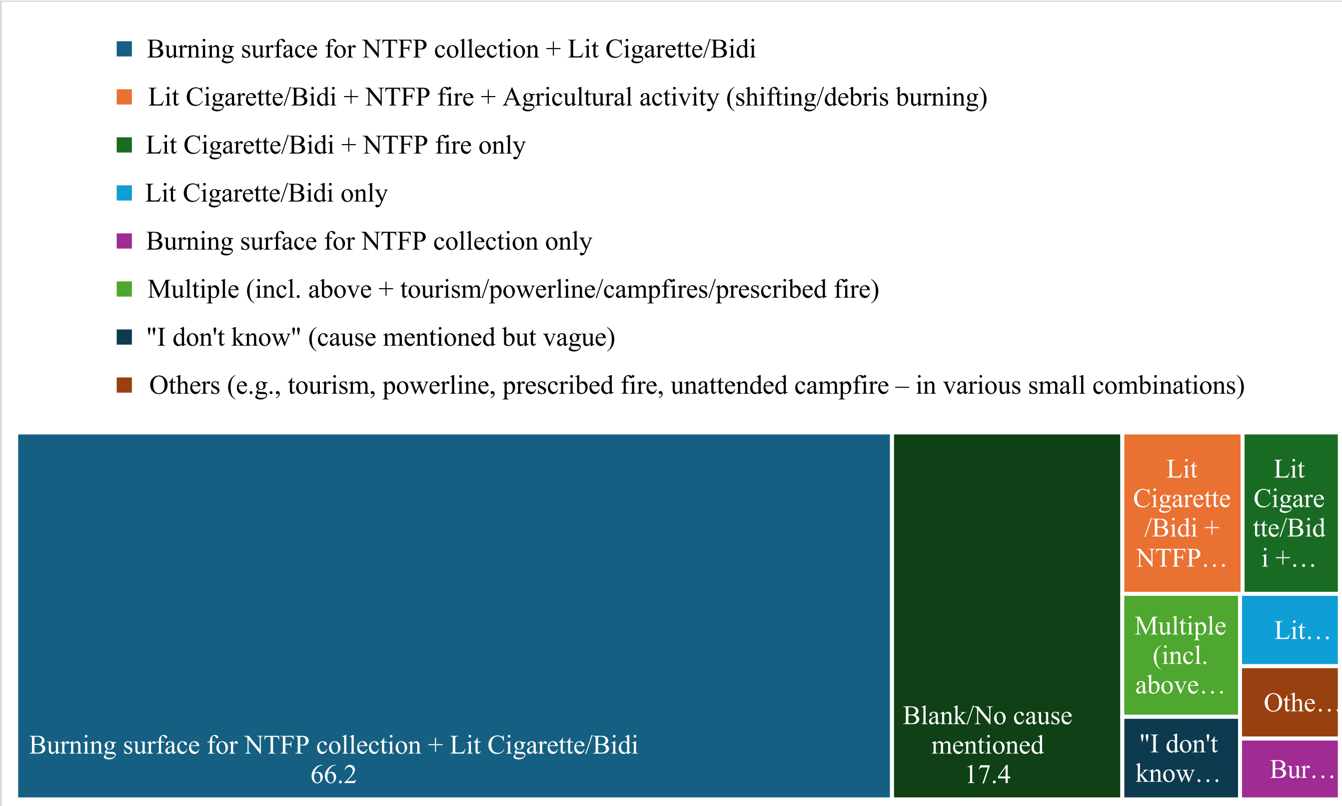


Fig. 5. 4 Manmade causes of forest fire in (%)

Though rarely mentioned, a few respondents identified institutional or infrastructural negligence such as faulty power lines or unregulated tourism as contributing factors, suggesting a broader awareness of systemic risks among some community members.

5.3.2.1 Social and Spatial Patterns in Perception

As perceptions across the Scheduled Tribes and other caste groups were broadly aligned in attributing fire to human activities, qualitative interviews suggest some variation in framing responsibility:

- Tribal respondents (Gond and Korku) who rely on forest-based livelihoods often view fire as an unavoidable by-product of subsistence activities, such as clearing ground vegetation for speedier mahua or tendu harvesting. One tribal elder in Kesla[23] noted, *"Mahua jaldi chahiye toh jharna padta hai, kabhi kabhi aag zyada phail jaati hai."* (If we want mahua early, we must clear the undergrowth, sometimes the fire spreads too much.)

[23] It is ***Block*** division (a small administrative unit in a district) in Hoshangabad district.

- In contrast, some non-tribal respondents and local elites highlighted forest inhabitants' ignorance or recklessness, citing smoking and uncontrolled fires as examples of irresponsibility.

There were also noticeable variations at the village level. Remote settlements closer to core forest regions stressed livelihood-based reasons like NTFP or grazing demands, however, villages near tourism zones or with stronger forest preservation enforcement tended to mention fewer explanations or emphasize external concerns (e.g., tourists or plantation contractors[24]).

In total, the community perspectives emphasize that fire is profoundly entangled with socio-economic routines, resource extraction practices, and governance shortcomings. Even though only a small percentage of "natural causes" were identified, this may be more indicative of the daily presence of human agency in fire ignition than the lack of natural hazards. Additionally, different societies have slightly different moral interpretations of fire, such as necessity, accident, or negligence, which points to the vitality of culturally sensitive fire management measures.

5.3.3 Communities' Perceived Economic Impacts of Fires

5.3.3.1 Agricultural and Livestock Resources

Forest fires can have consequences on rural livelihoods, particularly for agrarian and pastoral communities that depend on land, crops, grazing resources, and livestock. This part presents the perception of households surveyed regarding the impacts of fires on their agricultural and livestock-related assets.

a) Perceived impacts on fire agriculture

Agriculture is one of the primary livelihood sources in the study area. However, when asked whether forest fires had any direct impact on agricultural activities, a striking majority—295 respondents (73.4%)[25], reported that fires do not affect agriculture. Only 1 respondent perceived an agricultural impact, while 107 respondents (26.6%) identified themselves as non-farmers, indicating no direct engagement in agricultural activities.

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[24] The plantation contractors sometimes took the plantation contract and not planted the given number of plants, in that case to escape from the evaluation they arrange setting fire so they can easily claim that we had planted all the trees but due to fire they got vanish or destroyed.

[25] Percentages are calculated based on valid responses for each question (N = 402 unless otherwise indicated).

The overwhelmingly negative response regarding fire impacts on agriculture is due to several reasons as revealed during fieldwork and in-depth discussions with local farmers in the study region. These underlying causes include:

a) Geographic separation of agricultural fields: The majority of agricultural plots are situated at a considerable distance from forest fire-prone zones, thus reducing direct exposure to fire events.

b) Containment of fires within forest boundaries: According to local observations, fires are often limited to woodland regions and rarely cross forest boundaries, which stops them from spreading to nearby agricultural lands.

c) Community-based fire prevention strategies: Indigenous fire mitigation techniques that serve as barriers between cultivated land and woodlands have been developed by many farmers. The regulated or 'prescribed' burning of fire-prone biomass between forest boundaries and agricultural fields before or during the fire season is one commonly used technique. The risk of fires spreading to farmlands is greatly decreased by this preventive measure. In addition to being successful, these methods have strong roots in regional ecological expertise and cultural customs. (See Fig 5.5).

During a field interview, Ramesh[26] a local farmer, shared that this method of prescribed burning has been practiced for generations in his community. He stresses its efficiency in protecting agricultural land from uncontrolled wildfires. He did, however, also voice concern that this long-standing custom has been upset by new legal limits put in place by forest officials, endangering both ecological safety and cultural continuity.

As agriculture is generally considered vulnerable to environmental stressors, in this region, it appears relatively insulated from the effects of forest fires. This resilience can be attributed to a combination of geographical distance, localized fire behavior, and the persistence of traditional ecological knowledge.

[26] It is a pseudo name used here to hide the identity of the respondent. Even all the names who refers to the respondents are pseudo or dummy in nature.

Fig. 5. 5 A local farmer conducts a traditional prescribed burn between a transitional forest boundary and agricultural field in Kaveli village, Hoshangabad District, Madhya Pradesh. ***Source:*** *Author, April, 2024)*

b) Change in grazing distance after fire

Respondents were asked if the distance they went to graze livestock increased after a fire, even within the forest fire season, to assess the spatial effects of forest fires on pastoral livelihoods. According to the responses, 131 people (32.6%) thought that grazing distance had increased following fire events. Even though Fig. 5.6a only shows a portion of the sample, it shows that over one-third of families that relied on livestock saw a change in the location of fodder resources. This change may be attributed to the temporary degradation or inaccessibility of nearby grazing areas, the destruction of traditional pathways used for livestock movement, or a precautionary reallocation of grazing activities to more distant zones deemed safer or richer in vegetation. Such changes can result in comparatively high labor demands, especially for women and children who are often responsible for daily herding. Due to higher physical strain and shorter feeding intervals, longer journey times may potentially have a detrimental impact on livestock productivity and health. In order to ensure the resilience of pastoral livelihoods and develop effective fire adaption methods, it is imperative to comprehend and address this geographical shift.

Impacts of fire on grassland and fodder availability

In light of the dependence on forest-adjacent grasslands for livestock fodder, respondents were also asked to evaluate changes in grassland availability after fire events using a five-point Likert scale. 87 individuals (21.6%) out of 402 respondents, were excluded from further analysis since they were not collecting grass. Majority, 172 respondents (54.6%) out of 315 valid stated that grasslands were not much affected by fire, while 50 (15.9%) reported a slight reduction, 56 (17.8%) observed a moderate reduction, 36 (11.4%) perceived a significant reduction, and 1 respondent (0.3%) described the decline as extreme. As the majority of grass-collecting households did not observe any noticeable drop in grassland availability, a substantial minority (45.4%) did report varying degrees of decline (Fig.5.6). These disparate experiences probably reflect regional variations in household reliance on natural fodder resources, forest composition, and fire severity. Furthermore, a move away from conventional livestock operations may be indicated by the fact that over one-fifth of respondents do not gather grass. Access to market-based fodder, a greater reliance on stall-feeding systems, or a general decline in livestock ownership could all be contributing factors. Nearly one-fifth of the sample as a whole does not gather grass, which implies either:

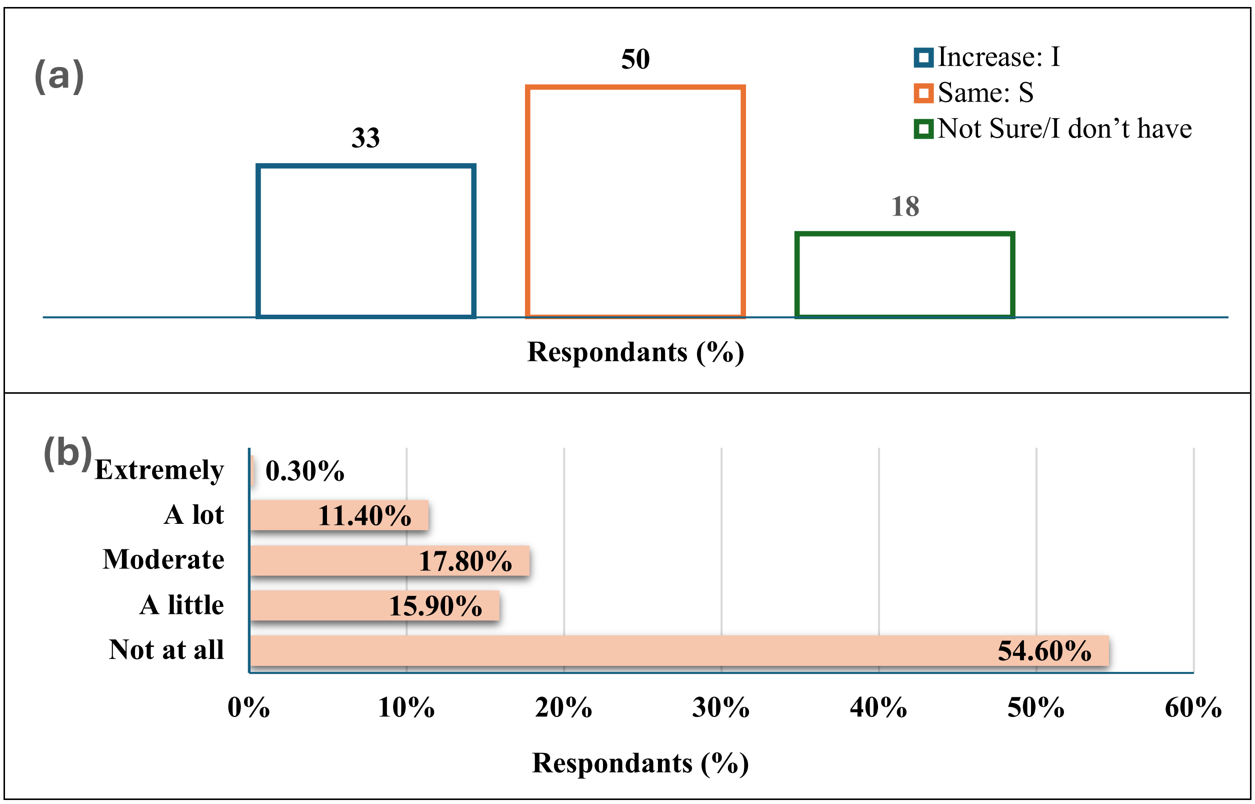
- A shift away from traditional livestock-based livelihoods.
- Limited dependency on natural grasslands (possibly due to stall-feeding or market-based fodder).

Overall, perceptions of grassland loss appear to be shaped by both ecological and socio-economic variables. These findings are important for understanding community-level experiences of ecological change and for designing responsive grazing and fodder management strategies in post-fire contexts.

c) Perceived impacts on livestock

In HFD livestock holds a major role as a supplementary livelihood source for many rural households. When asked whether their livestock had been affected by forest fires, 281 respondents

(69.9%) reported no impact, 52 respondents (12.9%) stated that their livestock had been affected, and 69 respondents (17.2%) either expressed uncertainty or disclosed non-ownership of livestock (Fig. 5.6). Only a small percentage of responders believe that livestock is more susceptible to the effects of fire than agriculture. The few consequences that have been documented could be the result of disturbances to typical grazing patterns after fire events or isolated decreases in the availability of fodder. The relatively high proportion of respondents expressing uncertainty suggests that a substantial number of households may not be actively engaged in livestock rearing or are not directly involved in animal care, limiting their awareness of potential fire impacts. The limited disruptions caused by forest fires, especially in open grazing systems, point out the need to include pastoral concerns in more comprehensive fire management and adaptation planning, even if forest fires are not generally considered a serious threat to cattle throughout the study region.



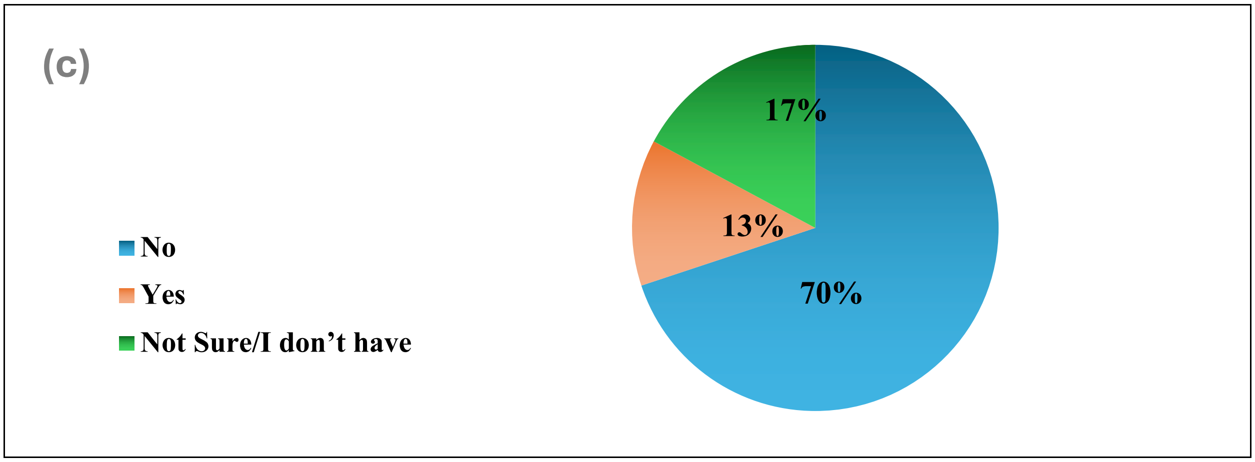


Fig. 5. 6 Household perceptions of forest fire impacts: a) post-fire change in grazing distance for animals—Increase (I), Decrease (D), Same (S), b) grassland decline after forest fires measured on a Likert scale, and c) perceived impact of forest fires on livestock—Yes, No, Not sure/Don't know.

Largely, the community perceptions conclude that direct fire impacts on agriculture are negligible, but livestock and grazing systems are moderately affected, particularly in terms of fodder scarcity and increased travel distances. These perceptions draw attention to the spatial and indirect aspects of livelihood disruptions caused by fires. Designing fire management and adaptation strategies that take into account the lived reality of populations who depend on forests requires an understanding of these subtleties.

5.3.3.2 Fire and seasonal employment

In addition to lasting occupations such as farming and livestock rearing, many households in forest-adjacent communities engage in seasonal or migratory employment i.e., typically short-term, low-wage work undertaken during agricultural off-seasons or periods of economic need. Given the interdependence between ecological stability and local job cycles, respondents were asked whether seasonal employment opportunities are affected by forest fires. The data reveals that all respondents indicated no perceived impact of forest fire on seasonal jobs. This uniform response suggests that:

- Seasonal employment is largely decoupled from forest-based ecosystems. Many such jobs located outside the village (e.g., brick kilns, construction work, or urban migration), and hence, are not directly disrupted by fire events.

- Fire occurrences are localized or seasonal and thus do not coincide with the periods during which seasonal jobs are sought.
- Households may not associate indirect effects (e.g., delayed NTFP income or forest access) with the broader structure of their seasonal employment.

The perception that forest fires do not influence seasonal job opportunities reinforces the idea that such employment serves as an external fallback strategy for economic security. This may also reflect the increasing diversification and detachment from ecological dependence for part of the rural workforce, especially among younger or landless members.

It is important, however, to view this result in conjunction with other livelihood domains such as NTFP collection and grazing which show a more tangible link to fire exposure. The apparent immunity of seasonal work to fire events may also underline the emergent resilience strategies adopted by vulnerable populations in the face of environmental uncertainty.

5.3.3.3 Fire and fuelwood availability

For rural and tribal communities depending extensively on forests for survival, fuelwood for them holds essential value, particularly in areas where alternate energy sources are still inaccessible or too expensive (Kumar et al., 2020). Fuelwood is not only essential for domestic cooking and heating in Hoshangabad, but it also provides a modest source of income, especially for women and landless, impoverished households. Environmental disturbances such as irregular rainfall, extreme temperatures, hot winds (Loo) [27], and forest fires can significantly disrupt access to this resource, with direct implications for household energy security and daily routines.

Among 402 households, 70 households (17.4%) reported that they do not collect fuelwood, either due to occupational shifts, increased access to alternative energy (e.g., LPG), or changing gender roles and livelihood patterns. These replies were eliminated from the Likert-scale analysis so that the focus may be on those who were still gathering fuelwood. Of the 332 valid responses, 39.3% said forest fires had a 'high' to 'severe' impact on their ability to harvest fuelwood. Specifically,

[27] The *"Loo"* is a hot, dry, and dust-laden westerly wind that predominates over the Indo-Gangetic Plain during the peak summer months of May and June (Banerjee et al 2021). Characterized by extremely high temperatures, the Loo poses serious health risks such as heatstroke and exerts a desiccating effect on vegetation. In Central India, its impact is particularly detrimental to tree cover and Non-Timber Forest Products (NTFPs), contributing to foliage browning, reduced biomass, and ecosystem stress.

30.4% chose "extremely," indicating that fires substantially impede access to forest resources for a sizable fraction of families. An additional 10.8% claimed that fires had a 'significant' impact on their access. The consequences are especially severe for individuals who lack access to alternative energy sources or varied livelihoods. In contrast, 48.5% of respondents saw little to no impact on their fuelwood collection activities after the fire. Of these, 38.2% stated that fires had "no impact at all," while others reported "a little" (14.2%) or "moderate" (6.3%) disturbance (Table 5.5). These differing perceptions are likely due to a variety of contextual factors, such as proximity to forest fire zones, degree of forest degradation, availability of coping strategies (e.g., changing collection routes, stockpiling fuelwood, or substituting with agricultural residue), and local institutional or conservation-related restrictions on forest access.

Table 5. 5 Household perceptions of forest fire impacts on fuelwood availability (measured on a Likert scale)

Perception Level	**No. of Respondents**	**Percentage (%)**
Not at all	127	38.25%
A little	47	14.16%
Moderate	21	6.33%
A lot	36	10.84%
Extremely	101	30.42%
Total	***332***	***100%***

The observed variation in family responses illustrates the variability of fire effects and the flexibility of forest-dependent populations. In many cases, communities have devised informal coping mechanisms to lessen the immediate effects of forest fires. However, for others, particularly in more rural and economically challenged places, fire-induced interruptions can aggravate already insecure lives.

This variation is vividly depicted through field interviews, such as one conducted in Jhiriya Jhora village, situated within the Bankhedi forest range in HFD. Comprising nearly 90 families, this remote village lies adjacent to dense forest cover and lacks robust infrastructure, with unpaved roads becoming inaccessible during the monsoon season. The local economy is shaped by seasonal agriculture, wage labor, and most remarkably, the daily collection and sale of fuelwood bundles in the Bankhedi market, located approximately 10 kilometers away. According to local description, nearly 90% of households (predominantly women), are engaged in the fuelwood economy. They walk on foot, carrying bundles of fuelwood on their heads to the market, and on their return journey, collect fresh bundles from the forest. After reaching home in the evening, they prepare dinner, only to repeat this routine—some once a week, others two to three times, and many as often as five to six days a week.

Raj Kumari, a 32-year-old Gond woman from the village (Fig. 5.7), offered a poignant glimpse into the daily rhythm of life and the impact of fires on her livelihood: *"I sell fuelwood bundles in the Bankhedi market. We leave early in the morning around 5-6 am, walk 10 kilometers, sell the bundle for ₹100–₹120, and collect another bundle while returning home in the evening. We do these five or six days a week. My husband does labor work, but it's seasonal. During the fire season, we are forced to walk deeper into the forest, which increases the time and effort, and our income falls by nearly half."*

Her statement encapsulates the intersection of environmental stress and gendered labor burdens. Although the forests surrounding Jhiriya Jhora is vast, fires often destroy accessible underbrush, compelling residents to travel farther to find fuelwood. This not only increases collection time but also reduces the quantity of wood transported to the market, leading to a reported income decline of 40–50% during peak fire months (February to May). Contrastingly, the respondents also added that fire is not occurring every year in their nearby forests. Besides, the seasonal overlap between fire events and lean agricultural periods intensifies livelihood vulnerabilities for such communities.

Utilizing both the quantitative and qualitative evidence from this study reflects a deeply uneven geography of fire impacts on fuelwood availability across the HFD. However, some communities appear resilient, whether due to geographic advantage, adaptive strategies, or reduced dependence on fuelwood, others remain highly exposed to ecological disruptions. This stresses the significance of designing context-sensitive along with culturally grounded forest fire mitigation and recovery policies. Due consideration should prioritize ecological restoration, improve access to alternative energy sources (specifically for women-headed and economically marginalized households), and should ensure equitable forest access within the broader framework of conservation and livelihood rights.

Fig. 5. 7 Raj Kumari with Collected Fuelwood in Jhiriya Jhora Village-She bears a smile on her face and stands beside a carefully stacked bundle of fuelwood tied against a tree near her home. Clad in a traditional blue saree with a head covering, she holds a smaller bundle in her hands, collected either for immediate domestic use or for sale at the local market. Behind her, more fuelwood is visible, along with cattle and household implements, reflecting the agrarian and forest-dependent lifestyle of the community. This picture symbolizes *the everyday perseverance and*

physical labor needed to maintain home energy security, especially for women who are mostly in charge of gathering fuelwood and cooking (***Source:*** *Author, December 2024).*

5.3.3.4 Forest fires impact on NTFPs

NTFPs are an important component of forest-based livelihoods in central India, meeting both subsistence and market demands. Forest-adjacent villages, particularly those of tribal origin, regularly harvest products such as Mahua (flowers and seeds), Tendu leaves, Achar, Amla, mushrooms, and honey. Out of 402 surveyed families, 347 (about 86%) reported collecting at least one NTFP, indicating a significant level of reliance. The majority of these NTFP-collecting households belonged to tribal groups, with Gonds (50%) and Korkus (31%) forming the dominant collecting communities, followed by Scheduled Castes (11%), Other Backward Classes (7%), and a small proportion from the General category (1%) (see Table 5.6). This social composition demonstrates the prominence of NTFPs in sustaining indigenous economies and highlights their vulnerability to ecological disruptions such as forest fires.

Assessment of NTFP collector composition across surveyed households reveals that collection is largely a household-level activity, with 45% of households reporting joint collection by both men and women, and 30% involving all members—men, women, and children. **Women are more involved than males in individual collection** (17% vs. 7%), emphasizing the importance of gender-sensitive policies that promote and recognize women's contributions (Table 5.6). Children were rarely participated alone, usually assisting older members**.** These findings are also aligned with the previous studies (Gangmei & Sophia, 2024; Jalonen et al., 2023). These data underline the gender-inclusive and family-centered nature of NTFP collection, reinforcing the need for community-based forest governance strategies in the context of fire-affected forest landscapes.

Table 5. 6: Composition of NTFP collectors by household type and social category

Category	Sub-category	No. of HH	Percentage (%)
Household type (collectors)	All (Male, Female, Children)	105	30.3
	Male and Female	156	45.0
	Female only	58	16.7
	Male only	23	6.6
	Female and Children	4	1.2
	Male and Children	1	0.3
	Total	***347***	***100***

Social Category	Gond (ST)	170	49.0
	Korku (ST)	115	33.0
	Scheduled Caste (SC)	34	10.0
	Other Backward Class (OBC)	26	7.0
	General (GN)	2	1.0
	Total	***347***	***100***

Fires in the region are reportedly increasing but remain statistically non-significant over time (Khan et al., 2024). However, communities frequently consider significant or accidental fire as harmful to NTFP collection and forest ecology, but they did not recognize fire as a protagonist actor who affects NTFPs as much as climate variability. (See table 5.8). To explore these perceptions, households were asked to report perceived changes (if fire occurs in their areas of NTFP collections) in six key dimensions—**availability, collection distance, collection time, quantity, quality, and market dynamics** (demand and price) for the major NTFPs. The response options were categorized into "Increased," "Decreased," "Same," and "IDK (NC/NA)[28]", providing a multi-dimensional lens into how fires impact both the ecological and economic aspects of NTFP harvesting.

Among all products, Mahua flowers emerged as the most critically affected. Approximately 67.2% of respondents (including all class) reported a decline in availability, and over half indicated increased difficulty in collection, with 57.7% and 62.4% reporting increases in collection distance and time, respectively. And 73.8% of respondents felt that demand remained unchanged, 12.2% noted a decrease in price (Table 5.7). Many interviewees explained that Mahua traders rarely raise prices, even when availability drops due to climate (irregular rainfall, temperature variability) or forest fires, but they often lower prices when the quality of the produce is compromised (Khan 2023). This points to a hidden economic pressure: forest fires are increasing labor input while failing to translate into better returns. As one respondent from Amjhira village in the Itarsi forest range put it,

"Sometimes after the fire, Mahua is harder to find, and the flowers are often half-burnt. Still, the trader pays the same or even less."

[28] Respondents who reported not collecting or not finding the particular NTFP in their locality were classified under the ***'Not Collected / Not Available'*** category.

Tendu leaves followed a similar pattern. A large proportion of households (71.1%) reported reduced availability (if fire[29] occurs during the tendu leave harvest season), whereas 64.2% noted longer distances for collection. Around 67.4% also noted that collection time had similarly increased. Despite these challenges, a majority indicated that both price (74.8%) and demand (76.4%) stayed steady, confirming the disconnect between ecological conflict and financial gain. This growing discrepancy between effort and remuneration suggests that forest fires could worsen livelihood stresses without equivalent changes to local market structures.

Mahua seeds, unlike flowers, were less frequently collected. Only 9.2% of households reported reduced availability, and nearly 59% selected "IDK (NC/NA)," indicating unfamiliarity or non-engagement with this product. Among those who collected Mahua seeds, increased collection time and distance were noted, although market price and demand were perceived as largely stable. Achar seeds showed moderate sensitivity to forest fires, with 26.8% reporting a decrease in availability and 27.4% reporting reduced quantity. Price responses were mixed, with around 8% of households reporting a decline. However, as with Mahua seeds, most respondents had limited familiarity with Achar, and over two-thirds marked "IDK" in response to most indicators.

Amla collection was reported by only a small subset of households, with over 83% of respondents selecting "IDK" in response to Amla-related questions. Conversations with local communities across various forest ranges in Hoshangabad revealed that the primary reason for this low level of collection is the significant decline in the number of Amla trees in the forest. According to respondents, this decline is driven more by unsustainable or overharvesting practices such as cutting down entire trees just to collect Amla fruits from a single branch than by forest fires. Additional contributing factors include climate variability, particularly rising temperatures and irregular rainfall patterns, which have further stressed Amla regeneration. Even though forest fires were frequently listed as a cause, their perceived impact on Amla was deemed minor when compared to anthropogenic pressures and climatic variables. Of the 67 households that reported gathering Amla, about 10-11% reported substantial reductions in availability, quantity, and quality. These responses indicate that Amla may be ecologically sensitive to environmental disruption, its limited spatial distribution and falling population hinder its availability and recognition as a fire-

[29] There are well documented studies who claimed that if low intensity fire or prescribed cultural burning set before the tendu harvest season most likely in November or December then the Tendu leaves will be good in texture, size, quality, and quantity (see chapter 2 under the heading 2.3 for more details).

affected resource in the broader community. Similarly, honey collecting had a localized impact. Honey collection, which is practiced by fewer than 15% of families, has seen slight losses, with 7% reporting reduced availability and 6.2% reporting greater effort.

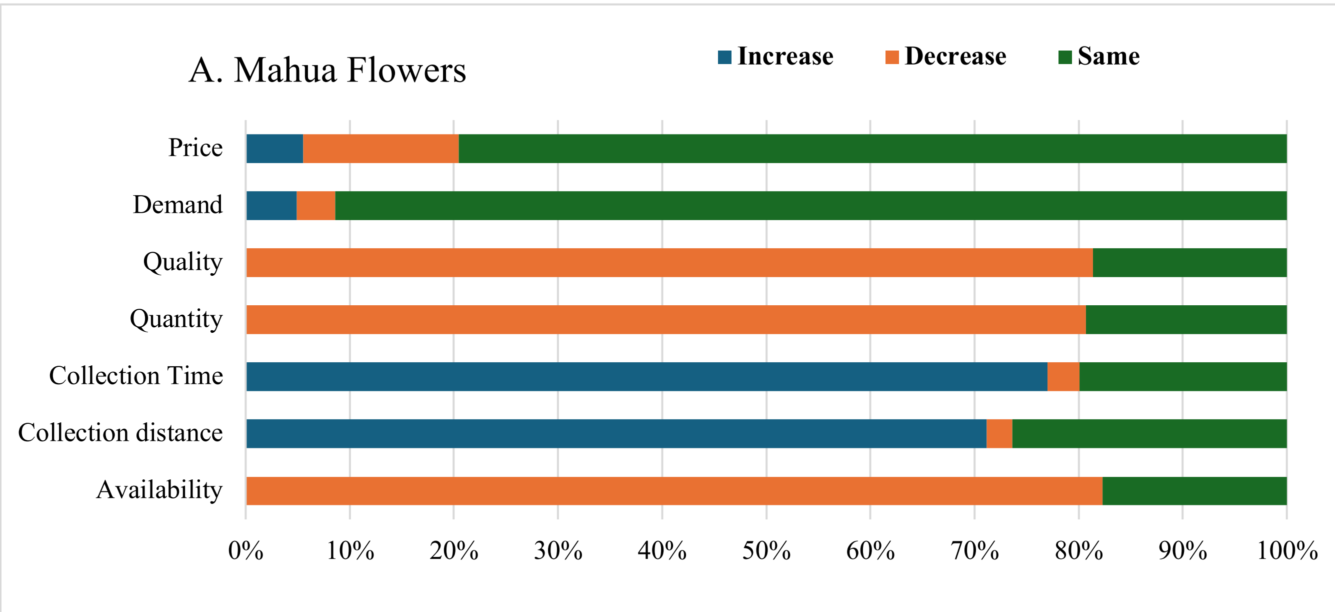
Mushrooms were the least collected among the surveyed NTFPs. Less than 15% of respondents reported collecting mushrooms, and those who did provided mixed perceptions. The data showed fairly balanced responses across increased, decreased, and unchanged categories, likely reflecting microclimatic variability and species diversity across forest patches. The other cause behind the less collection of mushrooms is its availability in the forest decreases due to the change in weather and rainfall cycles with time.

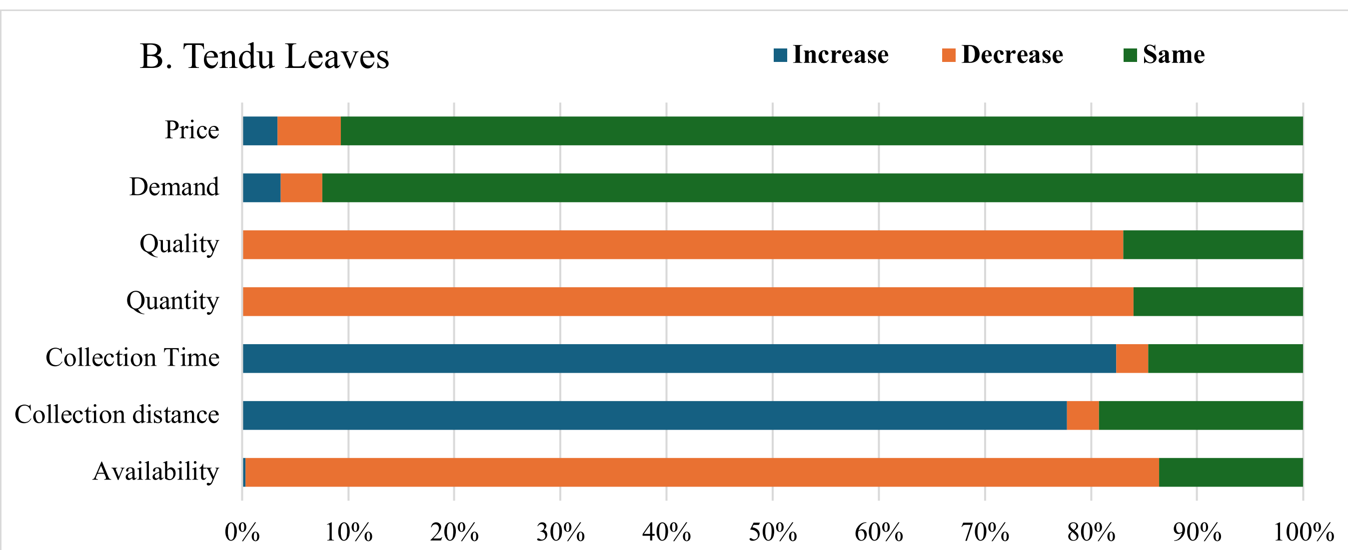
Table 5. 7 All households' (n=402) perceived impacts of fire on different NTFPs (HH in % & considering all 4 categories i.e., Increased, Decreased, Same, and NC/NA).

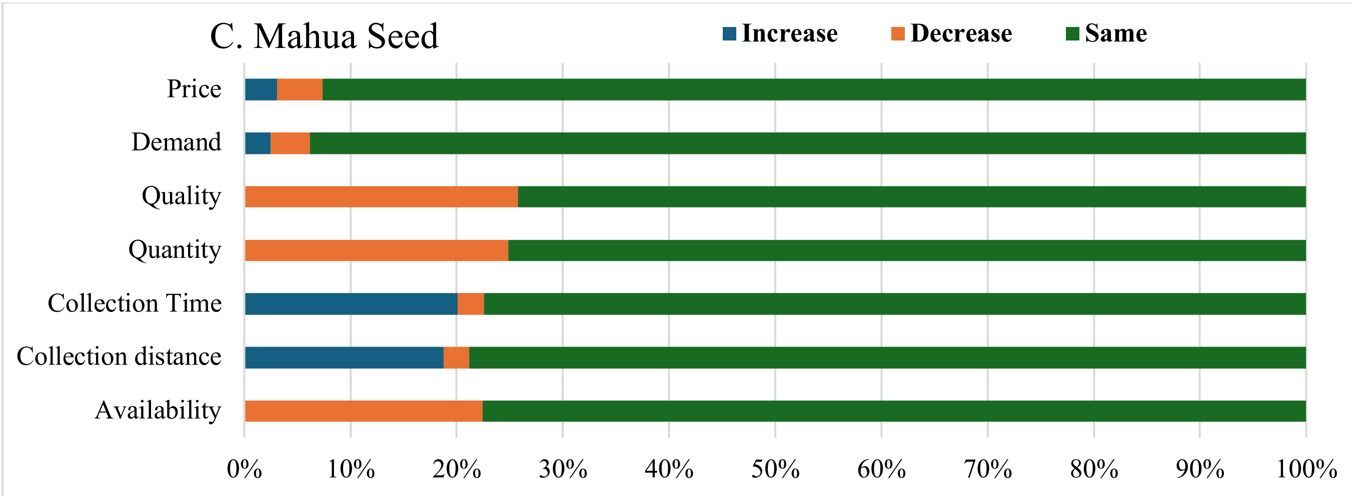
NTFPs	Availability decreased	Collection distance increased	Collection time increased	Quantity decreased	Price decreased
Mahua Flower	67.2	57.7	62.4	65.7	12.2
Tendu Leaves	71.1	64.2	67.4	69.2	5.0
Mahua Seed	9.2	1.0	1.0	9.9	1.7
Achar Seed	26.8	26.4	26.8	27.4	8.0
Amla	11.4	10.7	10.7	10.7	2.2
Honey	7.0	6.2	6.2	5.7	0.0
Mushroom	4.2	3.7	5.2	4.2	0.2

A comparative analysis of perceived impacts across products makes it clear that Mahua flowers and Tendu leaves are the most vulnerable to forest fire-induced disruptions. These two products are also the most widely collected and economically significant NTFPs in the study area. In contrast, products like mushrooms, honey, and Amla appeared to be less widely affected, either due to their ecological resilience or more limited spatial collection patterns. While significant number of respondents reported ecological impacts such as reduced availability and increased effort, market-related perceptions, particularly price and demand, remained relatively stable. Thus, for the better detection and visualization of these changes after fire, we prepared a separate graph representing only 3 classes (i.e., Increased, Decreased, Same) in percentage form (see Fig. 5.8A-G). This divergence indicates a structural disconnect between ecological stress and market response, potentially undermining household income security for those who depend on forest collection.

Oddly enough, the high frequency of "NC/NA" responses for less typically collected goods such as Amla, mushrooms, and Mahua seeds (see Appendix 5A) demonstrates geographical variations in forest resource (NTFP) availability caused by anthropogenic and climate exposure. These results underline the need of forest governance and fire mitigation techniques that take into account both biological variety and socioeconomic disparity. Therefore, community-specific and location-sensitive interventions are needed to boost resilient livelihoods in fire-prone forest ecosystems.






C. Mahua Seed
Increase
Decrease
Same
Price
Demand
Quality
Quantity
Collection Time
Collection distance
Availability
0%
10%
20%
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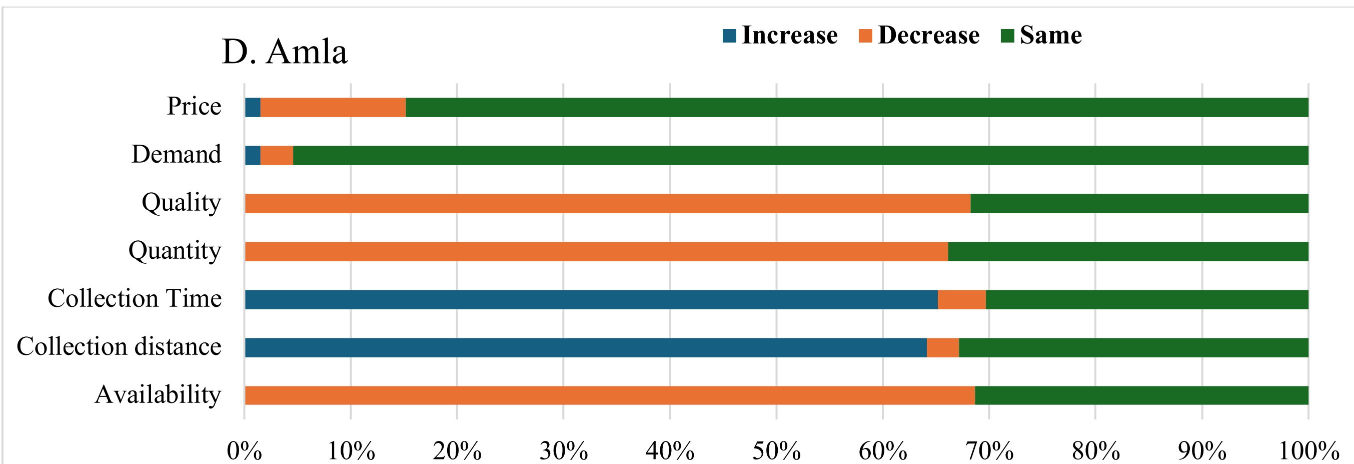
70%
80%
90%
100%


D. Amla
Increase
Decrease
Same
Price
Demand
Quality
Quantity
Collection Time
Collection distance
Availability
0%
10%
20%
30%
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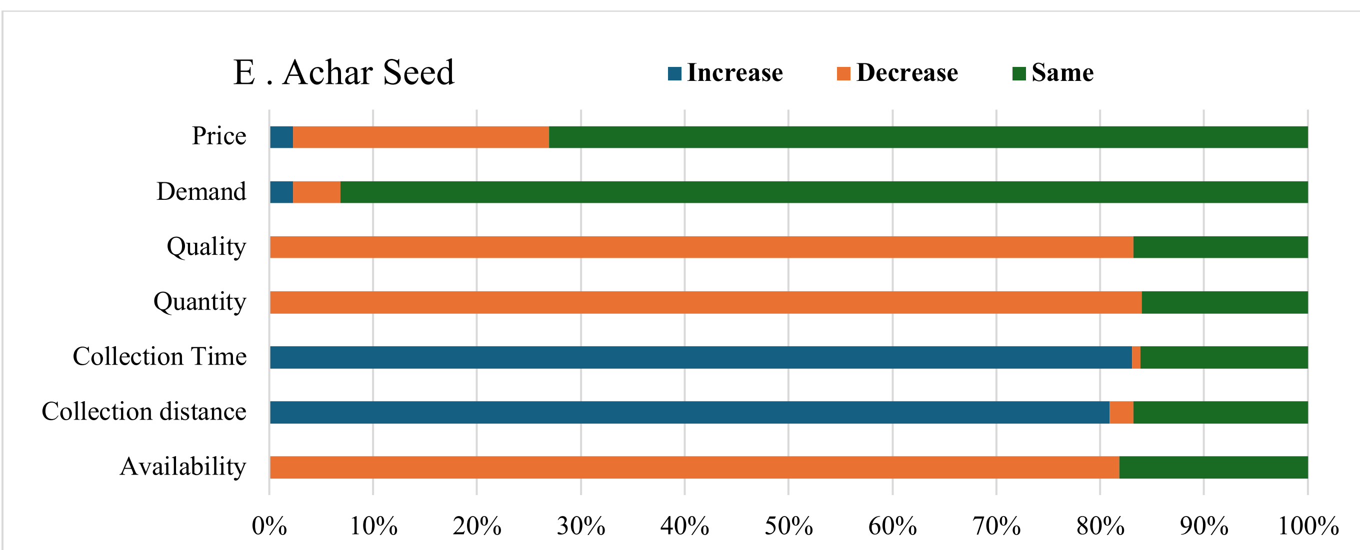
60%
70%
80%
90%
100%


E . Achar Seed
Increase
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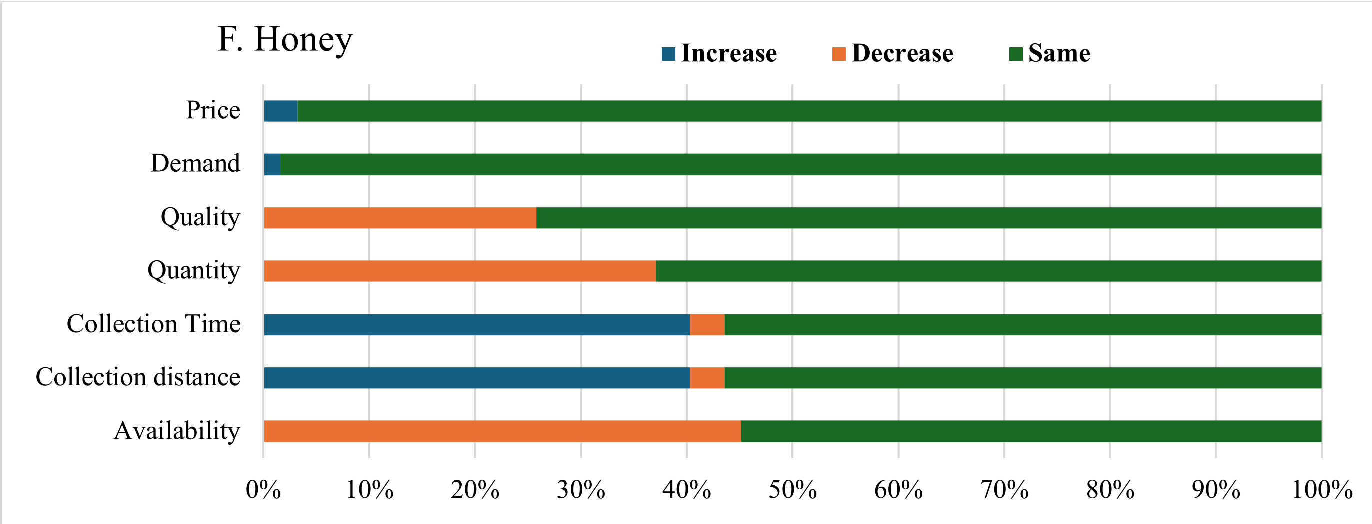

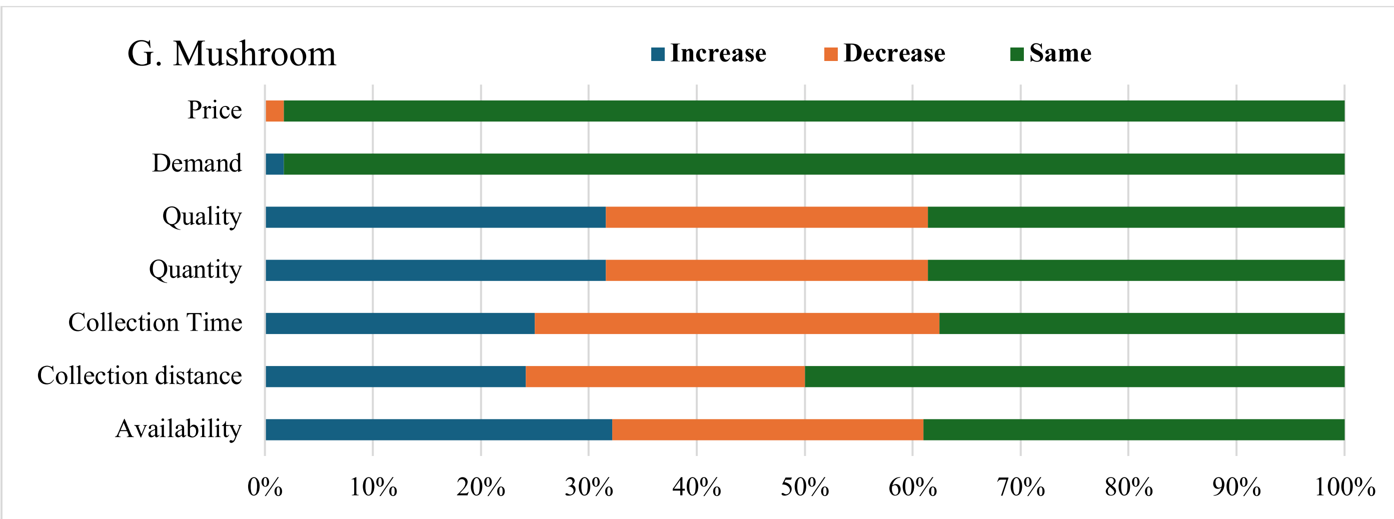

Fig. 5. 8 (A-G) Perceived impacts of fire on major NTFPs (HH in %) by excluding the NC/NA class.

5.3.4 Perceived causes of change in annual family income from forest resources

To better understand the drivers of fluctuation in forest-dependent household income, respondents were asked to mark five potential causes as per their rank, with Rank 1 denoting the most responsible factor and subsequent ranks indicating secondary, tertiary, and so forth. The responses reveal a layered perception of livelihood disruption, highlighting both climatic and structural factors.

The frequently mentioned cause of income reduction from forest resources was climate variability, specifically irregular rainfall, lightning, and temperature extremes. These variables were selected as the most important concern (Rank 1) by 222 (55.22%) respondents, followed by 145 (43.81%), indicating a clear community consensus that changing climate patterns pose the biggest threat to forest-based livelihoods. Unpredictable rainfall, heat, and harsh dry winds reduce agricultural productivity and also disrupting forest regeneration and reducing the availability of key NTFPs like Mahua, Tendu leaves, and mushrooms, on which many households rely for seasonal income.

During the field survey, one respondent, *Suktibai*, a Korku tribal woman from Jaali Kheda village, Itarsi, Hoshangabad, shared:

"For the past two years, I haven't been able to collect Mahua and Achar from the forest due to irregular rainfall and lightning during the pre-harvest season (January and February). With basic financial and logistical support from the NGO, I started a small poultry farm at home and also continuing my responsibilities as a housewife."

Her experience echoes a wider regional pattern of declining ecological stability, due to shifting monsoonal cycles and rising temperatures, which are forcing many forest-dependent households to adapt their livelihood strategies.

With 107 (26.62%) respondents giving Rank 1 and 124 (37.46%) giving Rank 2, fire is the second most often mentioned cause. Even though fires are frequently seasonal and geographically vary, their ongoing effects on fuelwood, grasses, and NTFPs are thought not to be a major source of economic stress. This is corroborated by the qualitative data, which shows that after fire seasons, many respondents reported a decrease in the availability of important forest products and an increase in collection effort. The frequency and intensity of fires in some places make them a chronic threat to the stability of livelihoods, even if they are not always considered the biggest disruptor.

The hegemony of local goons, mafias, middlemen traders, and unfair competition was also identified as a factor undermining income security. Similar situation has also been reported in the field-based research study of Khan, MA (2023). Back to the data, the hegemony of local influencers received Rank 1 from 27 (6.7%) respondents and Rank 2 from 26 (7.8%), indicating moderate concern. These players frequently set prices unilaterally, restrict access to forest markets, and take advantage of the absence of clear trading procedures. Households that rely on NTFP sales may see lower returns as a result of such exploitative power relations, which may contribute to sentiments of marginalization and financial vulnerability. 37 respondents (9.20%) gave government-imposed restrictions, such as those pertaining to forest access, mobility, or collecting practices, rank 1, while 24 respondents (7.2%) gave them Rank 2. Even though these regulations often depend on conservation goals, local populations may view them as obstacles to traditional means of subsistence, particularly if they are implemented without sufficient consultation, compensation, or alternate choices.

Interestingly, better job opportunities in nearby towns or cities were rarely perceived as a major cause of income decline from forests. Only 9 (2.2%) respondents ranked it as the primary cause, with slightly more assigning it lower ranks. This may suggest that although migration from rural to urban areas or diversification of employment is occurring, it is not commonly perceived as a contributing factor to the decline of forest-based livelihoods—at least not unintentionally. Instead, migration may be viewed as a parallel economic opportunity rather than a displacement mechanism.

Overall, the ranking remarks reveals a multi-dimensional understanding of income changes, with structural and institutional issues (goon hegemony, government restrictions), economic transitions (job shifts), and climate-related factors (irregular rainfall and temperature variability) being prioritized over fire. This perceived hierarchy points out the need for integrated livelihood and climate resilience planning, where governance and market reforms are taken into account along with fire management, climate adaptation, and equitable access to forest resources (see Table 5.8).

Table 5. 8: Perceived causes of change (decrease) in annual family income by respondents (%)

Cause	**Rank 1**	**Rank 2**	**Rank 3**	**Rank 4**	**Rank 5**
Irregular Rainfall / Lightning / Temperature Variability- including *Loo*	222 (55.2%)	145 (43.8%)	6 (9.1%)	0	0
Forest Fire	107 (26.6%)	124 (37.5%)	16 (24.2%)	1 (16.7%)	0
Restrictions by Government Officials	37 (9.2%)	24 (7.2%)	10 (15.2%)	0	0
Hegemony of Mafias / Middlemen / Unfair Competition	27 (6.7%)	26 (7.9%)	8 (12.1%)	0	0
Better Job Options in Nearby Towns/Cities	9 (2.2%)	12 (3.6%)	26 (39.4%)	5 (83.3%)	1 (100%)
Total Valid Responses	***402 (100%)***	***331 (100%)***	***66 (100%)***	***6 (100%)***	***1 (100%)***

Note: Rank 1 is the most responsible cause and later rank are secondary, tertiary and so on.

5.3.5 Perceived impact of fire on total annual family income

To adequately involved in understanding the economic consequences of fire, it is indeed crucial to assess household vulnerability, particularly in forest dependent communities or households rely on informal income sources. To estimate this dimension, households were asked whether forest fire had decreased their annual family income, either from forests or other sources. Responses were captured using a five-point Likert scale ranging from “Not at all” to “Extremely.”

As per survey outcome a substantial majority of respondents (74.8%) believed that forest fires had no influence (39.3%) or had a minor impact (35.5%) on their household income. However, qualitative findings from household interviews and key informant talks indicate that this perspective does not always reflect the lack of fire-related disturbances. Rather, it represents the marginal and supplemental nature of forest-based income in the larger family economy. Neither of the studied households relied only on one source of income or on forest resources. Instead, income from forest products was viewed as seasonal, supplementary, and dependent on various factors, including climatic conditions (such as rainfall variability, lightning strikes, and extreme temperatures), intense competition among collectors, government-imposed restrictions, and limited employment opportunities during the forest product harvest season. These factors contribute to the variable and fluctuating nature of forest revenue.

As explained by one of the key respondents, a retired forest guard from Hoshangabad forest range:

‘A representative household of 4-5 members can earn between ₹15,000 to ₹20,000 annually from forest resources, although this estimate is highly conditional. The actual income depends on several variables: household size, the abundance and flowering of mahua trees, the number of days allocated for tendu leaf collection by forest authorities, and prevailing NTFP rates in local markets. The harvesting window for key NTFPs is relatively short—tendu leaves are collected for 5–10 days in March or April; mahua flowers over 10–15 days during the same period; achar is collected for 5–10 days in April, only if trees are present in the vicinity; and Gulli (mahua seeds) for another 5–10 days in July–August, subject to availability’.

In some areas, mahua trees have been officially allocated to specific community groups to reduce inter-group conflicts and mitigate fire risks during the peak fire season, which extends from March to June. This institutional arrangement not only manages resource access but also influences collection intensity and timing. Given this narrow and volatile income window, even in optimal conditions, forest income seldom exceeds ₹20,000 per household per year, though larger families may earn slightly more. In this frame, the seemingly low impact of forest fires on household income is best understood as a result of livelihood diversification. With the transition away from core forest-based employment and toward agriculture, casual labor, industrial work, construction, seasonal migration, and other informal sectors, many households appear to have built economic buffers against environmental dangers such as forest fires. As a result, forest-based revenues are now considered a supplementary, risky supplement rather than a fundamental source of survival. Thus, forest fires may not be viewed as detrimental to household economies, this perspective stems from the structural precariousness and seasonal fragmentation of forest livelihoods.

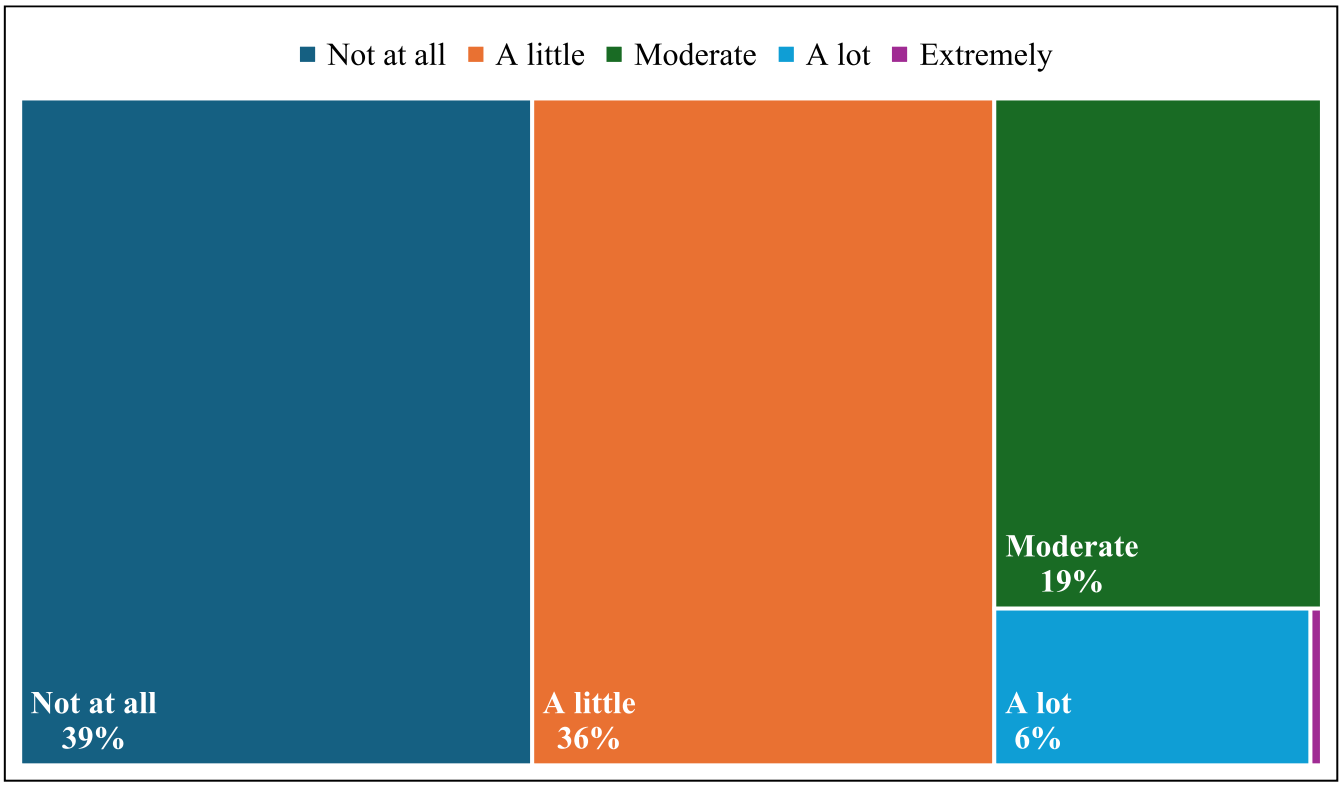

Fig. 5. 9 Does Forest fire decrease your annual family income from the forest or other sources?

A smaller segment (19.2% of respondents), reported a moderate impact, pointing to some income loss for households who are still heavily reliant on NTFP collection or subsistence agriculture. These interruptions likely stem from localized fire intensity, seasonal dependence on forest resources, or limited alternative incomes. Only 5.9% (24 households) reported high to extreme impacts, suggesting that severe economic losses due to fire are rare. These outlier situations shows high forest dependency or exposure to frequent, strong fires have gradually reduced forest productivity.

Therefore, forest fires cannot be viewed as the main driver of income loss by most households. However, the other challenges such as irregular rainfall, soil degradation, market volatility, and restricted forest access, appear more instrumental. For policymakers, this underlines the need to address broader livelihood vulnerabilities rather than focusing solely on fire-related damages.

5.4 Discussion

This discussion addresses the third Objective of the thesis by examining how forest-dependent communities perceive the economic impacts (socio-cultural factors—exclusively offered in chapter 6-7) of forest fires at the household level and critically review the alignment or misalignment between dominant fire-centric narratives (i.e., fire being as destructive force) and lived livelihood realities in fire-prone tribal landscapes. The analysis shows that fires are not widely perceived as the primary source of livelihood vulnerability. Instead, perceptions of impact are mediated through spatial patterns of forest use, livelihood diversification, customary resource arrangements, and broader climatic and institutional contexts.

5.4.1 Locating Perceived Economic Impacts of Fire

This study finds that forest fires, though responsible for ecologically disruption as confirmed by numerous regional and local-scale studies from central India (Saha, 2002; Ray, 2023; Sahu et al., 2024) but are not the primarily contributors to socio-economic vulnerability in the Hoshangabad region. Instead, the climate-induced factors are responsible, which include irregular rainfall patterns and elevated temperatures during the pre-harvest period of NTFPs, emerging as the dominant causes behind affecting forest-based livelihoods. The direct impacts of fire on local communities are shaped by their existing socio-economic structures, livelihood diversification, and wider climatic changeability. This leads us to conclude three points.

- **Firstly**, there were significant differences in perceptions of fire-related vulnerability among livelihood activities. Agricultural households reported little direct impacts from forest fires, owing to the spatial separation of croplands from forest interiors and the continued use of indigenous fire-buffering practices such as preventive burning along field margins. In contrast, pastoralist groups and forest-dependent households particularly women engaged in fuelwood collection—reported greater sensitivity to fire-related disruptions, including increased labor burdens, longer collection distances, and periodic income fluctuations. These effects were most visible in remote settlements with few alternative livelihood options and close proximity to fire-prone forest zones.

- **Secondly,** the data reveals a persistent mismatch between ecological stress and market response. Amid widespread reports of reduced supply of major NTFPs, market pricing for these goods remained relatively stable. Despite the government's MSP mechanism, just 6% of families reported selling NTFPs (excluding Tendu leaves) at MSP prices. In contrast, 94% of respondents sell below MSP, primarily due to structural barriers, exploitative trade dynamics and limited access to government procurement channels. Structural constraints such as lack of storage facilities, limited transport access, and distance from markets, further constrained households' bargaining power, often resulting in distress sales and reduced income stability.

Finally, climate variability emerged as a compounding stressor that respondents consistently ranked as more disruptive to forest-based income than fire itself. Irregular rainfall, temperature extremes, and lightning events were widely perceived to reduce resource availability and undermine harvest predictability. These perceptions are backed by Sharma et al. (in press)[30], who verify a clear trend of increasing rainfall irregularity in the Hoshangabad region. Their study reveals that such climatic variability has led to premature fruit drop and weakening fruit quality, thereby reducing overall harvest volumes, and adversely affecting local consumption and the income of communities engaged in NTFP collection and sale. While direct economic losses from individual fire events were generally reported as limited, local people expressed concern about the gradual erosion of ecological security[31] and livelihood reliability. Fires are seen not only as events

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[30] This article has been accepted for publication in a book and is currently in press mode.

[31] *Ecological security* refers to the continued and dependable access to vital natural resources such as fuelwood, Mahua flowers, Achar, Amla, medicinal plants, tendu leaves, and clean water; the stable functioning of ecosystems including seasonal predictability, soil fertility, and biodiversity; the regenerative resilience of forest landscapes in the face of recurring disturbances like fire, drought, or extraction; and the protection of culturally significant ecological sites such as sacred species of forest and community-managed fire use that are critical to traditional livelihoods.

but as signs of a larger shift in climate variability, forest governance, and the weakening of community rights to forest resources (Jain & Das, 2018) .

Collectively, these research observations establish the empirical basis for understanding why forest fires are widely perceived as having a relatively low direct economic impact in the study area, despite their ecological significance.

5.4.2 Why is the impact of fire perceived as Low ?

Based on extensive field surveys and a broader comparative perspective, the studied villages can be broadly classified into 4 categories. This classification banks on distance from nearby major cities or markets**,** availability, and accessibility of NTFPs, and the functioning of customary rights (CR) under the umbrella guidelines of the Forest Department. Drawing on prolonged field engagement, the following village typology helps explain why fire is widely perceived to have a relatively low socio-economic impact.

a) The category-A of villages is mostly collected NTFPs and other forest-based resources from their agricultural land (despite being located close to open or scattered forest) . They have Mahua and Amla trees in their agricultural fields and due to high uncertainty and very short span (< 1week) of tendu leave collection discourage them from participating in the tendu picking conducted by the local govt body in coordination with the forest officials. Consequently, households restrict their collection activities to Mahua, Amla, Chironji, and fuelwood from trees located on their land or in nearby open forests, rather than venturing into deeper forest areas (see Fig. 5.10A). Livelihoods are further diversified through agriculture, seasonal agricultural labor, and, in some cases, short-term migratory labor in nearby towns. As most forest fires occur deeper inside the forest or beyond their routine resource-use zones, the socio-economic life of these villages remains largely unaffected by fire events.

b) These villages consist of households that collect NTFPs and fuelwood mainly from nearby open forests, common community land, and scattered forests located close to their settlements. These villages typically lack agricultural land and therefore more depends on proximate forest spaces for their livelihood (which is generated through selling NTFPs and fuelwood). Collection activities (including *Mahua*, *Tendu* leaves, *Amla*, and *Chironji)*, are spatially limited and do not involve frequent movement into fire-prone deep forest areas. As a result, although fires do occur in the broader landscape, their direct economic dependence is not significantly disrupted by fire events.

c) The category-C villages are those who have already allocated the major NTFP producing trees such as Mahua, Amla and chironji with the help of forest official and CR. Accordingly, each household is assigned designated trees, and this allocation is intergenerational, thereby reducing conflict over resource access. Importantly, these allocated trees are usually located in human-influenced landscapes, such as agricultural margins and nearby open or scattered forests, rather than deep forest interiors. The involvement of the Forest Department in these arrangements also results in closer monitoring, which restricts careless fire settings and other destructive practices. Consequently, the perceived impact of fires on livelihoods in these villages remains limited.
d) Category-D villages are located very close to urban settings or major markets. Owing to better alternative livelihood opportunities, residents increasingly prefer wage labor or informal employment in nearby cities rather than forest-based livelihoods during their permitted time & agricultural off season (when there are no, or less agricultural related duties left). Thereby instead of going to the forest and risking their lives from being bitten by snakes or attacked by wild animals such as bears; they prefer to go to the cities and earn a good livelihood. NTFP collection in these villages is therefore occasional and supplementary rather than central to livelihoods. Fuelwood is typically collected from trees near houses, agricultural land, or nearby forest edges. In several instances, households from Category-C villages access forest areas near Category-D settlements for NTFP collection, as residents of Category-D villages themselves are less dependent on these resources. This reduced reliance on forest interiors further explains the low perceived impact of fires.

Thus, considering all four village categories, a consistent pattern emerges: most fires occur in deeper forest areas, away from settlements, as also demonstrated through regression analysis in Chapter 3. In contrast, the everyday livelihood activities such as NTFP and fuelwood collection primarily take place either on agricultural land or within open and scattered forests close to habitation, significantly weakens direct livelihood exposure to fire events.

This spatial and livelihood-mediated attenuation of fire impacts is not unique to central India but reflects a broader pattern observed across fire-adapted socio-ecological systems globally. Similar observations have emerged from diverse geographies. In the Brazilian Amazon, NTFP-dependent communities such as Brazil nut and rubber collectors have demonstrated resilience to low-intensity, seasonal fires, while land tenure conflicts and market instability pose greater threats to livelihoods (Hecht, 2007; CIFOR, 2014). Aboriginal fire management in Australia illustrates how fire functions as a constructive ecological and cultural tool, with prescribed burning rooted within long-term livelihood adaptation strategies (Bowman et al., 2011; Steffensen, 2020). Likewise, in African savannas and woodlands, community-managed fire regimes linked to pasture renewal, hunting, and cropping exhibit minimal livelihood disruption, with rainfall variability and tenure insecurity emerging as more pressing concerns than fire itself (Archibald, 2016). These comparative cases reinforce a central argument of this study: the socio-economic significance of fire is shaped less by fire occurrence per se and more by the spatial organization of livelihoods, institutional arrangements, and political-economic contexts.

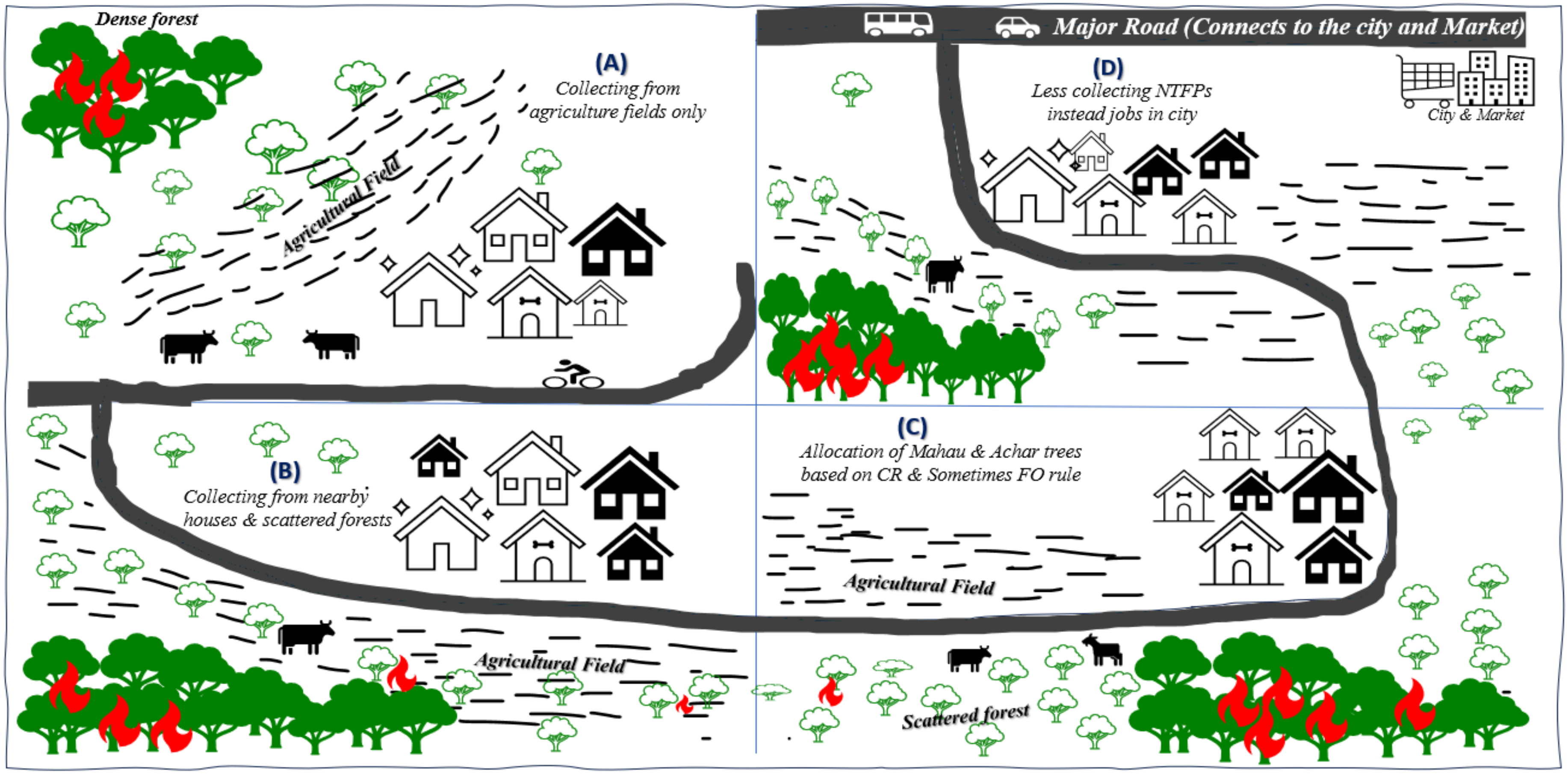

Fig. 5. 10 Field-based sketch showing village-wise patterns of forest use, NTFP collection, and fire occurrence in the study area. The drawing summarizes 4 types of villages observed during field visits, based on distance from markets, dependence on forest resources, and everyday movement into forest spaces. **(A)** Villages where most NTFPs (Mahua and Amla) are collected from trees located within agricultural fields or from nearby open forests; people rarely venture into dense forest areas, where fires usually occur. **(B)** Villages that depend on nearby open or scattered forests for fuelwood and seasonal NTFP collection since they are landless but generally avoid deeper forest (main fire-prone areas). **(C)** Villages where Mahua, Chironji, and similar trees are already allocated to households under customary rights (CR), sometimes with Forest Office (FO) involvement; these trees are mostly near villages or field edges, reducing conflict and limiting movement into dense forest. **(D)** Villages located close to main roads and markets, people prefer wage work or city-based jobs and collect forest products only occasionally. Overall, the sketch reflects that most fires are seen in dense forest areas away from settlements, while everyday NTFP collection and fuelwood use happen closer to villages in open or scattered forests, which helps explain why people perceive fire impacts on livelihoods as low *(**Source**: Author)*.

5.4.3 Rethinking Fire-Centric Impact Narratives

Empirical evidence from the Hoshangabad region demonstrates a clear misalignment between dominant fire-centric descriptions and lived livelihood encounters and realities. In the study region, fires are not widely perceived as the primary driver of livelihood vulnerability. As agricultural lands remain largely unaffected due to their spatial separation from dense forest zones and the persistence of indigenous fire-buffering practices such as preventive burning along field margins. During an in-depth interview, Ramekh, a Gond farmer in his sixties from Kaveli village, Itarsi Range, described fire as a sacred boundary marker:

"We burn the line just after Holi, when the winds are calmer, and the fields are still bare. My father did this, and his father before him. It keeps the fire out and marks our land with the blessing of fire. But now the Sarkar has started putting restrictions, and I worry that soon they will stop it completely."

More significantly, respondents repeatedly identified climate-induced stressors such as irregular rainfall, rising temperatures, and shifting seasonal patterns, as the dominant factors affecting forest-based livelihoods. Declines in the availability, quality, and timing of NTFPs were consistently attributed to climatic variability rather than fire.

Suktibai, a Korku woman from Jaali Kheda village, Itarsi, explained: *"For the past two years, I haven't been able to collect Mahua and Achar from the forest due to irregular rainfall and lightning during the pre-harvest season (January and February). With basic financial and logistical support from the NGO, I started a small poultry farm at home along with continuing my responsibilities as a housewife to run my family as well as livelihood."*

Such oral evidence highlights that livelihood vulnerability is increasingly shaped by climatic uncertainty and institutional constraints rather than by seasonal or prescribed fires.

5.4.4 Interpreting Livelihood Resilience and Diversification

These results of the study are consistent with political ecology theories that critique universalized disaster narratives and emphasis how institutions frame environmental phenomena as crises while overlooking local adaptive practices (Blaikie & Brookfield, 1987; Robbins, 2012). In HFD communities address fire through spatially surrounding and culturally informed behaviors, whereas state-led methods typically frame fire as a threat that needs to be controlled. Additionally, the frameworks for persistence and social-ecological systems (Berkes

& Folke, 1998; Folke et al., 2005) shed light on how communities in Hoshangabad absorb and adjust to frequent fire events through prescribed burning, activity zoning, and livelihood diversification.

Forest-based profits is combined with wage labor, public employment, agriculture, and seasonal migration in households. This diversification [32] buffers households against environmental shocks, reinforcing the finding that fire itself is rarely the primary stressor**;** vulnerability is instead shaped by broader climatic, market, and governance contexts.

5.4.5 Misread landscapes and fire narratives

This study align with Forsyth's (2003) concept of ***"misread landscapes"*** which critiques externally imposed environmental narratives that neglects value of indigenous local knowledge systems. Popular assumption that all wildfires are destructive ignores the socio-ecological realities where fire is normalized, contained, and even managed through community practices. During the field survey, many tribal community members reported that their traditional knowledge was not given much attention during official joint meetings or when fires problem were discussed in gram sabha (village). Instead, state approaches emphasize surveillance, patrolling, and fire line cutting, often without participation from tribal residents. A Korku Elder, in a village near Jhiriya Jhora shared:

"Earlier we used to burn the forest paths before Mahua season, now the leaves pile up like a carpet. When fire comes, it spreads fast, nobody can stop it".

Looking through this in a broader comparative context, the practices observed in the Hoshangabad landscape can be understood as locally static responses rather than exceptional or anomalous behaviours. In order to reduce surface litter and make it easier to collect Mahua flowers and Chironji, local communities routinely utilize low-intensity fire in open forests. When properly controlled, these methods mainly lower fuel loads and facilitate access without seriously harming the environment (Mistry & Berardi, 2016; Smith et al., 2024; Yadav, 2025). However, when fire in scattered forests is left unattended or carelessly, there is a risk of its spread into deeper forest areas, potentially leading to substantial ecological damage. In response, forest officials often enforce strict prohibitions on all forms of burning, including cultural and low-intensity fire. While having right the intentional in nature, this binary and

[32] As Scoones (1998) and Ellis (2000) argue, livelihood flexibility is a critical mechanism through which rural populations negotiate environmental variability.

suppression-oriented approach frequently produces unintended consequences. Due to the fear of penalty, collectors may ignite fires hastily and abandon them prematurely, to not being caught by forest officials, increasing the likelihood of uncontrolled spread of fires. These observations postulates the need for policy re-calibration. Allowing well-regulated cultural or low-intensity burning under soundly-defined and closely monitored standards, with the active participation of local communities and forest officials, might stop unattended fires and match conservation objectives with the realities of livelihood. Thus, it is necessary to integrate cultural practices with modern conservation principles, rather than positioning them in opposition.

5.5 Conclusion

Reframing Fire Impacts through Lived Economies and Situated Ecologies

This chapter sought to investigate the perceived economic repercussions of forest fires in Hoshangabad using a community-centred, qualitative, and descriptive lens. Thinking beyond the mainstream fire-as-disaster narratives, outcomes show that fires are not seen by local communities as the primary cause of livelihood instability and vulnerability. Instead, the socio-economic consequences of fire are mediated through a complex assemblage of climatic variability, livelihood diversification, market structures, and governance arrangements.

Among others, the important insight drawn from the survey of 402 households was that fire impacts are unevenly distributed across livelihood domains. Due to their geographical distance from dense forest interiors and the continued use of native fire-buffering practices, like preventive burning along field borders, agricultural systems in Hoshangabad region are comparatively fire-resistant. However, fire-related disruptions are more acutely felt within high forest-dependent livelihood spheres, particularly among households reliant on fuelwood for the livelihood. These impacts manifest not as catastrophic losses, but as incremental increases in labor time, collection distance, and physical effort, and these burdens disproportionately fall on women and economically marginal households in remote settlements. The chapter also demonstrates a structural dissociation between ecological stress and economic valuation. Despite widespread assumptions of deteriorating availability and quality of major NTFPs, market prices have remained relatively stable. Institutional mechanisms which were designed to protect collector's interests, such as MSP, storage infrastructure, and public procurement, are still poorly implemented or inaccessible in practice. As a result, ecological scarcity leads to increased labor without corresponding economic gains, so intensifying rather than mitigating existing vulnerabilities.

Importantly, the perception that fire exerts only a “low” impact on overall household income does not indicate ecological benignity. Instead, it reflects a broader transformation of rural livelihood systems. Majority of households no longer depend exclusively on forest-based income; instead, they pursue diversified livelihood portfolios combining agriculture, casual labor, seasonal migration, and limited forest extraction. Forest economical gain has thus become supplementary, episodic, and risk prone. This diversification acts as a buffer against environmental shocks, but it parallelly indicates a deeper underlying precarity, wherein forest livelihoods persist not as stable economic foundations but as fallback options in an increasingly uncertain rural economy.

The village typology established in this chapter brings more detail into how geographical position, market proximity, and customary resource arrangements influence perceptions of fire impact. A consistent spatial pattern emerges across all four village categories: the majority of high-intensity fires occur in dense forest interiors, while everyday livelihood activities (e.g., fuelwood collection, grazing, and NTFP harvesting) are concentrated in agricultural margins, open and scattered forests near settlements. This spatial mismatch notably dampens the direct economic exposure of households to fire events. At the same time, the criminalization of low-intensity cultural burning, along with a rigid suppression-oriented governance framework, has produced unintended consequences, including hurried ignitions and unattended fires leading to increasing ecological risk rather than reducing it.

Hence, the conclusions opposes universalized fixed narrations and assumptions that fires necessarily translate into severe livelihood collapse. Rather, they underline the need to understand fire as a situated socio-ecological phenomenon, surrounded within local histories of land use, cultural practice, market relations, and institutional power. In this context, fire's effects are contextual, relational, and mediated by larger political-economic processes; it is neither purely destructive nor intrinsically useful. The chapter therefore calls for a re-calibration of fire governance in central India, that shifts from technocratic suppression to measures that are context-sensitive, livelihood-aware, and community-informed. Recognising controlled cultural burning, strengthening NTFP market mechanisms, enhancing storage and transport facilities and aligning fire management with climate adaptation planning are all essential steps toward equitable and sustainable fire governance.

CHAPTER-6

Socio-Cultural Dimensions of Fire

Traditional Practices, Beliefs, and Local Knowledge

The global fire literature has filled with abundance of scholarship on forest fire discourse which framed fire as ecological hazards and economic disruptions, such a scholarship remains incomplete in the context of indigenous and forest-dependent people and communities (Eriksen, 2007; Lake et al., 2017; Copes-Gerbitz et al., 2021; Suhardiman et al., 2026). For many tribal communities (including Gond, Baiga, and Korku) in central India, fire is not only a byproduct of physical phenomenon of fuel, oxygen and spark but also a profound cultural phenomenon which is ritually significant, temporally meaningful, and symbolically potent (Jolly et al., 2025; Saha, 2002). It signifies transitions in harvesting seasons, declares the rhythms of forest-based sources of livelihoods, and is typically crucial to religious festivals and ceremonial practices in the socio-cultural lives of the tribal people and local communities. Considering these roles of fire, this chapter proceeds from the economic analysis of the previous chapters to spotlight the position of traditional or Indigenous knowledge (IK)[33] in shaping and regulating forest fire-related traditional practices. These traditions are not just a bundle of utilitarian practices but represent a distinct epistemological framework which engrained in generational human-nature bonds, age long oral traditions and culturally transferred understandings of forest ecosystems. The analysis offered in this chapter is drawn from ethnographic fieldwork, including participant observation, semi-structured interviews, informal discussions, and life history accounts conducted across selected tribal villages in the HFD by using the same methodological framework as mentioned in chapter 5. Through directly engaging with local knowledge bearers, ritual specialists, and community elders, this chapter aims to reveal the layered meanings of fire that goes beyond its material impacts and irradiate the lived cultural realities that shape and are shaped by fire.

[33] *Indigenous knowledge* is the to age long set of traditions, practices, rituals and understanding which have evolved by indigenous/tribal or local communities through their close interaction with the natural environment across the generations and time (Rist et al., 2010). This knowledge majorly derived from socio-cultural, religious and spiritual practices of these communities and is passed down from generation to generation by the mean of oral traditions, rituals, and hands-on experiences (Nikolakis et al., 2020). In India, *Tribes*, also known as aboriginal communities, indigenous people, Adivasi, Janjati, or Scheduled Tribes. These people have been residing in forests or remote areas from the main populated land for countless generations (Charsley, 1997; Shah, 2007).

6.1 Traditional Ecological Knowledge (TEK) and Fire

TEK is the collective body of knowledge, practice, rituals, traditions and belief progressing by adaptive processes and passed on through generations by cultural and traditional transmission (Rist et al., 2010). This rich reservoir of wisdom is knitted in the long-term observation and interaction of indigenous communities with their local ecosystems (Berkes, 2012). TEK is not only just a static archive of past practices and stories but also a dynamic, evolving knowledge system that informs the ways in which indigenous peoples understand and manage the natural world, including fire (Yadav, 2025; Rist et al., 2010). In tribal groups of Central India, fire is not considered primarily as a destructive element, rather it is labelled and understood through multiple cultural lenses as sacred, seasonal, and agricultural. Sacred fires are associated with rituals, festivals, and spiritual communication, including those which seen during ancestor rituals. Seasonal fires mark the changes in agricultural calendar as they are often set intentionally in *Rabi* or *Zayed* [34] crop clearing. Agricultural fires, especially for shifting cultivation or surface clearing of leaf litter and dry biomass, are managed through precise local knowledge (e.g., when air is calm, weather is cold, low fuel load, and preferred time is early morning under the observation of sufficient local people) that minimizes ecological harm (Mohd et al 2024).

The diffusion of fire-related knowledge primarily travels through oral traditions including folktales, communal songs, ritual chants, and proverbs. Such knowledge system is rarely codified in writing but is passed down through lived experience, storytelling by elders, and participatory seasonal activities (Sugiyama et al 2025; Martínez-Torres et al., 2016). For example, many children in tribal villages learn about fire timing and control by accompanying elders during forest product collection or agricultural burning. A 78-year-old, Bhura Ram, from the Korku tribe (Bankhedi forest range) shares his practice of living with fire as:

"We don't need paper to know when to burn. My father taught me with his eyes and his hands. He showed me the stars, the wind, and the trees. We sing the old songs before Holi to tell the fire where to go and when to stop. It's in our blood, not in the books."

[34] Rabi crops are winter crops sown in India between October and December and harvested between March and April. Common rabi crops include wheat, barley, mustard, peas, and gram. They rely primarily on residual soil moisture and may require irrigation. While ***Zaid crops*** are short-duration summer crops grown between the rabi and kharif seasons, typically from March to June. Zaid crops benefit from warm, dry weather and irrigation. Common examples include watermelon, cucumber, muskmelon, and fodder crops.

This rich body of local knowledge often contrasts sharply with modern (top-down) forest management approaches that tend to view fire exclusively as a hazard. The scientific sources of knowledge on fire management frameworks classically stress suppression and control activities, disregarding the local ecological role that fire plays in certain landscapes and the socio-cultural systems that have co-existed with fire (see the below Table 6.1).

Table 6. 1 The traditional ecological knowledge vs scientific forestry framework to fire.[35]

Dimension	**Traditional Ecological Knowledge**	**Scientific Forestry Framework**
Understanding of Fire	Multi-layered: seasonal, agricultural, sacred	Hazardous event to be suppressed[36]
Transmission of Knowledge	Oral: songs, stories, observation	Formal education, manuals, and training
Fire Use Practices	Controlled seasonal and cultural burning, ritual fire use	Prohibition or suppression of burning, limited prescribed burning
Role of Community	Active participants and stewards of fire regimes	Passive recipients or violators of fire-related laws
Epistemology[37]	Embedded in local cosmology and livelihood	Based on external scientific models and risk calculations

The attrition of TEK has been significantly accelerated by both colonial and postcolonial forest governance regimes. For instance, the Wildlife Protection Act of 1972 institutionalized a model of fortress conservation, which prioritized exclusionary protection over participatory management (Bisht, 2020; Jolly, 2022). Such intervention steps of the government separate indigenous communities from their ancestral forest surroundings and delegitimized their traditional knowledge systems. And these institutionalized frameworks are replacing them with technocratic and bureaucratic modes of control. In numerous examples, communities that historically acted as first responders during fire seasons were systematically excluded from forest access, leading to the erosion of both ecological knowledge and forest health (Agrawal, 2005; Berkes, 2012).

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[35] This table is the output of the information sourced from the reviews of different studies on TEK and scientific approaches to fire. These studies has been presented and cited in chapter 2.

[36] Here, it became a bit binary (I have presented for shake of clear understanding, however; nowadays the scientific approaches have also started to recognize the positive outcomes of the cultural and seasonal burnings.

[37] *Epistemology* is the study of knowledge or the investigation of the self-generated question—how we know what we know?

This pattern of marginalization of traditional ecological knowledge has had especially profound consequences in regions like the Hoshangabad of central Indian where huge tribal population exits. In that way, the exclusion of traditional fire practices and replacement with uniform suppression strategies have often disrupted ecological balance and increased vulnerability to large-scale forest fires (Mariani et al., 2022; Boerigter et al., 2024; Suhardiman et al., 2026). Similarly, such types of themes are also explored in the eruditely edited volumes by the *Rights and Resources Initiative (2012),* where researchers including *Sundar and Kothari* examine the socio-political sidelining of tribal communities and the degradation of traditional ecological knowledge systems.

As one elderly **Korku** household, hailing from the Hoshangabad forest range, shared with us:

"Now we are completely stopped from using the small fires (by the forest department), which we have been using for generations for clearing the forest floor, in order to easily collect mahua flowers, achar, mahua seed (Gulli). We also used to perform small intensity fires just before the monsoon, so we get the fresh grass during and after the monsoon. Now, due to restrictions on burning by the forest officials, we are forced to abandon our cultural fire use practices. Nowadays, clearing the forest surface ground manually takes much more time and effort to collect forest minor products (primarily mahua, achar and Gulli) and fodder for our animals."

This oral testament stresses the intimate link between traditional ecological knowledge and cultural practice, and how state-driven restrictions can disturb both subsistence livelihoods and inclusive and sustainable fire management traditions. Therefore, identifying, recognizing, and reintegrating traditional knowledge into contemporary (modern) fire management models is a matter of ecological necessity, cultural justice with the native people. It bargains pathways for more adaptive and culturally consonant approaches to fire in the forest commons.

6.2 Rituals, Festivals, and Fire Symbolism

In the light of native understanding of Gond, *Korku*, and other tribal groups in Hoshangabad, fire acts as an innate cultural element with profound symbolic meanings. Numerous trees are not just botanical bodies but spiritual habitats and considered them sacred and inviolable.

This study's ethnographic survey uncovered a wide range of sacred trees worshipped across villages, including *Saaj (Terminalia tomentosa)*, *Mahua (Madhuca indica)*, *Peepal (Ficus religiosa)*, *Bargad (Ficus benghalensis)*, *Palash tree (Butea monosperma)*, *Tulsi (Ocimum sanctum)*, *Bael (Aegle marmelos)*, *Neem (Azadirachta indica)*, *Dahiman (Cordia macleodii)*, and others (see the description of these trees in Table 6.2). This deep reverence for the tree species translates into specific ecological morals and ethics that encourage communities to not cut down these trees or lighting fires near them. These actions are not just spiritual does but also serve as traditional fire prevention practices, suggesting how ritual knowledge contributes to forest management.

Table 6. 2: Main revered tree species and associated beliefs systems (based on field survey information)

Sacred Tree	Believed Significance	Associated Practices
Saaj	Abode of *Bade Dev*	Not cut; rituals during Mahua season
Mahua	Symbol of fertility and sustenance	Worshipped in Chhath, offerings made
Peepal	Linked to ancestors/clan spirits	Avoid cutting; used in daily prayers
Banyan (Bargad)	Protection, longevity	Circled during festivals, tied threads
Tulsi	Purity, feminine power (*Vrinda Devi*)	Kept in courtyards; fire not lit near it
Bel	Sacred in Shiva worship	Leaves used in puja; tree not harmed
Neem	Healing tree, protective spirit	Branches used for rituals
Palash	Sacred in Lord Shiva, Brahma, and the Moon worship	Gonds are utilizing Plash in their totems, ancestral worship, burial practices, and use it in Bidri puja while the Korku practice it in festivals like Hareli and uphold totemic traditions. Both tribes apply its flowers, leaves, and wood in ceremonies and daily life, echoing their deep connection with nature and prohibiting its cutting, encouraging its planting, and ensuring its conservation through cultural veneration and from fire as well.
Dahiman	Revered during community festivals and rituals marking transitions like births or seasonal changes	It comes under the sacred groves category and uses in birth and death ceremonies, reflect its cultural centrality which discourage its cutting and encourage its conservation.

These revered trees are the fundamental part of everyday religious life of both the tribals. As one village elder from Hoshangabad re-counted: *"Saaj mai bade dev rehte hai aur Isliye in pedon ke paas aag nahi lagate. Har saal jab mahua girta hai, hum pooja karte hain in pedo ki Mahua ke foolo se." (The Saaj Tree is considered as the symbolic living place of Lord shiva (Bade dev). Therefore, we never cut and light fires near them. Every year, when Mahua falls, we worship the Saaj tree from the mahua flowers.)* The Gond and Korku tribes also plant fruitbearing trees like *Wild Mango, Jamun, Bael, Jackfruit*, and *Custard Apple* during their month-long Hari Jiroti festival and other occasions.

a) Hari Jiroti

It is one of the major tribal festivals of the central India which dominantly celebrated by the Gond and Korku groups. It performed annually during the monsoon or post-harvest season, and this ritual points to the renewal of the relationship between humans, forest deities, and ancestral spirits. It particularly involves the collective worship of sacred groves and trees such as *Saaj, Mahua, Peepal, and Bargad,* which are considered as the homes of village deities whom they call in local language as *Gram Devta or Bade Dev*). Villagers gather to offer mahua flowers, local liquor made from Mahua flowers or rice, and symbolic food items at shrines often located under or near these sacred trees. Fire engages in a symbolic character in the form of incense burning and earthen lamp lighting, representing purity and the presence of divine energy. Ritually embedded local songs and folk dances are performed, and elders recount the stories related to forest divine spirits and past events. All these activities are reinforcing community values and ecological respect. A local household from Sukhtawa range, Mr. Kahu, told us: *"Hari Jiroti ke din hum devta ko dhoop batti, phool, mahua chadhate hain… aur naye ped lagate hain. Yeh prakriti ka tyohaar hai." ("On Hari Jiroti, we offer dhoop batti (incense) and Mahua flowers to our deity... and plant new trees. It is a festival of nature.")* Consequently, this festival is an expression of environmental ethics and communal identity deep-rooted in traditional ecological knowledge.

b) Bidri Puja

It is a spiritual and cultural observance held by forest-dwelling tribals including the Gonds in the Hoshangabad and also prevalent in other parts of central India. Bidri Puja is primarily centered on protecting the natural environment and appeasing forest spirits, in comparison to yearly festivities like *Hari Jiroti*, which focus on more general communal rejuvenation. In Bidri puja tribal people performed a cultural ceremony for paying tribute to the Bidri Dev (a guardian spirit believed to keep watch over the forest and its inhabitants). It carried out deep into sacred groves or on the edge of the forest. Fire is utilized emblematically to activate the presence of the spirits instead of as a destructive force, and offerings include Mahua flower derived local liquor, grains, and seasonal flowers are presented to the deity.

A collective most frequent answer received during the interaction with the tribals while recording the daily living records, that is -*"Hum Bidri devta ke samne aag jala kar mang karte* *hain ki van surakshit rahe." (We light the fire (for perform worship rituals) to invoke Bidri Devta and pray for the protection of our forests.)*

Bidri Puja is unique in that it explicitly invokes fire as a protector. It reflects Bidri as reversal ritual for the destructive potential of forest fire. It shows a well ingrained local traditional wisdom, in which ecological constraint and forest management are in line with spiritual values. These descriptions express how TEK combines pragmatic conservation with spiritual devotion. Local belief systems transform fire into a controlled, sacred phenomena that is constrained by ritual. This symbolic ecology provides comprehensions into alternate fire governance paradigms that are based on inter-generational knowledge systems, reciprocity, and mutual respect.

c) Munda Ritual among the Korku and Gond Communities

It is a culturally significant ritual celebration followed by the Korku and Gond tribal people, mainly in the Hoshangabad region and nearby districts of Madhya Pradesh. Bring into line with seasonal and agricultural cycles, this ritual is usually carried out between the transitional months of May–June and November–December. Sagon (teak) wood is carved with symbolic representations of deceased community members, mainly those who died in the previous year, as part of the ritual. After that, these wooden effigies are partially buried vertically in wooded locations, most often under revered trees like teak or Bargad (banyan) in the open forest. The community gathers at these sites to perform ancestral worship, offering cooked food as prasad and performing ceremonies meant to honor the spirits of the deceased (see the visual documentation of the ritual in figure 6.1). This practice is based on the core cultural belief that both human prosperity and ecological well-being depend on the blessings of ancestors. An abundant supply of NTFPs, healthy crops, and good fortune are all thought to be ensured by performing this ritual. Additionally, the community's protective bond with the environment is strengthened by the spiritual sanctification of forest areas. Many people feel that their ancestors still live in these forests which gives them a moral and spiritual duty to protect them from dangers like forest fires.

Therefore, the Munda ritual establishes a rich tradition of ecological reverence and reveals how spiritual cosmologies contribute to community-based conservation ethics. It illustrates the entwined relationship between cultural practices and environmental conservation.

Fig. 6. 1 Visual documentation of the Munda ritual performed in Hiran Chapda forest, Itarsi Range, Hoshangabad, Madhya Pradesh (May 2024) -(a) depicts a carved wooden effigy representing a deceased child, placed as part of a ritual for the child's salvation (Mukti); (b) shows a set of four carved figures symbolizing four deceased members of a family, collectively honored in the ritual for ancestral peace and blessings; (c) and (d) portray the cultural practices associated with the ritual, including the preparation of prashad (ritual food offerings) beneath a sacred banyan (Bargad) tree. Traces of fire and ash are visible, indicating the ceremonial cooking and symbolic purification process *(Source: Author)*.

6.3 Fire Management through Customary Practices

While state-led forest governance in India largely treats fire as a threat to be extinguished, many indigenous communities in Central India possess a parallel tradition of customary fire management. This system is regulated by generations of TEK, transmitted orally, and ingrained in seasonal cycles, cultural practices and codes, and nature's indications, developed after an age longed close observation of surrounding environment; it is neither accidental nor anarchic (Berkes, 2012). Small cultural intensity burning, frequently knows as *Preventive burning,* is one of the methods used by local people to manage dry biomass (i.e., grasses, dry leaves, and minor fuelwoods), removes undergrowth, and promotes the regeneration of specific forest species and fresh grasses, usually prior to the monsoon (Saha, 2002). Another tactic to prevent overexposure and enable the forest to recover is rotational burning, which entails burning only specific regions each year (Ramnath, 2001). To prevent fire from spreading beyond designated borders, natural firebreaks like streams, barren trails, or even cleared strips are maintained.

During the field observation, one very intensely respected rule among the Korku and Gond people found that they were not typically setting the fire when mahua flower is falling from the tree (they do set small intensity fire before the mahua falling time but nowadays due to restrictions paused by the forest department the small intensity fire has also been stooped). In words of a local mid aged Korku man from Saheli village —*"Hum log Mahua ke phool girth samay aag nahi lagate he, kyoki woh (yani Mahua) Van devta ka daan hai." (We avoid setting fire when the Mahua flowers are falling as because we consider it as gift from the forest God and if we set fire that time, it considered the disrespect to him.*

These types of customary fire management practices spread through an oral code of conduct, frequently prescribed by elders or religious figures in the community. These rules are sensitive to ecological calendars, such as avoiding fire during key flowering and fruiting seasons of Mahua flowers, Tendu leaves, Achar and coordinating burning during safe humidity periods.

Grounded on field survey interactions, particularly with the adherents of Gond and Korku tribal communities, we identified a consistent set of responses regarding their customary rules and practices related to fire use. Through thematic grouping of these recurring descriptions, we categorized their traditional knowledge and forest-use practices into five distinct domains, as detailed in table below 6.3. These categories reflect practical forest management strategies and cultural norms that have guided community-based fire management for generations.

Table 6. 3: Major Customary practices performed in the HFD *(Source: Author and his understanding from the field study).*

Domain	Customary Practice	Associated Rules / Norms	Cultural or Ecological Purpose
1. Fire Management (Cultural Burning)	Seasonal surface burning (locally known as *Shaal alaana* or *Baari saaf karna*)	○ Fire is set mainly in early summer (March–May) under calm wind conditions. ○ Burning is done in patches and always supervised by elders. ○ Sacred trees and dense canopy areas are excluded.	▪ Clears dry biomass to prevent large wildfires. ▪ Facilitates NTFP collection (e.g., Mahua, Achar, Gulli). ▪ Stimulates regrowth of grasses for cattle.
2. Forest Access and Use Rights	Clan-based allocation of forest trees/patches for resource collection (Mahua, Achar, Tendu, etc.)	○ Forest collection zones are informally divided among hamlets or kin groups or sometimes by forest dept also to minimize the clashes. ○ Outsiders require consent from elders. ○ Certain trees or areas are off-limits during specific seasons.	▪ Ensures equitable access to forest produce. ▪ Prevents overharvesting and intra-community conflict.
3. Sacred Tress (Dev Van / Sarna)	Designated forest patches preserved for worship and spiritual purposes	○ No fire, felling, or extraction allowed. ○ Worship is conducted during annual rituals (e.g., *Bada Dev* festival). ○ Seasonal restrictions on entry or use.	▪ Preserves biodiversity refugia. ▪ Reinforces spiritual and cultural connection with forest.
4. Knowledge Transmission and Social Sanction	Oral tradition through elders, *Gonds & Baigas* (ritual specialists), and *thakurins* (senior women)	○ Fire practices taught informally. ○ Offenders may face public reprimand or exclusion from community rituals.	▪ Maintains intergenerational knowledge transfer. ▪ Upholds adherence to sustainable practices.
5. Dispute Resolution	Local, customary mechanisms for resolving conflicts over forest use or fire damage	○ Disputes handled by village council or elders. ○ Penalties include compensation in kind or labor. ○ Rarely involves the forest department or external courts.	▪ Quick resolution without legal escalation. ▪ Strengthens internal accountability.

However, the Forest Department's approach stresses blanket fire suppression, and they generally perceived fire as harmful events, irrespective of context, and forest guards are tasked with extinguishing any detected fire (Table 6.4). However, this policy has often proved counterproductive, preventing traditional burns has led to fuel load accumulation, increasing the risk of uncontrolled fires during dry days.

Table 6. 4: Aspects of fire management based on Community practices vs. State fire suppression (*Source: Based on author's understanding)*.

Aspect	**Community Practices**	**Forest Department Approach**
Fire Use	Controlled burns for forest health, fuel management	Fires seen as harmful, extinguished on sight
Timing	Seasonal: pre/post monsoon, avoids flowering seasons	No consideration of local seasonal timing
Decision-making	Collective, often led by elders or religious figures	Centralized, top-down
Firebreaks	Maintained using natural barriers and cleared lines	Infrequently maintained or absent
Purpose	Regeneration, pest control, NTFP enhancement	Fire suppression and legal compliance
Ecological Knowledge	Embedded in TEK, adaptive to local biodiversity	Limited engagement with local knowledge

This contrast highlights the disconnect between state policy and indigenous practice, reinforcing the need to integrate community fire knowledge into broader forest governance frameworks. These local systems are cultural relics and represent viable, adaptive fire management strategies rooted in intimate ecological understanding.

6.4 Gendered and Caste-Based Practices Related to Fire

The knowledge and practices around forest fire are unevenly distributed within forest-dependent communities, shaped by social hierarchies such as gender, caste, and tribal affiliations, influencing who performs, controls, or is affected by fire-related practices (Eriksen, 2014; Huffman, 2013). Women, particularly from Scheduled Tribes (STs), show a crucial but often undervalued role in managing fire in daily forest-related work (Elias et al., 2020). They are typically responsible for collecting firewood, Mahua flowers, and Tendu leaves, all of which are sensitive to fire cycles. During the survey, it has been found that in many villages, women also participate in fire rituals, such as lighting the ceremonial fire during *Hari Jiroti* or *Bidri Puja*, but they are often excluded from formal decisions on when or where to burn. Women have practical knowledge about safe harvesting times, fire patterns, and post-fire regeneration but they are rarely consulted in fire management decisions made by men or Forest staff.

And another entity is the caste dynamics which also influence access to forest resources after fire events. Dalit and other marginalized groups often report being blamed for accidental fires or accused of negligence when collecting forest products. A Dalit man from Khamariya village described, *"After the fire event, they (the forest department) say 'you people burn it for wood,' but we go only to pick what's left. We are always watched."* These patterns underscore the juncture of fire, power, and inequality in forested regions. A more inclusive fire governance system should recognize the position of women and marginalized castes as recipients of benefits, active knowledge-holders and decision-makers in ecological stewardship.

6.5 Case Studies (Village Ethnographies)

The micro-ethnographies from a few selected villages from the study area, show how indigenous ecological knowledge, ritual symbolism, and seasonal patterns accompany fire activities. These case studies contrast the singular narrative of fire as a hazard that is common in state discourse with the numerous or plural ontologies[38] of fire.

a) Case Study 1: Fire as a sacred boundary marker (Kaveli Village, Itarsi Range)

Local farmers in Kaveli village, whose agricultural lands share the borders with the dense forest, engage in a customary type of prescribed burning which is known as *Rekh Jalaav*. In order to stop forest fires from spreading from nearby forests to their agricultural fields, this technique entails placing controlled fire lines at the edge of farmed areas. As described by a 60-year-old Gond farmer Ramesh during a field interview, *"We burn the line just after Holi, when the winds are calmer and the fields are still free from crops. This is what my father used*

[38] In this context, ***ontologies*** defined as the differing ways of understanding and experiencing reality. This term travel beyond knowledge (*epistemology*) to describe the fundamental nature of being or existence. When the case studies highlight the *plural ontologies of fire* then they point towards the fact that tribal and indigenous communities perceive fire as a cultural tool, ecological regulator, and spiritual. They are not limited to the understanding which frame fire as destructive hazard (as in state or scientific discourse). These various meanings stand against to the dominant, singular ontology within state institutions that frames fire primarily as a risk to be suppressed or controlled.

to do, and his father did it before him. It identifies our land with the blessing of fire and keeps the fire out of it. However, the sarkar (forest department) has begun imposing restrictions, and I'm concerned that eventually they will outright forbid burning.”

In addition to serving a practical purpose, Fireline serves as a ceremonial barrier that separates the forest's spiritual domain from human-managed territory. In order to invoke protective deities, villagers frequently scatter mahua ash along the boundary. However, this practice has been interrupted by the Forest Department's increasing restraints and their blanket fire control approach and policies, which are viewed locally as being both ecologically and culturally irrational.

b) Case Study 2: The burning moon cycle and Korku elders (Dhaknipura village)

Among the Korku tribal elders of Dhaknipura village of the Seoni Malwa forest range within the HFD, fire use is deeply synchronized with lunar calendar. Burning usually happens during the Chaitra moon's declining phase, when the wind is moderate, and the dry leaves have completely fallen. Locals refer to this time as Nindhani Purnima, or "fire sleep," during which flames are supposedly calmer and less violent. An elderly informant, Budhiya Bai, a 78-year-old Korku woman, she recounted: *“We avoid burning during growing moon because during this time there are high probabilities that fire can grows with high and may spread wildly. During dark moon, it listens better. We say fire has moods, like people.”* This practice exposes a cyclical cosmology that views fire as a sentient force whose actions are connected to ecological and celestial cycles. In contrast to state-led fire calendars, which are inflexibly bureaucratic and frequently out of step with regional seasonal variations, it exhibits a refined temporal awareness.

c) **Case Study 3: Fire, myths, and Mahua collection season in Morpani village**

It is in the Sukhtawa forest range and here the Mahua tree holds sincere ecological, economic, and cultural significance for the tribal communities, especially the Korku people. Mahua's blossom and harvesting season, which usually lasts from March to April, falls during Central India's busiest fire season. Fires can seriously disrupt the flowering process, burn the forest floor, and degrade the amount and quality of flowers collected during this time, endangering a vital seasonal source of income. However, fire is not only seen as a problem in this situation. Fire has two roles in local cosmology: it is both sacred and useful. Tribal oral traditions state that the Mahua flower, which represents a delicate balance of heat and purity, is thought to have originated from the magical union of fire and moonlight. In the words of Mr. Lal Singh, belonging from Morpani village, an elder Mahua collected, shared with us, *"If burn is completed before Mahua falls, it helps clear the snakes and the thorns. But if it is done late, it burns the gift. That is a big sin commit with the forest god deity."* This reflects a form of moral ecology, in which the ethics of environmental actions such as fire use, are exited in reciprocal relationships with forest spirits, seasonal cycles, and community well-being, rather than being dictated by formal legal prohibitions. However, recent enforcement by the Forest Department against all forms of fire (including culturally controlled burns) has disrupted this ecological pattern. In discussions with one Korku family actively preparing for Mahua collection (see Figure 6.2), it was observed that: *"Due to restrictions on using fire before Mahua flowering, we are forced to abandon our age-old cultural burning practices. Now, we must manually clear the ground, which takes much more time and effort."* This shows the tension between formal fire repression policies and traditional knowledge, raising questions about the cultural costs of rigid environmental regulation.

d) Case Study 4: Learning fire through festival and conflict (Jhiriya Jhora Village)

It is a mixed-caste village located near the Bankhedi forest range, where fire use practices are inherited from elderly members of the community, actively learned, and negotiated through community festivals, seasonal work, and everyday forest interaction. Such as the Hari Jiroti festival, represents a local springtime celebration, serves as an unofficial training ground for young boys and girls to observe and participate in forest clearing and firebreak creation. During the festival, older villagers lead groups into the forest to remove dry leaf litter, build fire lines (*rekha banaana*), and sometimes conduct symbolic low-intensity burns. These are framed as acts of purification and regeneration. Youths often accompany elders, learning fire etiquette in both pragmatic and ritual terms.

However, tensions exist between tribal and non-tribal settlers (particularly dominant-caste agriculturalists), who view fire mainly as a risk. One forest worker from the OBC Yadav community remarked: *"These Adivasis are the main culprits who burn the forest every year and label it as their annual practice part. But we have crops. If it spreads, who will take responsibility and compensate me?"* Contrary to this narration, tribal youth like Ms. Maya Bai, a 21-year-old from the Gond community, expressed her frustration: *"We know when and where to do burning and when not to. But nowadays they are putting all blame on us even if there's a fire from the electric wire."*

This case studies reflect how intergenerational learning of fire is shaped by the cultural mounts, festivals, seasonal beats, social conflict, and mistrust. Fire becomes a political climax, one that reveals power orders, the contested legitimacy of knowledge, and the shifting dynamics of ecological authority.

Fig. 6. 2 A Korku family (a mother with her two children, and a dog) is clearing the forest floor manually for Mahua flower collection in Morpani village *(Sources: Author, March, 2024)*.

6.5.1 What do these case studies tell us about fire, knowledge, and culture?

The above-mentioned village ethnographic case studies provide texture, grounded, and empirical living reality into how the ontology of fire is perceived —socially nurtured, symbolic, and contested practice. Across diverse villages and communities, several themes emerge:

- *Fire as situated and contextual knowledge:* Traditional fire practices, whether used for boundary marking, forest regeneration, or NTFP preparation are shaped by place-based ecological cues, including soil moisture, lunar cycles, flowering seasons, and winds. The knowledge lies in everyday routines, festivals, and oral traditions rather than codified manuals. Importantly, villagers often differentiate between good fire (controlled, purposeful) and bad fire (accidental, destructive), a tinge which is very so often absent from state-led fire suppression discourse.
- *Inter-generational and personified learning:* To transfer and diffuse fire knowledge, communities do not depend on formal mode of education instead they propagate their knowledge through seasonal festivals like *Hari Jiroti*, or practical field rituals during agricultural cycles, however, these are informal ways but powerful learning sites. Youths

observe, learn, replicate, and internalize when and how to do the burning, as well as when not to burn.

- *Fire and identity: sacredness, symbolism, and sense of belonging:* From *making Fireline* in Kaveli to the mythologization of the burning moon among Korku elders, fire holds spiritual and cosmological meanings. It shows not just physical space, but also cultural and moral boundaries. Trees like *Palash* and *Dahiman* are recognized as sacred and burning them is seen as a moral sin.
- *Conflict, marginalization, and fire-politics:* On one side (tribals) fire is considered as part of stewardship. Contrary to this, the other side (dominant non-tribal or OBC groups, and frequently forest officials) perceived fire as an agent of destruction. This results in blame politics, where indigenous (tribals) are often scapegoated for accidental or natural fires. For instance, the Jhiriya Jhora case reveals how social hierarchies and mistrust shape who is allowed to use fire, and who is silenced or criminalized.
- *State policies vs. Customary Systems:* These cases show a deep epistemological rift between customary fire management practices (based on traditional knowledge, ecological familiarity, and flexible practice) and the state's restrictive, surveillance-driven method to fire control. Where communities emphasize prevention through controlled burns, forest authorities focus on prohibition, often ignoring the ecological costs of fire exclusion.

Lastly, these micro-ethnographies highlight the need to re-think and reframe fire from threat to a cultural practice, a form of local ecological reasoning, and a site of contested authority. Any future fire governance should begin with the 3Rs approach that stands for reconsidering, recognizing, and respecting the traditional knowledge systems sourced practices in forest fire management.

6.6 Friction between Traditional Fire practices and State Policies

In forested regions of central India, the customary fire knowledge systems rooted in generations of ecological learning—are increasingly clashing with statutory forest governance regimes that criminalize local fire practices. This friction stems from fundamentally different notions of fire itself: while locals (including tribals and non-tribal people) see fire as a tool for regeneration, protection, and livelihood, the state tends to view it as a hazard to be suppressed and penalized.

6.6.1 Criminalization and Surveillance of Customary Burning

As the amendment in the Indian Forest Act and reinforcement of fire repression policies, the use of controlled burning by communities has often been treated as illegal. During the field interaction with the various local people across the study region, they had collectively reported cases of fines, warnings, and even confiscation of tools when traditional prescribed burns were steered, even keeping with local safeguards in place. In the wording of Ms. Nandu Bai, a mahua flower collector woman from Kaveli Village, *"We were clearing dry leaves from the edge of our fields by burning them, just like our elders used to do. But the forest guard came, took our phawda (hoe), and told us we would be reported. Even he didn't ask why we were burning."*

Contrast, forest department officials express concern about uncontrolled fire spread**,** particularly during dry days. For them, the lack of documentation and unpredictability of community burns presents a fire risk. As the Itarsi forest range officer shared with us-*"People set fires without informing us. If it spreads, they don't have the capacity to control it. Our job is to prevent forest loss, not encourage open fires."*

6.6.2 Mistrust and Miscommunication

Both the tribal community group (Gond and Korku) described that their traditional knowledge-based practices were not taken seriously during joint meetings or when fires were discussed in gram sabha (village level assembly) meeting. Instead, state representatives consider emphasizing more surveillance, patrolling, and fire line cutting, often without participation from tribal community people. This one-way communication leads to distrust and contestation, with villagers feeling they are being punished for following their ancestral sourced practices. On the contrary side, officials often assume locals are careless or deliberately destructive (Table 6.5).

Table 6. 5: Contrasting Perspectives on Fire Use *(Source: Derived from the information received during the field survey responses from both sides)*

Theme	Community Perspective (TEK)	State Perspective (Forest Dept.)
Cause of Fire	Natural + intentional for forest cleaning, boundary	Intentional fire by locals, seen as mismanagement
Control Mechanism	Early burning, fire breaks, community monitoring	Strict prohibition, patrols, and post-burn penalization
Fire Knowledge Transmission	Oral, seasonal, intergenerational	Scientific, centralized, technical training
Role of Fire	Regeneration, NTFP facilitation, safety tool	Risk factor, threat to biodiversity and infrastructure

The less inclusiveness of traditional knowledge of fire use has serious repercussions, in the form of increasing community resentment and potentially reducing the effectiveness of fire control itself. Several recent wildfires across the geographies[39] and study region were reported to have spread more rapidly due to thick dry leaf litter**,** which elderly argued could have been cleared with small, pre-monsoon fires. As a Korku elder from a village near to Jhiriya Jhora expressed, *"Earlier we used to burn the forest paths before Mahua flower season, but nowadays now the leaves pile up like a carpet in the forested areas and when fire comes, it spreads like a superfast train which nobody can stop it."*

6.7 Why TEK Matters for Fire Policy

The central framing of fire governance in India remains rooted in a technocratic paradigm[40] (Bisht, 2020). Within this framework, TEK is often dismissed as anecdotal, outdated, or unscientific source (Jolly, 2022; Suhardiman et al., 2026). However, as this study and particularly this chapter, presents through various grounded and local lived experiences of communities with fire reveals that traditional bodies of knowledge constitute a flexible, adaptive, and contextually grounded system of ecological reasoning and cognition, formed by longstanding inhabitation, cyclical forest beats, and intergenerational trial-and-error practicals.

TEK-based fire practices are not static folklore; rather, these are what a prominent fire historian Stephen Pyne (1997) calls a *"vernacular fire regime"*, a way of living with fire rather than simply fighting with it. These practices develop with the passage of time from close knowledge of local flora, fauna, seasonal timing, and spiritual cosmologies. As fire scholars including Pyne (1997), Bowman (2009), Christine Eriksen (2007;2014), Mistry (2016), and Anna Tsing (2024) argue, the marginalization and exclusion of these generational local knowledge reproduces a gap in information and reflects a deeper epistemological bias: the favoring of centralized, calculative authority over local lived realities, experiential knowledge. This epistemic lopsidedness is particularly strong in India, where the Forest Department's institutional culture tends to criminalize fire use, even in cases where it is ecologically favorable. With this contrast, TEK provides a low-cost, community-based model of adaptive resilience, capable of responding to shifting weather patterns, local fuel loads, and traditional resource needs. Such systems often include oral rules (e.g., not burning during Mahua

[39] The *Camp House Fire* (2025). https://en.wikipedia.org/wiki/Camp_House_Fire, *Jones Road Fire* (2025). https://en.wikipedia.org/wiki/Jones_Road_Fire *(These two-wildfire example were used here as a contextual reference to recent fire spread under dry fuel conditions.)*

[40] One that casts fire primarily as a threat, to be prevent or suppressed through top-down interventions, including surveillance, strong fire line cutting, and punitive regulation

flowering), customary seasonal calendars, and collective monitoring practice, forms of knowledge that cannot be captured by satellite imagery or GIS alone. Moreover, TEK would not be romanticized as anti-modern motion, but understood as part of hybrid fire governance that combines grounded customary norms with scientific principles. Similarly, Tania Li (2007), argue that the recognition of indigenous knowledge is a matter of environmental productivity, policy justice, and democratic participation. And when fire governance excludes those who live neighboring to the forest, it not only fails to control fire, but it also erodes trust, weakens co-management, and expands ecological vulnerability.

In this manner, the matter of TEK is not limited to empirical objectivity but it holds a theoretical grounding: it represents a relational ontology of fire, where fire is seen not as an enemy but a necessary ecological process to be stewarded. As Pyne (2019) said, eliminating fire entirely from an ecosystem, is not a solution to the harmful effects of uncontrolled forest fire. In many regions, ecosystems have become deeply tied with human-managed fire practices over time. As a result, banning fires altogether through strict fire suppression in forested areas or national parks can threaten the survival of certain species that have evolved to depend on periodic burning. This exemplifies that fire plays a composite and significant role in shaping the planet and addressing fire-related challenges requires more than simply removing fire from the equation. Recognizing this opens new avenues for participatory fire policy, co-management frameworks, and culturally attuned climate resilience. There is a need to substitute technocratic tools with indigenous ones and rethink fire policy itself as a dialogic in a pluralist domain (where both satellite data and moon cycles, predictive models and oral taboos, forest officers and Korku elders co-produce fire knowledge for a shared future).

6. 8 Concluding Remarks

Fire has been seen within the lived experience of forest-dependent communities in the study region in both the frames—feared and revered. It obliges as a cultural indicator, an ecological signal, and a symbolic presence fixed in seasonal beats, spiritual rituals, and livelihood driven practices. This view challenges the mainstream narrative i.e., fire is enemy to forest health, biodiversity, and livelihood modes. Across communities, fire is used intentionally and carefully regulated by their generational environmental cues and practices such as lunar cycles and traditional rituals that translate ecological prudence. Local practices including boundary burns before sowing, ritual cleansing through fire during village festivals, or the careful timing of Mahua collection amidst fire risks all reflect a deep entanglement of cultural meaning and ecological adaptation. These are arbitrary customs, informed and time-tested responses to the forest's seasonal and ecological changes. However, traditional fire knowledge is non-homogeneous; it is shaped by gender roles, caste positions, and age-based authority. Women, Dalits, and marginalized groups often play crucial but invisible parts in both the material and ritual dimensions of fire, ranging from collecting NTFPs in post-burn landscapes to mediating communal norms during burning events. Still these groups are frequently excluded from formal fire management discourse, both within and outside the village.

Regulatory frameworks, frequently based on criminalization and suppression, misunderstand or outright ignore the logic of traditional fire practices. This gave birth to the emergence of major tensions between place-based knowledge and the state's technocratic approach to fire governance. Instances of fines, equipment seizure, or distrustful surveillance by forest officials have led to growing mistrust, contestations, and weakening collaborative possibilities between state and community performers. This disconnect is administrative and it reflects hidden epistemic hierarchies where scientific management is privileged, and Indigenous knowledge is dismissed as outdated or unreliable. But far from being static or irrational, traditional ecological knowledge reveals flexibility, resilience, and an ability to respond adaptively to changing environmental conditions. It provides a counter-alternative to fire policy which built exclusively on suppression, exclusion, and technocratic control.

In due course, what emerges is a call for fire governance entrenched in co-production: one that acknowledges TEK as a legitimate and policy-relevant system of environmental understanding (Mistry & Berardi, 2016; Smith et al., 2024; Suhardiman et al., 2026). By valuing Indigenous knowledge cum perspectives and nurturing sincere co-management, fire can be reframed from the dominant tag of ecological disruptor to a site of cultural continuity, local agency, and adaptive resilience.

CHAPTER-7

Fire Governance

Through the Lenses of Community Participation and Institutional Interfaces

The effectiveness of forest fire management is closely tied to community engagement and the responsiveness of local institutions (Suhardiman et al., 2026). This chapter presents and analyzes the responses related to the presence and functioning of forest management institutions like the *Joint Forest Management Committees (JFMCs)* or *Van Samitis*, the degree of voluntary participation in fire suppression and mitigation cum management, perceptions of government responsiveness, and local perspectives on governance and market challenges by following the same method of inquiry as did for previous chapter.

7.1 Existence and Functioning of JFMCs or Van Samitis

Out of 385 respondents who answered the question, a slight majority (213) households (approximately 55%), confirmed the existence of a Van Samiti (Joint Forest Management Committee or forest fire committee) in their village, while 172 respondents (45%) reported no such institution. In villages where these committees were present, respondents mentioned that the typical committee comprised 10–11 members. Their primary responsibilities included notifying forest officials about fire outbreaks, monitoring signs of forest degradation (such an illegal logging, construction, and forest land encroachments), sometimes voluntarily serve in tendu leave collections and plantations drive's management at village level, and reporting incidents involving wildlife, such as animal attacks.

Regardless of the formal presence of the JFMCs, the real engagement and representation of the locals appear limited (see Fig 7.1). Locals expressed their lack of enthusiasm to join Van Samitis or JFMCs, citing that these bodies hold little practical value in improving their livelihoods or income on ground. Respondents often perceived that most decisions are made either by higher-level forest officials or by dominant caste groups who control the committees. As a result, lower caste and marginalized community members feel excluded and perceive their participation as symbolic rather than substantive. Furthermore, being a member often led to unpaid responsibilities, which many prefer to avoid in favor of paid labor elsewhere.

In some villages such as Lalpani, Nanupura, Jaali Kheda (particularly in the Itarsi forest range), a contrast perception emerged. Here, respondents indicated a willingness to join Van Samiti or JFMCs, mainly because of the perceived benefits of being associated with forest officials. However, even in these areas, opportunities for broader participation appeared limited, with several community members reporting that they were never given a chance to be included.

Fig. 7. 1 This picture shows the glimpse of the group discussion which has been conducted with Korku tribal community people at Lalpani village, reveals that many locals hold a keen desire to join Van Samiti or JFMC in their village so they can build better coordination with forest officials, However, due to many barriers which limit their meaningful participation, include caste-based barring, lack of transparency in decision-making, absence of tangible benefits, and the burden of unpaid responsibilities. This group discussion indicates the weak institutional representation and the socio-economic limitations that hinder inclusive forest governance and fire management *(Source: Author, December 2025).*

In total, only 28 respondents (around 7%) of the sample reported having served as a member of a Van Samiti or JFMC committee. This limited participation suggests a major disconnect between institutional forest governance structures and the local communities. It raises critical concerns regarding the inclusivity, awareness, and participatory functioning of such institutions, which are central to effective and equitable forest fire management.

7.2 Community Participation in Fire Suppression

Even with limited formal membership-based participation, there is strong evidence of informal community engagement in fire response in Hoshangabad (Fig. 7.2). Also, a significant 239 respondents (62%) stated that they have voluntarily participated in fire suppression activities. These efforts are often unpaid, led by a sense of community responsibility and dependency on forest resources. However, there is no systematic compensation mechanism for such services. Community members reported receiving occasional employment during plantation drives, with daily wages ranging between ₹250–₹400. This reveals a gap between the state's reliance on community labor and the lack of institutional recognition or reward for their contribution during fire events.

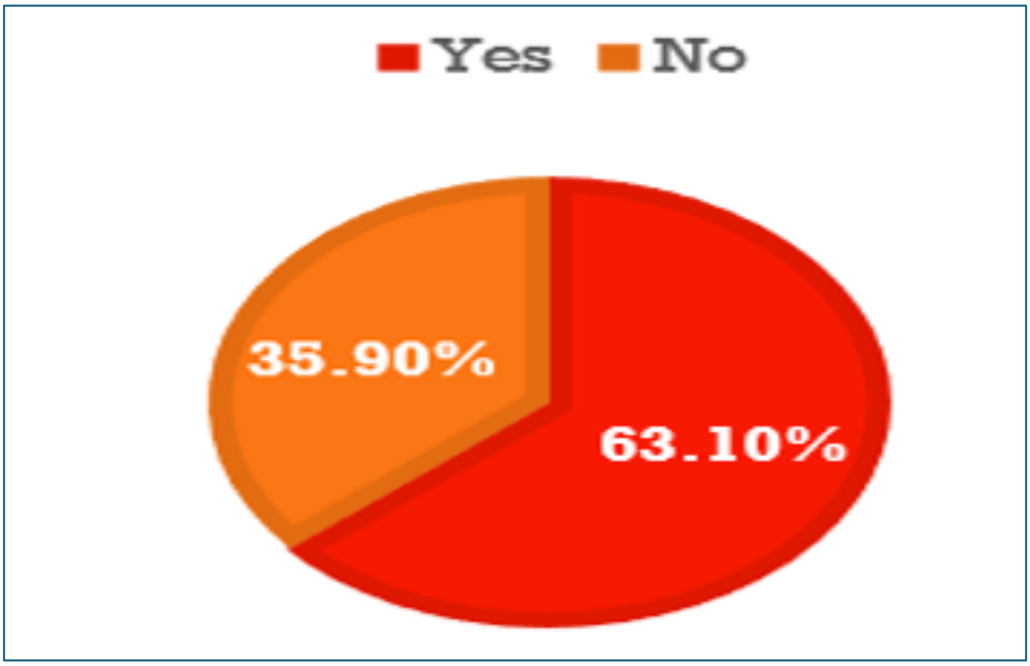


Fig. 7. 2 Do you voluntarily participate in fire suppression during a fire?

7.3 Government Responsiveness and Control Measures

Encouragingly, 370 out of 378 respondents (97.9%) affirmed that government authorities did respond to fire incidents. Responses from the field note that local forest guards (beet guards) often took the lead, while talking with the forest official from different level by visiting their officials to grab both sides picture – one from forest dependent communities and another from the forest officials. After having a detailed discussion with the forest officials from the different forest ranges of the Hoshangabad we came to know their mechanisms, practices, and deploying measures, which we categories into 4 types of measure (Fig. 7.3) based on the field responses are as follows:

A. Removing dry ground fuel (leaf litter and twigs) with air blowers.

B. Engaging community members through verbal calls for assistance.

C. Clearing vegetation along roadsides to act as fire breaks.

D. Creating fire lines using moist leaves and cleared trails.

Fig. 7. 3 Illustrative examples of four key fire control measures undertaken by the Forest Department with community involvement, based on field interviews conducted in HFD. These are —removal of dry ground fuel using air blowers (a), engaging community members for assistance (b), creating firebreaks (c) creation of fire lines (d). The photos visuals are expressive in nature and sourced from various forest regions across India. While not specific to Hoshangabad, they visually demonstrate the techniques described by local forest officials. *(Image source: The Hindu, 2024; The New Indian Express, 2021; Roundglass Sustain, 2025; Mongabay-India, 2020).*

While these efforts were generally appreciated, several respondents expressed concern over the reactive nature of the response, the lack of advanced preparedness, and the absence of firefighting infrastructure like water tanks or protective gear for local volunteers.

7.4 Distribution of Mahua Collection Nets under the Green India Mission

Under the broad coverage of Green India Mission (GIM), Madhya Pradesh state government has introduced an initiative to distribute nets for *Mahua* flower collection. The primary rationale behind this scheme is to reduce forest dependence during the *Mahua* season (March to April), when collectors often clear forest ground by setting small burnings, to get facilitate easy collection of the fallen flowers (World Bank, 2022). Through this initiative it was expected that communities would no longer need to burn dry leaf litter and grass when they spread nets under trees, thereby decreasing the frequency of forest fires and net mahua flower is better in quality compared to the surface fallen flowers (see fig 7.4) so it will contribute and enhance their livelihood also.

Fig. 7. 4 Mahua flower collection Net under the mahua tree (A,C) and the fresh and cleaned mahua flowers collected from the net (B), *(Source: Author, April, 2024)*

Contrary to its noble aim, this initiative was observed during our fieldwork in the HFD, where forest officials confirmed the distribution of *Mahua* flower collection nets to local communities who used to collect Mahua from the open or scattered forest cover. However, feedback from tribal respondents, particularly Gond and Korku groups, exposed critical implementation gaps. Although the idea was well-intentioned, in practice the distribution process was frequently prejudiced by local patronage networks. Many nets were reportedly allocated to influential villagers with political or social connections to forest department personnel, rather than to marginalized or active *Mahua* collectors.

Also, in several cases, the Mahua collection nets were not set up at the right places like in the scattered or open forest areas where *Mahua* trees are naturally found and where the chances of spreading fire are high rather than in private agricultural fields (see Fig 7.4). This compromised the intended purpose of forest fire prevention and limited the benefits for traditional forest-dependent households. The field survey responses from nearly all sampled villages perceived the skewed nature of distribution, and in many forest ranges, the scheme had yet to be implemented altogether. This emphasizes the need for more transparent and rightful mechanisms of benefit-sharing under forest-related welfare programs, especially those targeting ecological risk reduction and livelihood security.

7.5 Local Suggestions for Improving Fire Response, NTFP Markets, and Addressing Socio-Economic Constraints

The households in Hoshangabad who depend on forest derived resources for their livelihood and sustenance put forward a range of context-specific suggestions that highlight deep-rooted socio-economic constraints, governance problems, and livelihood vulnerabilities (Fig. 7.5). The responses have been divided into three broad thematic areas for the ease of better address. These thematic areas are: NTFP market and pricing reforms, fire management and support mechanisms, and forest governance and access rights.

7.5.1 Pricing reforms in the NTFP Market

A major concern has been identified in the field observation was an unfair pricing practices and exploitation by Baniya/Bichauliya (middlemen trader), who buy NTFPs particularly Mahua, flower, mahua seeds, Achar and Amla at meagre prices from the locals and sell at the high rate in the market. This is widely happening in the Hoshangabad region because during the peak harvest seasons, prices drop sharply due to market saturation, and in the absence of local storage facilities or accessible government procurement systems, villagers are forced to sell at their NTFPs at distress prices to these Baniya/Bichauliya. This not only leads to economic loss but reinforces dependence on exploitative intermediaries.

A local key respondent from Jaali Kheda Village (Itarsi), Mr. Yogesh, working actively in advocating for tribal welfare in his area. He shared:

"There is a need to address the scarcity of water in our village and prevent illegal re-settlements in the forest area which are often ignored by the local governing bodies. Alos, there is immediate requirement of government interfere to support and create proper storage facilities for NTFPs, so that we can store our produce—like Mahua, Achar, and Gulli—and sell them at the right time for a better price in the nearby market rather than selling to intermediators or middleman traders at exploitative rate. Right now, middleman traders buy Mahua from us at ₹25–30 per kg during the harvest season (March and April) and later sell it for ₹80–90 per kg. If we had storage, we could also sell at better rates, like the traders do."

These issues and concerns were raised by several households and community representatives across the study region. Collectively, considering these issues and wide field interactions with local stakeholders, the following suggestions emerged as potential policy and governance interventions:

- Establishment of local purchasing committees or cooperatives to eliminate middlemen.
- Need to implement MSP for major NTFPs such as Mahua flowers, Mahua seed, Achar, Amla etc.
- Ensuring timely and transparent payments, particularly for Tendu Patta collectors, many of whom reported delays and underpayments.
- Creation of NTFP sell markets at village level and sell-monitoring centers where grievances could be formally raised.
- Storage infrastructure to allow villagers to sell their produce later at better rates.

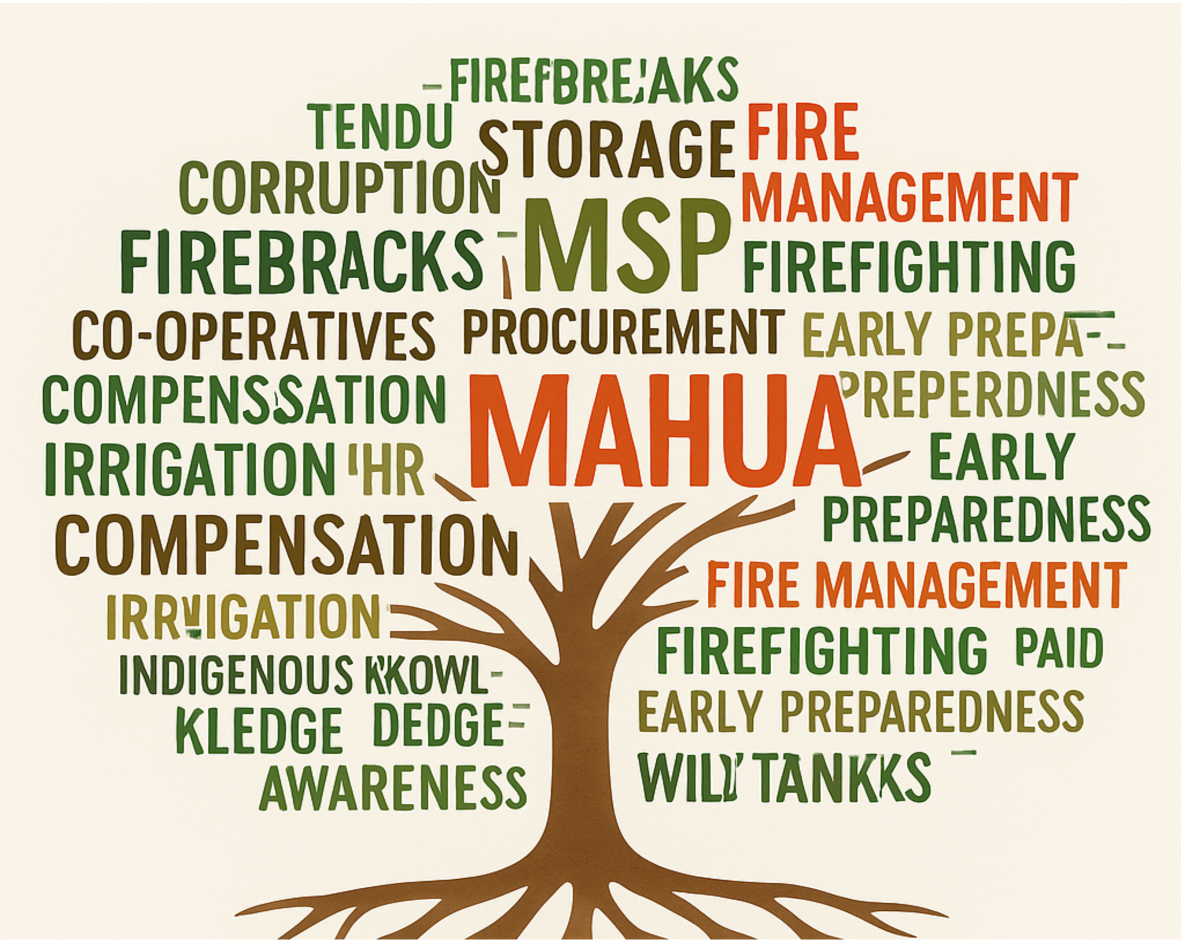


Fig. 7. 5 Word-tree diagram reflects the community's suggestions noted during the field survey, stresses priorities for improving fire response mechanisms, solidification of the NTFP market systems, and addressing broader socio-economic challenges. The figure was generated by

compiling all qualitative suggestion statements into a text corpus and applying a word-tree analysis to identify recurrent terms and phrases. Dominant and frequently repeated terms such as early preparedness, firefighting support, MSP and procurement apparatuses, storage facilities, compensation, irrigation, and the central role of **mahua** - appear as major community-articulated urgencies. The abundance of these phrases reflects shared local perceptions of systemic gaps and signifies areas which need the immediate institutional, policy, and governance interventions.

7.5.2 Fire-management and necessary support

For the effective and timely fire response and firefighting mechanism, the communities particularly emphasized two things. First, there is the need for early fire preparation and second, paid local participation in firefighting efforts. And a collective suggestion across the respondents was that voluntary work in suppressing fires should be financially compensated, and that basic infrastructure should be fed, such as :

- Firebreaks or fine lines created before the dry summer season.
- Government support in the form of fire-response training and incentivize the fire mitigation participation of the villagers or locals during the fire season.
- Formation of Small pani tanki (water tanks) or local ponds for firefighting nearby the fire vulnerable zones as per utilizing the local indigenous knowledge and modern fire detection and management technology.

7.5.3 Forest access, socio-economic challenges, and governance,

Across the HFD, local community members of Gond and Korku tribes have criticized current forest access restrictions, lack of infrastructural support, and inadequate state responsiveness and cited the construction of boundaries and fencing that hampered the traditional movement of people and livestock, disrupted firewood collection, and reduced grazing access.

As per the accounts of Mr. Dol Singh from Borkunda (Banapura Range), *"Upon the creation of forest boundary, we have a shortage of domestic use firewood and grass (fodder) for our animals. They (forest officials) should have at least provided some relaxation, particularly those who are residing in the very close boundary of forests. These types of provisions should be entertained and ensured pathways for local people while constructing the boundary"*. Another description by Mr. Ganeshiya from Naya Raikheda (Pipariya block) stated: *"They* *(forest department) constructed the forest boundary by tapping the fencing. And now we cannot even enter to the many parts of the forests earlier where we used to go freely ."*

Furthermore, these issues were also shared by others, including Ramchandra from Gotabari (Banapura Range), who shared: *" We are (were) using fuelwood for a long time for the domestic purpose such as cooking and to warm up during the winters. However, after the fencing we face a lot of difficulty in collecting the firewood, and we have not been provided with LPG cylinders yet."* Likewise, Bijay from Lalpani (Itarsi) revealed: *"Now, we cannot perform fuelwood collection using our bullock carts anymore."*

Besides restricted access, the households shared strong dissatisfaction with broader socio-economic and administrative concerns and challenges, containing:

- The corruption and aggravation in the form of bribes, fines, and confiscation of tools by the by concerned forest officials.
- Reported repeatedly the lack of transparency and awareness regarding government schemes or associated benefits with the forest use.
- In recent years (last 5-6 years) the visibility of wild boars in the crops has been increased and often time leopards also seen, damaging the crops and endangering livestock and human lives.
- Time to rethink and re-organize compensation schemes in a more compensatory and effective manner, provide supply for irrigation water, and recognize the indigenous forest management practice and inclusive governance.
- There is also a break in market access and price realization for NTFPs. As locals, including Nehrulal from Kasda Khurd (Sukhatawa) informed: *"To receive a fair price for the NTFPs, at least there ought to be a local committee to purchase NTFPs, as we have for tendu leaves. Because nearby markets are too far away from our homes we can't go easily to sell there."*

On policy front, household emphasized for the requirement of Minimum support price scheme to be implemented on ground level and ensure the direct government procurement of minor forest produce. As Laxman from Amjhira village of the Itarsi forest range, shared: *"The state government should directly interfere in the minor forest produce sell and buy Mahua at the right price and regulate the market price timely."* Reverberating to this account, Others like the Rampal (forest staff) in Matapura demanded: *"There must be a strict surveillance of the people and settlement who inhabits near forests and ensure proper MSP should be executed."*

Lastly, household admitted that there is a lack of awareness on various relevant schemes, emphasizing a communication and policy outreach gap.

All these comprehensions show a complex junction of livelihood insecurity, ecological vulnerability, and governance gaps. Thus, addressing these problems and challenges needs not only technical solutions but also a shift toward inclusive, community-led forest governance that incorporates and respects the local knowledge system, labor, and rights of forest-dependent communities.

7.6 Concluding Observations

The concluding observations reflect a clear gap between the formal structure of participatory forest governance and their real functioning at the ground level. Institutions like JFMC or Van Samitis have their on-record presence in many villages, however their effective operation remains largely symbolic in nature on ground, inhibited by elite capture, unpaid responsibilities, and limited decision-making power for side-lined community people. Simultaneously, the chapter shows that the voluntarily community engagement in fire control and management is both widespread and indispensable across the Hoshangabad landscape, though informal and inadequately recognized. Reflecting that local people are protagonist in fire mitigation and conservation activities, motivated by livelihood dependence and moral responsibility rather than institutional incentives. The local government responses towards fire incidents were generally recorded timely during the field survey, still remain reactive due to poor form of infrastructure, lack of modern fire suppression tools, and insufficiently oriented toward preparedness or volunteer safety. Alike, well-intentioned policy interventions such as the distribution of Mahua flower collection nets demonstrate how governance outcomes are often diluted by patronage, uneven execution, and weak accountability. Henceforth, the empirical evidence highlights that fire governance in the Hoshangabad is moulded less by the absence of institutions than by the quality of their engagement with local realities. So, the effective and equitable forest fire management needs a paradigm shift from technocratic approach (i.e., top-down control) toward transparent and community-centred fire governance that participates fair compensation, livelihood security, market reforms for NTFPs, and acknowledgement of indigenous knowledge and their practices. In this sense, the occurrences of forest fires are not just as an ecological or technical challenge, but as a governance issue which is profoundly inserted in questions of participation, justice, and rural political economy.

CHAPTER-8

Conclusion and Way Forward

Key Findings, Policy Implications, Limitations, and Future Directions

8.1 Summary: Chapter-wise Key Findings

This thesis analyzed the dynamics of forest fires and assessed socio-economic and cultural impacts of fire on forest-dependent communities in the HFD of central India. Using a mixed-methods framework grounded in pragmatism by combining geospatial analysis, HH survey data, and qualitative accounts, the study provides an integrated understanding of how forest fire intersect with livelihood systems, traditional ecological knowledge, and governance structures at micro level (i.e., village).

a) Geospatial and Fire Dynamics (Chapters 2-3)

Remote-sensing based analysis indicate a noticeable increase of fire activity across the Hoshangabad. The trend tests show a positive, though not statistically significant, rise in frequency and magnitude of fire events. Spatially, the fire signal is highly concentrated: teak and degraded forests together account for over 91% of MODIS-detected fire incidences, identifying these forest types as the most vulnerable to ignition and spread. Fire density mapping highlights persistent hotspots in the central, northern, and eastern ranges (particularly in Bankhedi, Itarsi, Seoni Malwa, Banapura, and Hoshangabad) while some areas experienced less fire events during the study period. Also, similar pattern was detected in the EHSA map analysis, emphasizing sporadic hotspots in the central, northern, and eastern ranges.

Proximity and risk-analyses express that anthropogenic exposure is a primary driver. Fire occurrences closely track roads and agricultural edges, implicating transport networks and routine collection activities as major ignition agents. Further, AHP-based geospatial risk model also confirms, five of the nine ranges (Seoni Malwa, Banapura, Itarsi, Bankhedi, and Hoshangabad, emerge as high to very-high fire-risk zones, corroborating fire incident counts and the AHP risk map. The remaining ranges show fire activity but with lower extent and intensity, falling into low–to–medium risk categories in the AHP risk assessment model. Peripheral teak-dominated belts are particularly susceptible and largely fall within high–to–very-high ignition-risk classes; conversely, moist-deciduous, and green-moist stands exhibit comparatively lower fire susceptibility.

Collectively, these geospatial results indicate that preventing landscape-level fire risk in Hoshangabad will require targeted interventions in teak and degraded forests, careful management of road–forest interfaces, and measures that address the everyday human activities (especially NTFPs collection).

b) Socio-Economic Impacts on Communities (Chapters 4–5)

The household survey, supported by qualitative data, reveals that forest fires have uneven socio-economic consequences across the HFD, particularly for households heavily dependent on NTFPs. Families who depend on mahua flowers, tendu leaves, chironji (Achar), and fuelwood are affected due to fire occurrences, as fire reduces the availability of these resources, destabilizes seasonal yields, and depresses market value due to irregular supply. Households expressed longer walking distances to collection sites, increased time spent searching for forest produce, and a growing physical burden—sensed most by women and elderly collectors, who bear the majority of NTFP collection activities. These disruptions translate into income losses that compound seasonal livelihood instability and elevate vulnerability among forest-fringe communities. However, the study shows that the impacts commonly emphasized in policy and media such as widespread crop damage, major loss of livelihood, not fully ring with lived experiences in the region. Though fires do contribute to resource stress, communities more frequently attribute their hardships to irregular rainfall, temperature variability, lightening and hot winds, tightening governance regimes, and declining access to forests, rather than to fire during the field inquiry. These research observations highlight the limitations of dominant fire-centric vulnerability narratives, which overstate fire impacts while overlooking broader climate and socio-economic drivers that shape livelihood vulnerability in Hoshangabad region of central India.

c) Cultural and TEK Dimensions (Chapter 6)

The ethnographic descriptions reveal that fire is perceived as a culturally surrounded practice woven into the beats of local life. Communities use fire intentionally and with care for mahua flower collection, grass and grazing renewal, pathway clearing, and periodic village-cleaning rituals. All these practices are reflecting an intergenerational cultural ecology that view fire as a tool rather than a threat. These practices are regulated by a cultured body of traditional ecological knowledge, including early-morning cool burning to minimize spread, the use of community watchers to contain flames, and the maintenance of informal fire-lines around sacred groves and culturally significant sites. Such practices highlight precaution, timing, and containment, standing in sharp contrast to state policy framework that universally labels burning as dangerous, destructive, or illegal.

This fundamental deviation produces persistent friction between community-based fire knowledge and state-led suppression rules. The blanket criminalization of burning delegitimizes TEK, leading to mistrust, contestations, non-cooperation, and episodes of mutual blame during fire incidents. The study displays that these tensions are administrative and deeply relational which is shaping the whole motion that how communities interact with forest staff and how they perceive state authority. Eventually, the conclusions highlight the need to recognize TEK as a legitimate, place-based fire management system rather than treating it as an obstacle to forest protection and governance.

d) Governance and Institutional Interfaces (Chapter 7)

The fire related governance assessment in Chapter 7 discloses substantial gaps between institutional structures and ground realities. The formal existence of many JFMCs or Van Samitis function largely on paper, with limited participation, irregular meetings, and symbolic community representation. Fire-response systems remain chronically understaffed, poorly equipped, and overwhelmingly reactive, activating only after incidents rather than preventing them. Community perspectives further underline these inadequacies: respondents repeatedly called for fair and transparent NTFP pricing, better access to regulated markets, distribution of mahua flower collection nets, and short-term employment opportunities during the fire spell to counterbalance income losses. They (the community) also highlighted the urgent need for sharper communication channels with forest guards, particularly during fire alerts, fire-line preparation, and post-fire assessments.

These conclusions point to a persistent misalignment between top-down mandates and the lived realities of forest-dependent communities. Policies framed at higher administrative levels rarely translate into practical support at the village level, resulting in weakened preparedness, inconsistent enforcement, and declining trust in forest institutions. The outcomes of this research also demonstrate that without meaningful community participation and institutional responsiveness, fire governance relics fragmented, reactive, and ill-suited to the socio-ecological dynamics of the Hoshangabad landscape.

8.2 Addressing the central research problems (a relational reading)

This thesis began with a core set of research problems[41] and the chapters collectively establish that the answers to these questions are not isolated but relational, emerging from the interaction between landscape fire dynamics, community livelihoods, and governance arrangements.

Fire as a socio-ecological process rather than an autonomous hazard- Chapters 3 and 4 showed that forest fires in Hoshangabad are neither random nor uniformly distributed and destructive. The occurrence of fire in two decades shows an upward trend (although insignificant statistically), the clear clustering of fires in teak-dominated and degraded forests, and the strong associations with roads, agricultural edges, and NTFP zones reveal that ignitions are deeply entangled with human activity, forest use, and landscape structure. Fire risk is produced through everyday socio-ecological relations such as mobility patterns, livelihood calendars, leaf-litter accumulation, and seasonal dryness, rather than by climatic variables alone. The AHP model reinforces this relationality by showing that risk concentrations occur where ecological flammability, livelihood dependence, and accessibility intersect. Thus, the first research problem, understanding spatial–temporal fire dynamics, cannot be unglued from the social worlds that shape ignition patterns.

Livelihood vulnerability is not fire-centric- Chapters 5 reveal that fires affect the availability, accessibility, and market stability of NTFPs including mahua, tendu, chironji, and fuelwood; however, communities do not view fire as the primary threat to their livelihoods. Instead, respondents consistently highlighted irregular rainfall, temperature variability, lightning, dry hot winds, diminishing forest access, unfair pricing of forest produce, and labor precarity as the most decisive pressures. Women and elderly collectors face lopsided burdens in the form of longer trips, reduced yields, and rising uncertainty. But these burdens are understood as symptoms of broader structural constraints, not fire alone. These conclusions address the second research problem by showing that dominant fire accounts, stressing fire as the central disruptor which poorly reflects in the local lived accounts. Livelihood vulnerability in

[41] *(a)* How do fires vary spatially and temporally in the Hoshangabad Forest Division, and what biophysical and socio-economic factors shape these variations? *(b)* How do communities perceive the socio-economic and cultural impacts of fire, and to what extent do these perceptions align with or challenge dominant policy discourses? *(c)* Why do top-down, fire-centric framings persist in Central India despite evidence that livelihood vulnerability is shaped more profoundly by climate variability, market instability, and governance structures? *(d)* How can community knowledge systems and lived experiences inform more grounded approaches to fire governance?

Hoshangabad is multi-causal, and fire often becomes a proxy for deeper governance and ecological stressors.

Why does fire-centric discourse persist? - The persistence of fire-centric policy discourse in Central India cannot be explained simply by scientific (mis)understanding. Chapter 7 shows that governance structures from JFMCs that function largely on paper to fire teams that operate reactively, are implanted in a system where fire is administratively coded as a deviation from normal forest conditions. This stems from three intersecting tendencies:

a) Technocratic visibility: Satellite fire "detections," accumulated into annual hotspot lists, increase the spectacle of fire while obscuring its purpose, scale, and socio-ecological context.

b) Administrative simplification: Any burning within forest boundaries is automatically classified as a "forest fire," regardless of whether it is a small, controlled, livelihood-linked burn or a large accidental spread.

c) Governance convenience: A fire-centric framework provides a manageable, event-focused explanation for degradation, diverting attention from politically sensitive issues such as land-use change, industrial encroachment, weak institutional capacity, and declining access rights.

Altogether these factors mutually reinforcing configuration helps response the third research problem: fire-centric framing persists because they align with existing governance structures, institutional incentives, and conservation logics, not because they reflect the grounded realities of forest-dependent communities.

Recognition gaps: TEK, cultural practice, and controlled burning- Chapter 6 illustrates that communities hold detailed traditional fire knowledge e.g., early-morning cool burns, watchers, informal fire-lines around sacred groves, and seasonal patch-burning based on moisture cues. These practices are entrenched in their cultural environmentalisms and serve multiple functions, resource regeneration, forest cleaning, and protection of culturally significant sites. Nonetheless these practices hardly find acknowledgement in state protocols because they challenge the assumption that fire is inherently destructive (Yadav, 2025). This directly addresses the fourth research problem by showing that TEK is not absent; it is systematically under-recognized within the dominant paradigm of suppression-based fire governance (Smith et al., 2024)

Across the chapters, a consistent pattern emerges: Fire dynamics (spatio-temporal), Livelihood impacts (NTFPs, labor, income variability), Cultural and ecological knowledge (TEK), and Governance structures (policies, institutions, frameworks), are profoundly interlinked. Fire in Hoshangabad is neither only ecological nor solely social but it is a relational process, shaped by interactions among climate, vegetation, mobility, market structures, forest access, cultural practice, and institutional arrangements. Addressing the central research problems requires acknowledging these relations. Dominant fire narratives fail not because they are entirely wrong, but because they are partial, privileging certain variables (ignitions, pixels, biomass, legal prohibitions) while sidelining others (livelihood calendars, market vulnerability, cultural practices, governance gaps, climate irregularity).

Therefore, this thesis annotations show that moving beyond fire-centric discourse is not just a conceptual shift but a practical requirement for socially equitable and ecologically meaningful fire governance, particularly in Hoshangabad and in-general for central India.

8.3 Theoretical Alignment and Contributions

This thesis is theoretically anchored in three interlaced and complementary frameworks i.e., political ecology**,** resilience and adaptation theory, and livelihood diversification**.** Through these frameworks it advances original contributions to the study of forest fire, resilience, and environmental governance in India. Collectively, these frameworks enable a critical cross-examination of fire not purely as a hazard, but as a socio-ecological process which is shaped by power, knowledge, livelihoods, and institutional arrangements. ***First,*** political ecology provides the analytical lens by critiquing universalized environmental narratives and examining how institutions frame environmental disturbances, including fire, as crises requiring technocratic intervention (Blaikie, 1987; Robbins, 2012). This perspective reveals how dominant fire discourses depoliticize underlying socio-economic drivers and marginalize local practices. ***Second***, resilience and adaptation theory accentuates the capacity of communities to live with, respond to, and adapt to recurring disturbances through locally set in strategies (Berkes & Folke, 1998). Empirical evidence from the Hoshangabad landscape reveals that forest-dependent communities have developed adaptive practices that mediate fire risk without perceiving fire as an existential threat. ***Third,*** livelihood diversification theory highlights how engagement in multiple income sources reduces vulnerability to environmental shocks (Scoones, 1998; DFID, 1999). The absence of single-livelihood dependence source among households in Hoshangabad strongly imitates a diversified livelihood setting, which curbs the perceived economic impacts of fire.

By integrating the geospatial fire analysis with household-level perceptions and detailed ethnographic understandings, the thesis situates wildfire within a political ecology and socio-ecological systems framework (Blaikie & Brookfield, 2015; Folke et al., 2004; Robbins, 2012). And accordingly, this integration generates several interrelated theoretical contributions.

Fires as Socio-Ecological Phenomena

A crucial theoretical contribution of this study is the reframing of forest fires from isolated biophysical events to co-produced socio-ecological processes. The spatial–temporal trends observed in Hoshangabad such as the concentration of fires in certain ranges and in teak and degraded forests, the strong correlation with roads, agriculture, and NTFP activity, and the influence of plantation histories, demonstrate that ignition, spread, and impact cannot be explained through climatic or ecological variables alone. Instead, they are shaped by interactions between vegetation composition, livelihood practices, and governance regimes.

This evidence challenges hazard-based fire science that conceptualizes fire primarily as an environmental disturbance (Doerr & Santín, 2016). By showing that fire risk is generated at the intersections of ecological flammability, mobility patterns, NTFP economies, forest access regimes, and plantation legacies, the thesis determines that fire is a socio-ecological phenomenon entrenched within material landscapes and livelihood systems.

Theoretically, this aligns with broader work in political ecology and socio-ecological resilience, which argues that hazards and vulnerabilities are produced through human–environment relations rather than through biophysical forces alone (Wisner et al., 2004). Consequently, fire governance should be conceived not as an ecological problem to be suppressed, but as a landscape-scale socio-ecological challenge requiring integrated interventions across ecology, livelihoods, and governance.

Misaligned Narratives Produce Misaligned Policies

A second theoretical contribution concerns the relationship between dominant fire narratives and institutional responses. The analysis reveals a persistent misalignment between how fires are framed in policy and media—as disasters or as outcomes of community negligence and how communities interpret their impacts. These fire-as-disaster or community-as-culprit narratives simplify multilayered fire dynamics and obscure deeper drivers of vulnerability, echoing critiques in critical disaster studies that highlight how dominant narratives reproduce institutional biases (Gaillard & Castree, 2022; Kelman, 2022). Such narratives steer resources toward fire control - equipment procurement, emergency response, and disciplinary enforcement whereas structurally underfunding preventive measures including livelihood diversification, fuel management, market stability, and secure forest access. Community testimonies from Chapters 5 to 7 constantly highlighted that improving NTFP price regimes, stabilizing markets, reducing corruption in procurement, and enabling secure access would reduce risky practices more effectively than legal prohibitions or firefighting expansion.

This mismatch establishes that policies are shaped not by grounded socio-ecological realities but by narrative logics that privilege technocratic visibility (remote sensing pixels), administrative simplification, and a narrow conservation ethos focused on tree cover (Robbins, 2012; Smith et al., 2024; Yadav, 2025). Theoretically, this thesis contributes to literature on environmental governance by showing how discursive constructions of fire directly structure institutional choices, reinforce inequities, and generate policy blind spots that demoralize long-term resilience (Büscher & Fletcher, 2020; Nightingale et al., 2020).

Traditional Ecological Knowledge as Co-Productive Fire Knowledge

A third contribution concerns the reconceptualization of TEK in fire governance. The ethnographic evidence supports that TEK in the Hoshangabad is neither outdated nor incidental. Rather, it constitutes a system of symbolized, practice-based landscape care with measurable effects on fuel dynamics and fire behaviour. Current suppressionist frameworks, however, criminalize all forms of burning, effectively marginalizing these knowledge systems (Yadav, 2025). The study's results align with decolonial and community-based fire management scholarship that argues for recognizing TEK as co-productive knowledge, capable of generating ecological, livelihood, and cultural benefits when meaningfully integrated into formal governance systems (Carmenta et al., 2011; Mistry & Berardi, 2016; Nikolakis & Roberts, 2020). Hence, by showing that TEK practices reduce fuel load, maintain culturally significant forest covers, and regulate livelihood charts, the thesis contributes theoretically to debates on knowledge pluralism and co-management. It argues that TEK should not be treated as emergency evidence invoked only during crises, but as a legitimate epistemic system capable of informing preventive and participatory fire strategies. Institutional recognition of TEK, through co-designed burns, participatory monitoring, and strengthened local governance, bids an alternative to fire control that is socially just, ecologically grounded, and operationally feasible.

Therefore, collectively these three claims advance a relational theoretical framework in which:

- **Fire is co-produced** by ecological, social, and governance factors.
- **Narratives shape institutions**, and institutional choices shape vulnerability.
- **Knowledge systems beyond the state** are essential for sustainable fire futures.

This moves beyond technocratic control models and contributes to a more plural, grounded, and community-informed theory of fire governance in study region and Central India which acknowledges the multiplicity of fire meanings, practices, and socio-ecological relations.

8.4 Policy implications -practice and principles

Based on empirical evidence, the thesis advances practical policy[42] directions grounded in two principles: firstly, protect biodiversity with sustained financial commitment, and second, place local well-being and agency at the core of conservation and fire governance. Further, for ease of understanding, the policy suggestions emerging from the study fall into **two levels**: (a) *Direct recommendations derived from study findings*, and (b) *Broader systemic recommendations* for bearable fire governance in Central India.

(a) Practical policy directions grounded in the study

- **Hotspot-centred prevention:** Prioritize Bankhedi, Itarsi and other mapped hotspots for co-managed fuel reduction, early-season patrols, and drone/thermal surveillance.
- **Integrate TEK into official micro-plans:** Recognize controlled early-season burns where culturally practiced and ecologically appropriate; co-design community burn protocols and monitoring.

[42] *Policy* (in the context of India's forest governance) is the legal provisions (such as the Indian Forest Act 1927, Forest Conservation Act 1980, and Wildlife Protection Act 1972), administrative rules (Working Plans, fire management protocols, Joint Forest Management resolutions), and operational directives issued by forest departments under the guidelines of concerned ministries that shape how fires are categorised, responded to, and governed. It also includes the narrative and bureaucratic logics. In this thesis, policy is understood not just as written legislation but as an *institutionalized practice* that structures everyday state–community interactions, determines whose knowledge counts in fire management, and shapes the distribution of power, responsibility, and vulnerability in fire-prone landscapes of Central India.

- **Strengthen NTFP value chains:** Establish village procurement points, MSP or price-support pilots for mahua and other major NTFPs, and local storage/processing to stabilize incomes and reduce stress-driven risky practices.
- **Revitalize and democratize JFMCs:** Reform membership, ensure women and ST representation, and allocate predictable funds for prevention and community crews.
- **Regulate road–forest interfaces:** Systematic pre-season clearing, signage, and restrictions on roadside drying/burning.
- **Create strong inter-agency fire coordination:** District-level coordination among Forest Dept., Panchayats, local communities, and Police for preparedness and combined action.
- **Invest in monitoring and research:** Continue multi-sensor remote sensing, couple it with ground-validation, and develop classification schemes that distinguish livelihood-related low-intensity burns from risky, high-severity events.

(b) Broader systemic recommendations for bearable fire governance in Central India.

- **Move from "Suppression" to "Fire-Adapted Landscape" Framework:** Through recognize that annual low-intensity fires are ecologically normal for dry deciduous forests. And need to develop a mixed strategy by combining - controlled/cultural burning, early fire detection, and prevention-oriented fuel management.
- **Institutional Reform of JFMCs:** Make JFMC membership inclusive and elected, not nominated. And assign fire-management micro-plans at the *range* level, co-produced with communities.
- **Livelihood Diversification to Reduce Fire Reliance:** Promote bamboo craft clusters (see Appendix 8A), mushroom cultivation, and agro-ecological schemes. And provide skill-based training for youth in poultry, micro crop cultivations, bee rearing, nursery management, or eco-tourism. For instance, a working PRADAN NGO [43] in Hoshangabad provides training and funds to increase the family income of tribals by diversifying their income sources and reducing dependence on forests.

[43] Visit for further info at https://www.pradan.net/

- **Strengthen Inter-Agency Coordination:** Reinforce a district Fire Coordination Cell linking Forest Dept., Disaster Management, Panchayats, local community representatives and Police. Also, conduct annual joint fire drills before the fire seasons.
- **Invest in Remote Sensing and Near–Real-Time Monitoring:** Adopt the Sentinel-2 based burn severity models, drone-based fire scouting, AI-enabled fire prediction tools, and train frontline forest guards in using mobile GIS applications.
- **Post-Fire Ecological Recovery and Restoration:** Prioritize regeneration in frequently-burned teak–degraded zones. There is need to introduce mixed species planting to reduce teak flammability. Also emphasize establishing soil rehabilitation programs for burnt slopes using mulching, native grasses, and check-dams.

On conservation financing and community rights

Given India's exceptional floral and faunal value, the state should increase dedicated conservation funding, but such allocation must be coupled with direct support for forest-dependent people. Funding should simultaneously: (i) secure ecological protection (restoration, soil/watershed work, mixed-species planting in degraded teak stands) and (ii) fund livelihood resilience (NTFP procurement, processing units, MGNREGA[44]-linked community fire crews). Only through parallel investments in ecology and people will conservation measures be durable and just.

8.5 Limitations and Future Scope

Although this study adopted a mixed-methods and interdisciplinary framework that generated comprehensive understanding into fire dynamics, community perceptions, and governance structures in the HFD, several limitations remain that also open important avenues for future research.

From a geospatial and remote sensing perspective, this study relied exclusively on MODIS fire-occurrence data filtered by forest mask and confidence thresholds. While this ensured consistency and reduced false positives, it may have excluded low-confidence fire events, potentially underestimating ignition counts. Fire Radiative Power (FRP) was used as a proxy

[44] *Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA)*, implemented in February 2006, is a rights-based social security programme in India that guarantees a minimum of 100 days of wage employment per year to every rural household willing to do unskilled manual work. It aims to improve livelihood security, create rural assets, and strengthen grassroots governance through participatory planning.

for fire intensity, but comprehensive ground validation across all sites was not feasible, limiting fine-scale assessment of fire severity. The long-term (>20 years) burned-area trends were not included because many Landsat scenes from 2001 to 2022 were incomplete, unavailable, or heavily cloud-affected during the fire season for the study region.

In the socio-economic and qualitative components, household surveys were conducted after the primary fire season, creating the potential for recall bias in reporting fire impacts, causality, and severity. Limited accessibility during the monsoon and in remote interior ranges also restricted ethnographic depth in certain villages. Additionally, however, the study documents broad patterns of Traditional Ecological Knowledge, fire-related cultural practices vary across communities, clans, and gendered roles; hence, the findings may not fully represent sub-group-specific variations.

These limitations highlight important future research directions. *First,* advancing long-term burned-area mapping in Central India will require the use of higher-resolution and more reliable datasets such as Sentinel-2, harmonized Landsat–Sentinel products, or SAR-based approaches (e.g., Sentinel-1). These sensors can significantly improve burned-area detection in cloudy, heterogeneous, and low-severity fire regimes where optical data alone are insufficient. *Second,* improving risk modelling will require sensor fusion approaches, integrating Sentinel-1 SAR, optical datasets, soil-moisture products, and on-ground fuel-moisture probes to refine ignition-risk forecasts. *Third,* longitudinal household panel studies are needed to examine post-fire income changes, labor shifts, migration, and long-term adaptation strategies. *Fourth,* experimental co-management pilots involving TEK-informed controlled burns, implemented collaboratively with communities and the Forest Department can help evaluate their ecological effectiveness and governance feasibility. *Fifth***,** targeted gender-focused research is required to better understand women's labor burdens, decision-making autonomy, and safety concerns within NTFP-based livelihoods. *Finally,* policy experiments in NTFP markets, such as MSP trials or decentralized procurement centres for mahua, tendu, and chironji, can help assess how market stability influences fire-related behaviour, livelihood security, and overall resilience.

Altogether, recognizing these limitations not only clarifies the interpretive boundaries of the present study but also outlines a clear agenda for future inquiry. Together, these pathways propose opportunities to extend understanding of fire as a socio-ecological process and to strengthen community-centered, evidence-based fire governance in Central India and elsewhere in similar geographies .

8.6 Concluding Reflections

This thesis confirms that fire in Hoshangabad is not reducible to a single explanation, nor to a single policy response. Fires are co-produced by land, labor, knowledge, and law. When policy imagines fire only as a hazard to be suppressed, it risks erasing the everyday forms of care and management that historically kept fuel loads low and livelihoods viable. Conversely, when community practice is romanticized uncritically, it risks overlooking present ecological changes and emerging socioeconomic pressures. The path forward requires neither pure suppression nor uncritical permissiveness; it requires a politics and practice of co-production - one that combines high-resolution science with local knowledge, conservation funding with livelihood support, and legal reform with institutional re-design. Doing so will not only reduce the frequency and severity of damaging fires but also secure the ecological and social futures of forests and the people who depend upon them.

As fire historian Stephen J. Pyne (2019) reminds us, *"Fire is not just an ecological event; it is a human artifact, shaped by our choices, cultures, and institutions."* In this light, governing fire responsibly requires attentiveness to the life worlds and experiential knowledge of those who live most closely with it. To understand fire, one must listen not only to the land but also to the people who dwell with and within it. Therefore, this thesis concludes by affirming that the future of fire governance in Central India (HFD) must be anchored in both ecological understanding and human lived experience and ground realities, embracing the diverse knowledge systems that shape this dynamic landscape.

APPENDICE

***Appendix* 2A** Major satellites (sensors) for burned area mapping with their specifications and operational details (modified from Chuvieco et al., 2019).

Satellite (Sensor)	**Operator**	**Launch Date**	**End Operation**	**Temporal Resolution (days)**	**Spatial Resolution (m)**
PASSIVE OPTICAL					
Landsat 1-3 (MSS)	NASA/USGS	23-Jul-72	7-Sep-83	18	80
SPOT 1-3 (HRV)	CNES	22-Feb-86	Continuing	26	2.5 to 20
Landsat 4-5 (TM)	NASA/USGS	16-Jul-82	5-Jun-13	16	30–120
Landsat 7 (ETM+)	NASA/USGS	5-Oct-93	Continuing	16	15/30–60
Terra (MODIS)	NASA	18-Dec-99	Continuing	1-2	250-1000
Aqua (MODIS)	NASA	4-May-02	Continuing	1-2	250-1000
ENVISAT (MERIS)	ESA	1-Mar-02	9-May-12	2-3	300-1200
Landsat 8 (OLI/TIRS)	NASA/USGS	11-Feb-13	Continuing	17	OLI: 15/30 TIRS: 100
PROBA V	ESA	7-May-13	Continuing	1-2	300
Sentinel 2A (MSI)	ESA	23-Jun-15	Continuing	5	10-20-60
Sentinel 2B (MSI)	ESA	7-Mar-17	Continuing	5	10-20-60
Sentinel 3A (SLSTR, OLCI)	ESA	16-Feb-16	Continuing	1-2	300 (OLCI), 500 (SLSTR)
GOES-R	NASA-NOAA	19-Nov-16	Continuing	< 1	500–2000
Sentinel 3B (SLSTR, OLCI)	ESA	25-Apr-18	Continuing	1-2	300 (OLCI), 500 (SLSTR)
ACTIVE RADAR					
Sentinel 1A (SAR)	ESA	3-Apr-14	Continuing	6	5-20
Sentinel 1B (SAR)	ESA	25-Apr-16	Continuing	6	5-20
PASSIVE OPTICAL & ACTIVE RADAR					
NOAA-7 (AVHRR)	NOAA	19-Oct-78	Continuing	1-2	1100
NOAA-19 (AVHRR)	NOAA	6-Feb-09	Continuing	1-2	1100
JPSS (VIIRS)	NOAA	28-Oct-11	Continuing	1-2	375-750

Appendix **2B** Spectral signature-based indices for assessing and monitoring forests cover health, burned areas, wildfire severity and post-fire recovery. Reproduced from *Khan et al (2025)*

S.No.	Indices	Formulae	Applications	References
1	Normalised Difference Vegetation Index (NDVI)	$\frac{NIR - Red}{NIR + Red}$	Used to evaluate vegetation condition, monitor land cover dynamics, identify drought-induced stress, and analyze land use transformations before and after wildfires	(Chuvieco et al., 2003; Degerli & Çetin, 2022; Gabban et al., 2008)
2	Normalised Burn Ratio (NBR)	$\frac{NIR - SWIR}{NIR + SWIR}$	Applied in detecting burned regions, assessing fire impact severity, and tracking vegetation regrowth in post-fire landscapes	(Key & Benson, 1999; Mamgain et al., 2023)
3	Composite Burn Index (CBI)	$\frac{\sum_{i=1}^{n} Si}{n}$	Facilitates post-fire assessments by measuring ecosystem alterations across multiple strata, including canopy, shrub layer, and surface vegetation.	(Key & Benson, 1999; 2006)
4	Composite Fire Index (CFI)	$f\left(\begin{matrix} Fuel\ moisture, Wi \\ Temperature, Relativ \\ Other\ facto \end{matrix}\right.$	Supports fire danger forecasting and informs fire management strategies by integrating variables like fuel moisture, wind, temperature, & humidity.	(Wagner, 1987)
5	Normalised Burn Ratio-SWIR (NBRSWIR)	$\frac{SWIR2 - SWIR1 - 0.02}{SWIR1 + Narrow\ NIR}$	Utilized for identifying fire-affected areas, evaluating burn severity, and gauging vegetation loss.	(S. Liu et al., 2020)
6	Normalised Difference Short Wave Infrared Index (NDSWIR)	$\frac{SWIR1 - Narrow\ NIR}{SWIR1 + Narrow\ NIR}$	Effective for mapping vegetation stress levels, classifying forest types, and estimating soil moisture variations.	(George et al., 2006)
7	Mid-Infrared	$10 * SWIR2 - 9.8 * SWIR1 + 2$	Aids in fire damage evaluation, burned area	(McCarley et al., 2018)

	Bi-Spectral Index (MIRBI)		mapping, and monitoring ecosystem recovery after fires.	
8	Burn Area Index (BAI) [Classical]	$\frac{1}{(0.1 - Red)^2 + (0.06 - N}$	Commonly used for detecting fire-impacted zones, assessing burn severity, and analyzing post-fire vegetation status.	(Martin & Chuvieco,1995; Ba et al., 2019; W. Liu et al., 2016)
9	Burnt Area Index for Sentinel 2 (BAIS2) [Modified]	$\left(-\sqrt{\frac{B6 * B7 * B8A}{B4}}\right) * \left(\frac{B12 - B8A}{\sqrt{B12 + B8A}} + 1\right)$	Designed for high-resolution fire scar detection, post-fire vegetation monitoring, and spatial assessment of burn dynamics using Sentinel-2 data.	(Filipponi, 2018)
10	Normalised Burn Ratio Plus (NBR+)	$\frac{(B12 - B8A - B3 - B2)}{(B12 + B8A + B3 + B2)}$	Enhance detection of burned landscapes, quantify fire impact, and tracks vegetation regrowth over time.	(Alcaras et al., 2022)
11	Differenced Normalized Burn Ratio (dNBR)	$Pre\ NBR - Post\ NBR$	Employ pre- and post-fire NBR values to evaluate fire severity and monitor changes in vegetation structure post-disturbance.	(Key & Benson, 1999; Mamgain et al., 2023)
12	Relativized Differenced Normalized Burn Ratio (RdNBR)	$\frac{dNBR}{Sqrt(abs(Pre\ NBR))}$	Normalizes dNBR to improve comparability across landscapes, supporting refined assessments of burn severity and post-fire vegetation response.	(Konkathi & Shetty, 2019)
13	Relativized Burn Ratio (RBR)	$\frac{dNBR}{(Pre\ NBR + 1.001)}$	Enables nuanced measurement of fire severity and assists in evaluating ecological changes in burned regions over time.	(Konkathi & Shetty, 2019; Parks et al., 2014)
14	Fire Index (FI)	$\frac{NIR - Red - 0.011 - NIR}{NIR + Red - 0.1 + Green}$	Helps delineate fire-affected zones, assess fire impact levels, and analyze vegetation conditions following wildfire events.	(Xofis et al., 2020)

Method	Algorithms/Models	Functionality (How It Works)	Application in Burnt Area Assessment
Pixel-based Classification	Maximum Likelihood Classifier (MLC)	Uses Bayesian probability to assign pixels based on likelihood from known class distributions, assuming Gaussian distribution.	Suitable for simple landscapes with normally distributed data. Limited by assumption and large training data requirement.
	Support Vector Machine (SVM)	Maximizes separation between classes using hyperplanes; supports linear & non-linear classification with kernel functions.	Applicable in complex patterns and high-dimensional data; ideal for heterogeneous burnt/unburnt areas.
	Random Forest (RF)	Ensemble of decision trees; combines multiple models for robust classification and reduces overfitting.	Used for large-scale, diverse regions; handles mixed pixels well but sensitive to imbalanced data.
	Decision Tree (DT)	Splits data based on attribute thresholds; interpretable and fast.	Useful for small datasets; prone to overfitting in complex environments.
	Artificial Neural Network (ANN)	Mimics human brain structure to recognize complex patterns using multiple interconnected layers.	Effective in capturing non-linear burnt patterns; requires large training data and high computation.
	K-Nearest Neighbors	Classifies pixels based on proximity to k-nearest labeled samples.	Simple and intuitive; works well in small areas, but less effective for large-scale or real-time applications.
Object-based Classification	Object-Based Image Analysis	Segments image into meaningful objects and uses spectral, spatial, and contextual features for classification.	Good for high-resolution data and heterogeneous landscapes; requires expert parameter tuning.

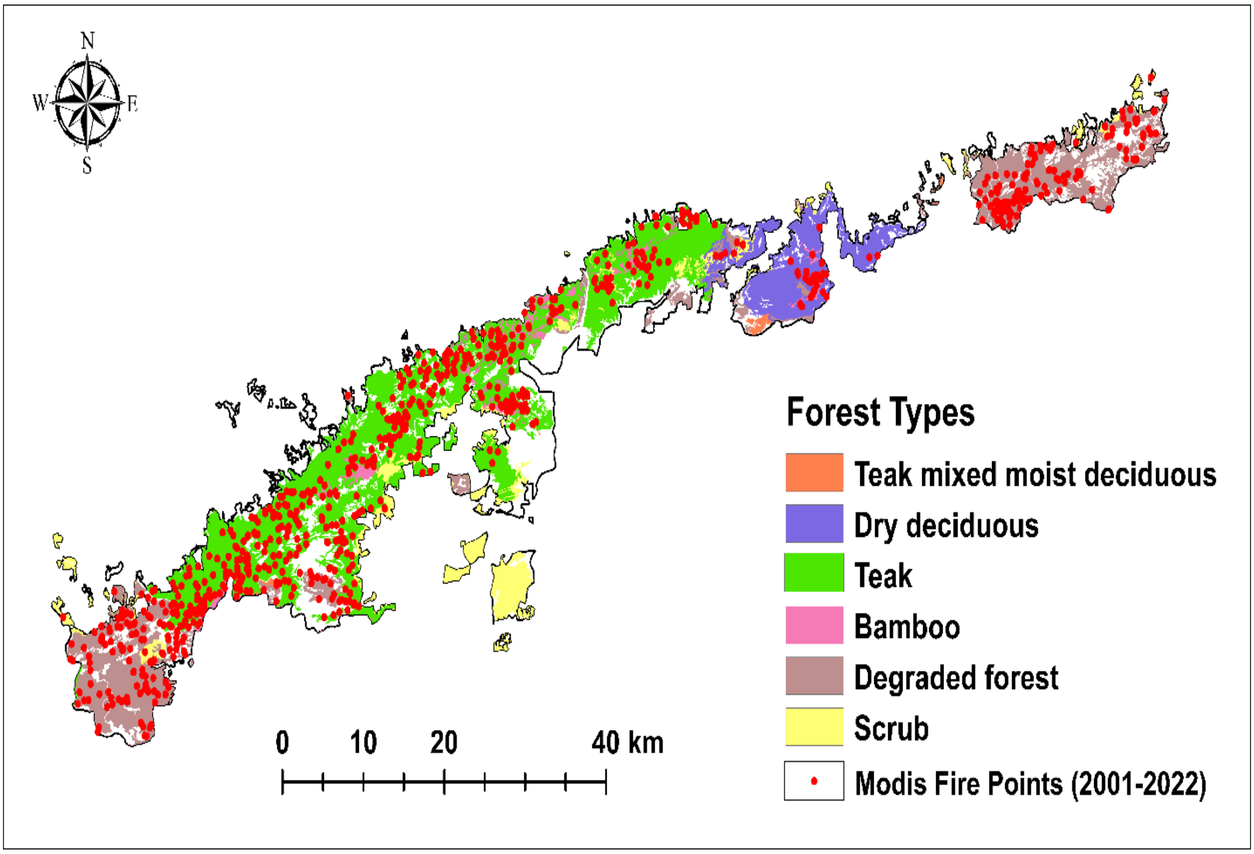
Appendix 2C. Major supervised methods with their specification.

Methods	Algorithms/Models	Functionality (How It Works)	Application in Burnt Area Assessment
CNN	VGG16, ResNet, EfficientNet, U-Net	Extracts hierarchical features from imagery. U-Net captures both local and global features with an encoder-decoder structure, suitable for multi-scale feature extraction.	Detecting fire pixels and burnt areas from multi-spectral, thermal, drone, SAR, and optical imagery.
Transformer-based Models	Pre-trained Vision Transformers	Captures long-range dependencies and global context in imagery data through self-attention mechanisms.	Segmentation of burnt areas, especially in large, complex forest regions like the Amazon.
FCN	DeepLab (DeepLabV3, DeepLabV3+)	Replaces fully connected layers with convolutional layers for pixel-wise classification. ASPP enhances multi-scale feature extraction	Delineation of burnt area boundaries, detecting both small, isolated patches and large contiguous burnt regions.
GAN	StyleGAN, FireGAN	Generates synthetic imagery with realistic fire & burnt area variations. Can also enhance image quality by reducing noise and boosting contrast.	Augments training datasets, improving model robustness. Enhances visibility of burnt areas in smoke, haze, or low-light conditions.
RNN	Vanilla RNN, LSTM, GRU	Processes sequential data, maintaining memory of previous states. LSTMs mitigate vanishing gradient issues, making them suitable for longer sequences.	Analyzing satellite imagery sequences to predict fire spread, monitor fire progression, and track post-fire recovery.
Object-detection Models	Mask R-CNN, Faster R-CNN	Detects and localizes objects within images or video frames. Mask R-CNN adds segmentation capabilities for pixel-level instance recognition.	Real-time detection & monitoring of active fires, tracking flame progression using high-resolution satellite, drone/surveillance imagery.
Specialized Architectures	Burnt-Net (Seydi et al., 2022)	Combines standard CNNs with quadratic morphological operators for enhanced burnt area detection.	Detection of burnt areas in post-fire.
Hybrid models & multi-modal integration	CNN-RNN hybrids, CNN with Hyperspectral & SAR data	Combines spatial and temporal feature extraction. Integrates multiple data sources (e.g., optical, SAR, hyperspectral) for enhanced feature learning	Near real-time wildfire progression monitoring, creation of wildfire susceptibility maps, and long-term fire hazard assessments.

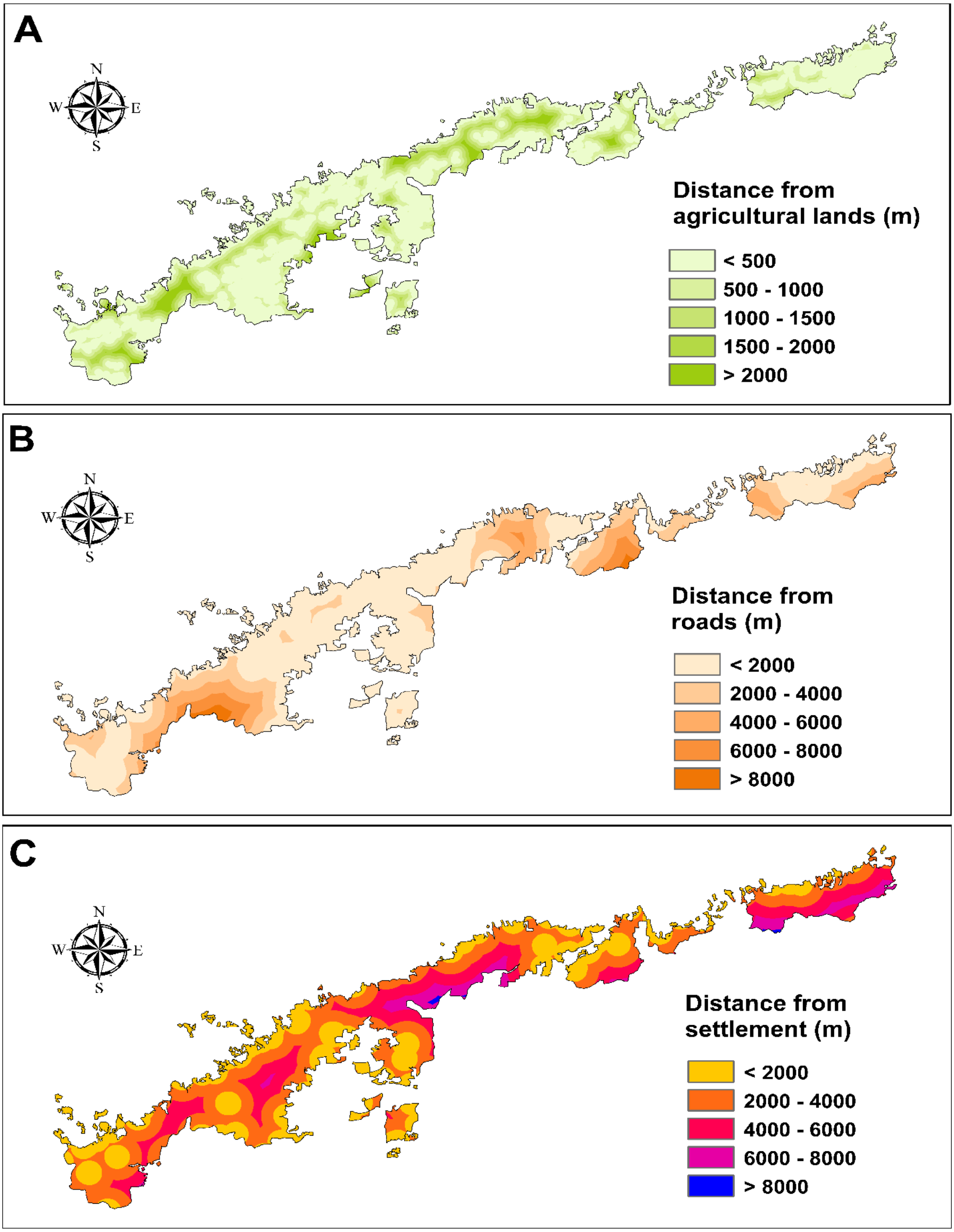
Appendix 2D. Major DL methods with their specifications.

Appendix 3A: Variable details of regression analysis

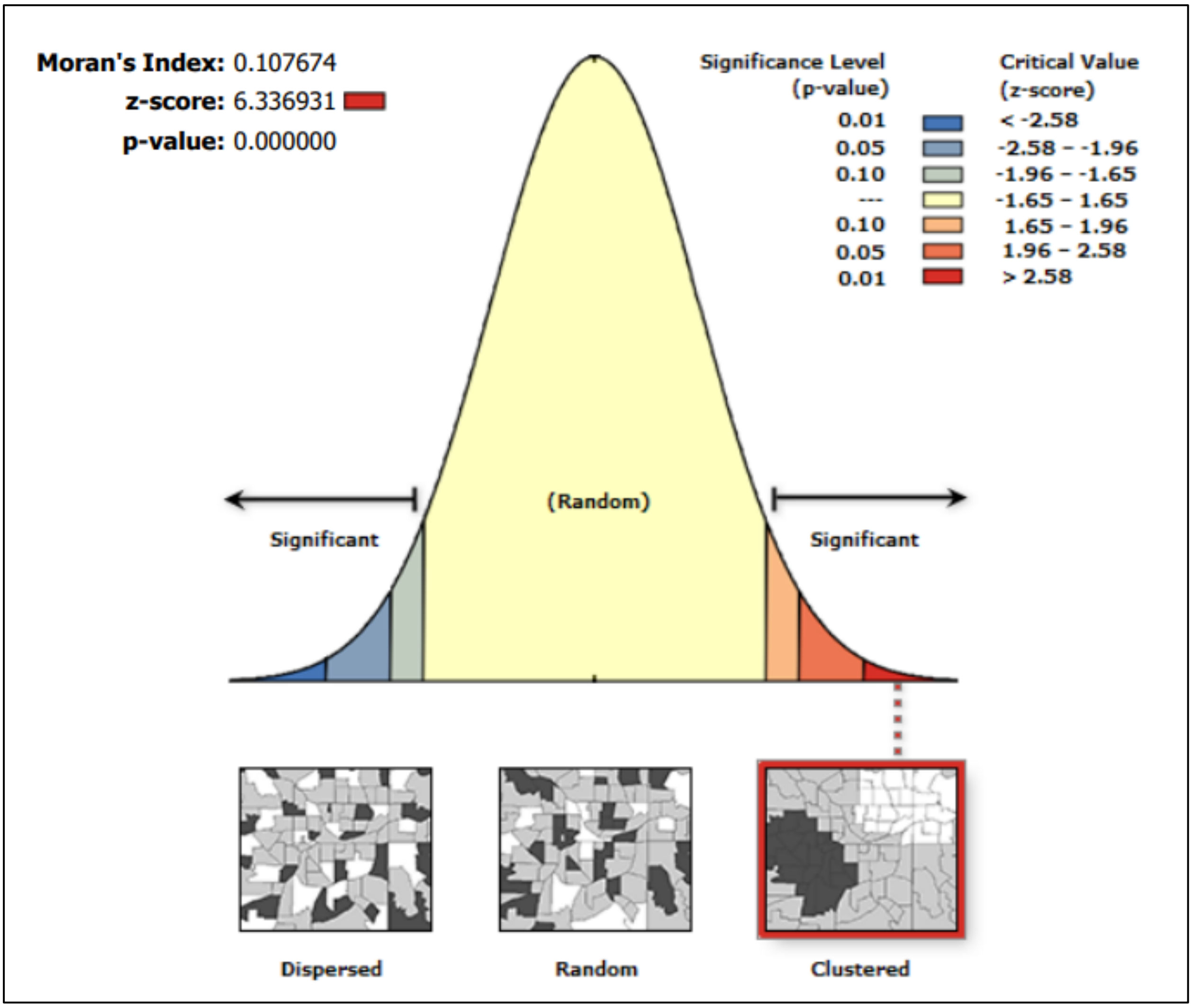
X - Independent Variable	**Y - Dependent Variable**
1. Distance from Agriculture lands (m)	No. of Fire Incidents (MODIS)
< 500	362
500 - 1000	196
1000 - 1500	110
1500 - 2000	57
2000 - 2500	20
Total	***745***
2. Distance from Roads (m)	No. of Fire Incidents (MODIS)
< 2000	381
2000 - 4000	194
4000 - 6000	112
6000 - 8000	50
8000 - 10000	8
Total	***745***
3. Distance from Settlements (m)	No. of Fire Incidents (MODIS)
< 2000	143
2000 - 4000	359
4000 - 6000	214
6000 - 8000	29
8000 - 10000	0
Total	***745***



Appendix 3B Forest Type Map with MODIS fire points (2001-22)



Appendix 3C. Proximity Analysis: (a) distance from agriculture (b) distance from roads (c) distance from settlements.



Appendix 4A. Spatial Autocorrelation Report

Appendix 4B. Saaty's Scale of Rating (Saaty, 1980)

Importance scale	Definition	Explanation
1	Equal Importance	Two variables have equal contributions to the effect
3	Moderate Importance	Experience and judgment slightly in support of one over the other
5	Strong Importance	Experience and judgment firmly in support of one over the other
7	Very strong Importance	Experience and judgment very strongly in support of one over the other
9	Extreme Importance	The evidence favouring one over the other is of the highest possible validity.
2, 4, 6, 8	Intermediate Values	When compromise is needed

Appendix 4C. Random Inconsistency Values (Saaty, 1980)

Number of Criteria	Random Inconsistency
1	0.00
2	0.00
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49
11	1.51
12	1.54
13	1.56
14	1.57

Appendix 5A: Perceptions of forest fire impacts on NTFPs (n = 402)

NTFPs	Parameter	Increase	Decrease	Same	NC/NA*	Total
Mahua Flower	Availability	0	270	58	74	402
	Collection distance	232	8	86	76	402
	Collection Time	251	10	65	76	402
	Quantity	0	264	63	75	402
	Quality	0	266	61	75	402
	Demand	16	12	297	77	402
	Price	18	49	260	75	402
Tendu Leaf	Availability	1	286	45	70	402
	Collection distance	258	10	64	70	402
	Collection Time	271	10	48	73	402
	Quantity	0	278	53	71	402
	Quality	0	274	56	74	404
	Demand	12	13	307	70	402
	Price	11	20	301	70	402
Mahua Seed	Availability	0	37	128	237	402
	Collection distance	31	4	130	237	402
	Collection Time	33	4	127	238	402
	Quantity	0	40	121	241	402
	Quality	0	41	118	243	402

	Demand	4	6	152	240	402
	Price	5	7	151	239	402
Achar Seed	Availability	0	108	24	270	402
	Collection distance	106	3	22	271	402
	Collection Time	108	1	21	272	402
	Quantity	0	110	21	271	402
	Quality	0	109	22	271	402
	Demand	3	6	122	271	402
	Price	3	32	95	272	402
Amla	Availability	0	46	21	335	402
	Collection distance	43	2	22	335	402
	Collection Time	43	3	20	336	402
	Quantity	0	43	22	337	402
	Quality	0	43	20	339	402
	Demand	1	2	62	337	402
	Price	1	9	56	336	402
Honey	Availability	0	28	34	340	402
	Collection distance	25	2	35	340	402
	Collection Time	25	2	35	340	402
	Quantity	0	23	39	340	402
	Quality	0	16	46	340	402
	Demand	1	0	61	340	402
	Price	2	0	60	340	402
Mushroom	Availability	19	17	23	343	402
	Collection distance	14	15	29	344	402
	Collection Time	14	21	21	346	402
	Quantity	18	17	22	345	402
	Quality	18	17	22	345	402
	Demand	1	0	56	345	402
	Price	0	1	56	345	402

** Respondents who reported not collecting or not finding the particular NTFP in their locality were classified under the 'Not Collected / Not Available' category.*

Appendix 8A. Gond tribal community members crafting baskets as an alternative source of income, utilizing native grass resembling bamboo in Amjhira Village of the HFD. His family has shifted in this livelihood is due to the decreased availability of Mahua and other NTFPs in the nearby forest *(Source: Author, April, 2024)*.

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