

Assessment of forest fire incidences, causes, and management practices in Bagmati Province, Nepal

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Abstract

Forest fires pose a growing environmental and socio-economic threat in Nepal, driven by both anthropogenic and natural factors. This study examines forest fire incidence, spatial risk patterns, causes, and management practices in Bagmati Province using a mixed-methods approach. Spatial and temporal data from MODIS/FIRMS (2014 to 2024) were analysed in ArcGIS to generate a fire risk map using a weighted overlay model. Model validation was conducted using Kernel Density Estimation and Visible Infrared Imaging Radiometer Suite fire hotspots data. Qualitative data were collected through purposively sampled key informant interviews with 29 stakeholders from Community Forest User Groups (CFUGs) and Forest Officers, as well as three focus group discussions conducted in high-fire risk zones. The findings reveal that a total of 46,546 fire incidents were recorded in Bagmati Province during the study period, with 92.87 per cent occurring during the pre-monsoon season (March to May). Approximately 34 per cent of the province falls within very high fire risk zones, particularly in the districts of Sindhuli, Ramechhap, Makawanpur, and Chitwan. Human-induced factors dominated fire ignition, accounting for over 75 per cent of reported causes. Despite existing community forest institutions, fire management effectiveness remains constrained by limited resources, weak coordination, and lack of early warning systems. The lessons from the findings highlight the need for coordinated, community-centered technological innovations to strengthen institutional capacities and enhance policy implementation which are vital for reducing fire risks and fostering sustainable forest fire management in the region.

Keywords: Bagmati Province, Community-based approach, Fire risk, Forest fires, GIS

INTRODUCTION

Forest fires, defined as uncontrolled combustion events in vegetated areas where the flame height exceeds 1.8 meters, constitute a significant menace to ecosystem integrity, biodiversity, and human well-being (Kane, 2024). Globally, an estimated 400 million hectares of land burn annually, contributing substantially to deforestation and land degradation (Robinne and Secretariat, 2021; Mishra *et al.*, 2023). The severity of this issue is underscored by several recent mega fires, including those in Australia (2019–2020), the Amazon rainforest (2019–2020), the western United States (2018, 2020), and British

Columbia, Canada (2017, 2018) (Xu *et al.*, 2020). South Asia is recognised as a global fire hotspot, with more than half of the forested terrain impacted by fires between 2003 and 2017 (Reddy *et al.*, 2019). Within the region, Bangladesh exhibits the highest concentration of forest fire hotspots (34%), followed by India (32%) and Nepal, where 20.5 per cent of forest areas are susceptible to annual burning (Reddy *et al.*, 2019; Pandey *et al.*, 2022). In Nepal specifically, approximately 40,000 hectares of forest burn annually, with a peak incidence between March and May (Kalwar, 2022). The Chure region is identified as the most fire-prone area in the country (Mishra *et al.*, 2023).

The etiology of forest fires is multifaceted, encompassing a complex interplay of natural and anthropogenic drivers. Rising temperatures, diminished precipitation, and protracted droughts driven by climate change exacerbate extreme fire weather, thereby extending fire seasons and expanding fire-prone landscapes (Pandey, 2021; Wang *et al.*, 2021; Pandey, 2025). For instance, significant warming across California over the last century, particularly in the late summer and early autumn, has heightened the risk of hydrological drought and consequently prolonged the fire season (Goss *et al.*, 2020). Nevertheless, in numerous regions, particularly developing countries such as Nepal, human activities are the predominant ignition catalysts. In Nepal, anthropogenic ignitions, often intentional, are estimated to account for 58 per cent of all forest fires (Kunwar and Khaling, 2006). The confluence of these anthropogenic pressures with shifting climatic patterns establishes a complex fire regime, presenting formidable challenges for forest management.

Forest fires have severe ecological consequences, including biodiversity loss, habitat destruction, and long-term shifts in forest composition (Wang *et al.*, 2021). In response to these threats, management strategies such as Community-Based Fire Management (CBFiM) have been developed (FAO, 2007). It seeks to engage local communities in the judicious management of land-use fires through coordinated planning, supervision of prescribed burning activities, and integrated fire monitoring and response systems (FAO, 2007). While Nepal has a long history of community forestry, the effectiveness of such approaches is increasingly challenged by socio-economic and political changes at both national and international scales (Shahi *et al.*, 2022). Although

community ownership is widely recognised as essential for proactive fire management initiatives, the growing frequency and severity of fires necessitate a critical reassessment of community-based regimes (Kunwar and Khaling, 2006; Tiwari *et al.*, 2022).

In Nepal, forest fires constitute a pressing and escalating environmental and socioeconomic problem, with forests in over 30 districts sustaining annual damage (ICIMOD, 2019). Bagmati Province, in particular, experiences a high incidence of forest fires, resulting in environmental degradation, economic losses, and fatalities (DPNet Nepal, 2024). Several knowledge and research gaps emerge from the literature. Despite numerous studies examining the spatial and temporal distribution of forest fires in Nepal (Parajuli *et al.*, 2015; Matin *et al.*, 2017; Parajuli *et al.*, 2020; Bhujel *et al.*, 2022), research on fire management practices and vulnerability assessments remains limited. For instance, Bhusal and Mandal's (2020) study on fire occurrence in the Arghakhanchi district, while informative, may not be generalisable to other regions. However, Mishra *et al.* (2023) briefly mentioned anthropogenic causes of forest fires, up-to-date and accurate vulnerability assessment, and a deep learning-based model (DNN) needed for better fire management. Similarly, only a limited number of studies, including Pandey *et al.* (2022) and Tiwari *et al.* (2022), have explicitly focused on forest fire management. Comprehensive fire research in developing countries and regions like the Himalayas is still lacking. Many studies (e.g., Goss *et al.*, 2020; Wang *et al.*, 2021) discussed the impacts of climate change on fire regimes, although considerable uncertainty remains in these projections. The prevalence of forest fires is exacerbated by watershed scarcity and prolonged dry seasons characteristic of the region. The complex

interactions between climate, vegetation, and human activities are often oversimplified in predictive models. Furthermore, there is a lack of rigorous, comparative studies evaluating the effectiveness of different fire management strategies, particularly in developing countries.

Compounding the issue, Nepal faces significant institutional, financial, and technological capacity constraints in combating forest fires and possesses limited comprehensive data on fire occurrence and its impacts (GoN, 2013). Because of its ecological relevance, high fire frequency, and increasing human stress on forest resources, the Bagmati Province was selected as a study area for this research. The province contains approximately 27.29 per cent forest cover and has experienced significant fire impacts, with nearly 4000 hectares affected (DPNet Nepal, 2024).

Moreover, Bagmati Province encompasses parts of the Terai Arc Landscape (TAL) and the Siwalik region, which are recognised as vulnerable to forest fires in Nepal, due to a combination of dry climatic conditions, flammable broadleaved forest types, and intensive human activities (Parajuli *et al.*, 2023). Previous studies on forest fire management have often overlooked Bagmati Province despite its high vulnerability to fires; consequently, research on effective fire management practices and community-based mitigation strategies in the province remains inadequate (Matin *et al.*, 2017; Kalwar, 2022; Mishra *et al.*, 2023; Pandey and Bhattarai, 2025). In this context, we investigate two research questions: i) What are the major causes, spatial-temporal patterns, and risk zones of forest fires in Bagmati Province? ii) How can local experiences and community knowledge contribute to understanding forest dynamics and improving forest fire management strategies in Bagmati Province?

Theoretical framework

The theoretical framework employed in this study is a dual-component model that combines the Social-Ecological System (SES) framework (Ostrom, 2009; McGinnis and Ostrom, 2014) with Collective Action Theory (CAT) (Ostrom, 1990; Poudyal *et al.*, 2023). The SES framework serves as the overarching structure, enabling a holistic analysis by identifying the key variables that influence fire dynamics across different system levels: the forest and its ecological characteristics (resource system), the local communities and their behaviours (users), the policies and institutions (governance systems), and the interactions among these components. In this study, SES variables were chosen according to Ostrom's (2009) framework and tailored to the context of forest fires in Nepal, supported by empirical literature and field considerations. This allows the study to explain why ecological factors alone are insufficient to predict fire incidents where social drivers override ecological susceptibility.

CAT becomes particularly relevant because forests in Bagmati Province are common-pool resources managed through Community Forest User Groups (CFUGs) that require coordinated action among multiple stakeholders. For this study, three core principles of Collective Action are central to analysing fire management:

1. **Communication and Coordination:** focuses on how effectively CFUGs, Division Forest Offices (DFOs), and local government exchange information and jointly plan strategies for prevention and suppression
2. **Capacity:** assesses the adequacy of financial resources, equipment, training, and institutional support that enable or constrain collective action

3. Trust and Reciprocity: evaluates the social capital and confidence among stakeholders that enable sustained cooperation

Thus, the framework addresses the social and ecological dimensions of the issue, connects research questions to collective action interventions, and offers a structured lens for examining management gaps and strengthening collective action for sustainable fire management.

MATERIAL AND METHODS

Study area

The study was conducted in Bagmati Province as shown in Figure 1, which covers 20,300 km² and accounts for approximately 13.79 per cent of Nepal's total land area (Bagmati Province, 2024). Topographically, the province is divided into four main regions, starting from the high Himalayan region (7,422m) in the north to the low plain Terai in the south (Bagmati Province, 2024). The province's wide elevation range allows it to support nearly all forest types found in Nepal. Tree species, including Sal (*Shorea robusta*), Sisoo (*Dalbergia sissoo*), and Khair (*Senegalia catechu*), predominate in the lowland Terai region. The forest composition changes with elevation, favouring temperate species, including pine (*Pinus roxburghii*), oak (*Quercus* spp.), and rhododendron (*Rhododendron arboreum*). Medicinal herbs and alpine vegetation are predominantly found in the northern parts of the province. In total, these forested areas cover 27.29 per cent of the provincial territory (Bagmati Province, 2024). Collectively, Bagmati Province has five protected areas, among which four are national parks (Chitwan National Park, Langtang National Park, Shivapuri Nagarjun National Park, and part of Parsa National Park) and one conservation

area (Gaurishankar Conservation Area) (DNPWC, 2024).

Due to the province's elevational gradient, the climate within Bagmati Province fluctuates greatly. The lowland Terai region has a humid, subtropical climate with hot summers and mild winters. The hilly regions have a temperate climate, while the northern mountainous areas are covered with ice and glaciers, resembling an alpine to tundra climate. On average, the province receives between 1,000 and 4,000 mm of precipitation annually, most of which occurs between June and September during the summer monsoon season (DHM, 2024). Annual rainfall is highest in Bharatpur, Chitwan (2550.1mm), making it one of the wettest areas, while Kathmandu receives the least rainfall (1360 mm), indicating a relatively drier climate in the valley compared to other regions (Bagmati Province, 2024). The winter season (December – February) brings snow to the northern areas, resulting in cold and dryness, while it is relatively warmer in the southern plains.

RESEARCH DESIGN

The study employs a mixed-methods approach, with qualitative research methods predominating, followed by quantitative data to complement and support the findings. The qualitative component of this research draws primarily on data collected through Key Informant Interviews (KIIs) and Focus Group Discussions (FGDs). Utilising a purposive sampling approach, the study conducted KII with 13 representatives from CFUGs and 16 forest officers from DFOs, while sites and CFUGs for the FGDs were selected based on the frequency of forest fire identified through Moderate Resolution Imaging Spectroradiometer (MODIS) data overlays and risk classification. To deepen the understanding, a spatial and temporal

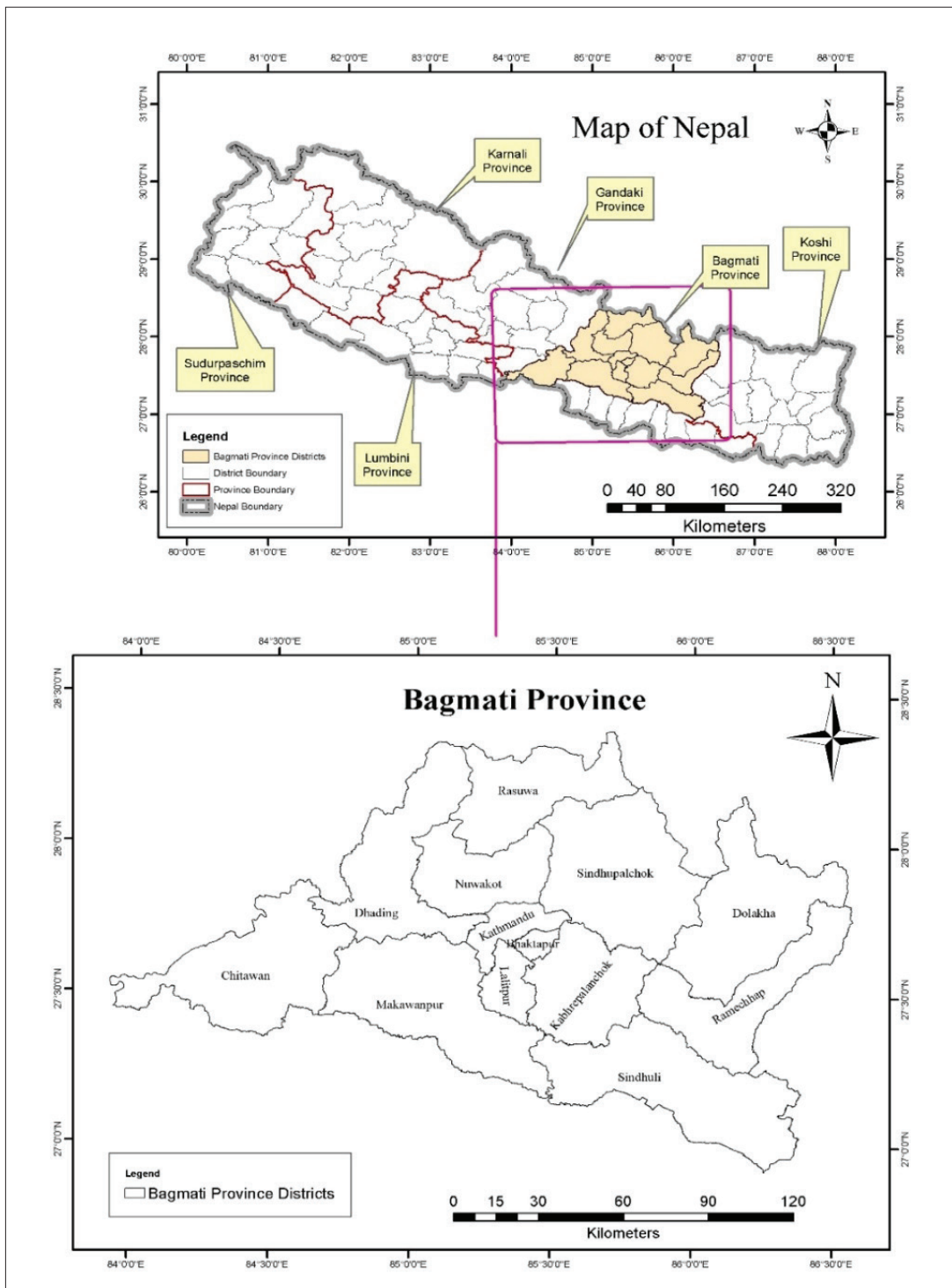


Figure 1: Map of the study area

perspective on forest fire events in Bagmati Province was examined using quantitative data. In particular, data from the MODIS and the Fire Information Resource Management System (FIRMS) were analysed to track forest fire occurrences over time and space. The real experience of local people from qualitative data and satellite data complements each other, contributing to the findings and analysis.

Primary data collection

- i) Key Informant Interview: A total of 29 key informants were interviewed. Initially, representatives of CFUGs were interviewed via phone calls using a questionnaire that included both open-ended and closed-ended questions. Additionally, forest officers, including two from Chitwan, were interviewed using a separate set of questionnaires administered through Google Forms. These interviews aimed to explore the major causes of forest fires, existing management practices in community forests, challenges encountered, and potential improvements, while also assessing the preparedness of forest officers in dealing with forest fires.
- ii) Focus Group Discussions: Three focus group discussions involving 6 to 12 participants each were conducted with different community forest groups in the study area. FGDs were carried out with Susheli and Piple Pokhara CFUGs in Makawanpur district, and Bandevi Shanti CFUGs in Godawari, Lalitpur district.

Quantitative data

MODIS data

The historical data were taken from NASA's FIRMS. A polygon encompassing the study area surrounding the temporal data from 2014 to 2024 was created using fire spots from

the EOSDIS Archive Data Tool. Confidence levels below 30 per cent of the total number of forest fires and fires discovered in agricultural and water bodies, as identified by MODIS, were removed to improve the accuracy and reliability of the fire dataset for the study area from 2014 to 2024. This eliminated thermal anomalies that false alarms, such as sun glint over water or marginal surface heating, could have caused. For the burnt area detections, the MODIS burned area product was downloaded in shapefile format from the University of Maryland "ba1" ftp server, which is now consolidated with Fuoco into a single server. These data significantly contribute to the research by providing objective, long-term, and spatially explicit information on forest fire occurrences in Bagmati Province from 2014-2024. They facilitate the identification of high-risk fire zones by detecting fire hotspots and burnt areas over time, enabling the creation of fire frequency maps and risk categorisation.

In order to do vegetation analysis, the land cover ICIMOD data (FRTC, 2022) were grouped into ten distinct classes. Vegetation extraction was carried out using ArcGIS by estimating the proportion of vegetation types in the research regions. Monthly mean land surface temperatures for Bagmati Province were derived from NASA/MODIS data for the period between 2014 and 2024. The average temperature in the province ranges from 5°C to over than 35°C. The slope is an extremely important factor among topographic factors that largely affect fire, especially when it is spreading (Goldammer and de Ronde, 2004; Yakubu *et al.*, 2015). Hence, for the slope study, DEM 90 M from DFRS was used, and the slope was extracted using GIS. The surface slope in this study varies from less than 5° to over 35°, while elevation ranges from below 1000m to 4000m. Elevation was incorporated into the

model based on its assumed direct relationship with humidity and fuel combustion. The aspect was generated using DEM and classified into nine classes. Distance from the road, including highway and associated roads, was extracted from ICIMOD, and proximity to settlements, including clusters of settlements in the study area, was extracted from the Department of Survey (2024). The distance has been grouped into 0-1000m, 1000-2000m, 2000-3000m, 3000-4000m, and 4000m and above.

In the findings and discussion section, these datasets are merged by triangulating insights from primary data (KII and FGD) with spatial and environmental variables derived from secondary data (MODIS, ICIMOD, DEM, and NASA datasets). For instance, the perceptions of CFUG members and forest officers regarding fire causes and management challenges are contextualised with MODIS fire frequency and burnt area data to validate spatial fire patterns. Similarly, vegetation classification, slope, elevation, temperature, and proximity to roads and settlements help explain the underlying environmental and anthropogenic drivers identified during the fieldwork. Overlaying these variables allows a spatial-temporal understanding of fire-prone zones and management gaps, enhancing the discussion by linking insights with geospatial evidence to draw meaningful conclusions and develop targeted fire management strategies.

Data analysis

In qualitative research, thematic analysis was used to examine the data and identify patterns in participants' responses. Firstly, all the interviews were transcribed and read multiple times, and codes were worked out based on the major points of the data. The selected codes were refined to ensure the consistency and coherence of the data. Similar types of code were grouped to form the main

themes, representing the core part of the data. The scale of qualitative data has been relatively small and manageable using Excel, which allowed for efficient categorisation, coding, and summarisation without the need for advanced statistical tools. Quantitative analysis was done in SPSS and ArcGIS 10.8. In ArcGIS, other than the basic function, buffering, kernel density function, and weighted overlay, different variables and results were analysed using weighted overlay. The weighted overlay is a GIS spatial analysis technique used to combine multiple raster layers with different influences to generate a single output layer. It is particularly useful in decision-making and suitability analysis (Jaiswal *et al.*, 2002).

Determining the risk model

Various indices have been proposed in literature to estimate fire risks using biophysical (vegetation, humidity, elevation, slope, aspect) and anthropogenic (proximity to settlements and roads) parameters (Jaiswal *et al.*, 2002; Filippidis and Mitsopoulos, 2004; Saglam *et al.*, 2008; Ca'ceres, 2011; Adab *et al.*, 2013; Mohammadi *et al.*, 2014; Sivrikaya *et al.*, 2014; Zhang *et al.*, 2017). The relative weights for variables were chosen (Parajuli *et al.*, 2020); hence, the risk model was developed with the equation below.

$$\text{FRI} = 40 \text{ LC} + 20 \text{ LST} + 10 \text{ S} + 10 \text{ RD} + 10 \text{ PS} + 5 \text{ A} + 5 \text{ E}$$

Where,

FRI = Fire Risk Index,

LC = Land Cover,

LST = Land Surface Temperature,

S = Slope,

DR = Distance from the Road,

PS = Proximity to the Settlement,

A = Aspect and

E = Elevation.

Table 1: Table showing the value assigned to determine the risk model

Variable	Weight (%)	Class	Value Assigned	Fire Rating Classes
Land Cover	40	Broad-leaved Closed Forest	1	Very High
		Broadleaved Open Forest	2	High
		Grassland	3	Medium
		Shrubland	4	Low
		Needle-leaved Open Forest	4	Low
		Needle-leaved Closed Forest	4	Low
		Barren Land	5	Very Low
Temperature (°C)	20	>30	1	Very High
		25-30	2	High
		20-25	3	Medium
		Oct-20	4	Low
		<10	5	Very Low
		<5	1	Very High
		5-15	2	High
Slope (%)	10	15-25	3	Medium
		25-35	4	Low
		>35	5	Very Low
		<1000	1	Very High
		1000-2000	2	High
Distance to Road (M)	10	2000-3000	3	Medium
		3000-4000	4	Low
		4000-5000	5	Very Low
		<1000	1	Very High
		1000-2000	2	High
Proximity to Settlement (M)	10	2000-3000	3	Medium
		3000-4000	4	Low
		>4000	5	Very Low
		<1000	1	Very High
		1000-2000	2	High
Elevation(M)	5	2000-3000	3	Medium
		3000-4000	4	Low
		>4000m	5	Very Low
		Flat/South	1	Very High
		East/South East/ South West	1	High
Aspect	5	West	3	Medium
		North West/ North East	4	Low
		North	5	Very Low

Ultimately, these parameter evaluations led to the creation of a fire risk zone map. In this study, spatial modelling has been done to obtain the combined effect of the aforesaid variables. Different weights were assigned as per the importance of the particular variable, as shown in the table 1. The highest weight was given to the land cover as it indicates forest type, fuel load, and fuel accumulation, which strongly influence fire susceptibility due to fuel inflammability. The second-highest weight was given to land surface temperature, which directly affects the likelihood of forest fires. The third highest weights were given to slope, distance to road, and proximity to settlement. Steeper slopes facilitate convective preheating, enhancing fire ignition and spread, while closer proximity to settlements and roads increases access for local people, grazers, and tourists, potentially contributing to fire occurrences. Elevation and aspect were assigned next, since human activity generally decreases with altitude, and sun-facing aspects receive more direct sunlight, making fuels drier and more combustible. Ratings for all variables were assigned from high to low based on their relative risk potential. Following the determination of each weight, ArcGIS 10.8 was used to overlay all layers.

Model validation

Model validation was conducted to assess its predictive accuracy, by combining it with a real-world dataset (Beguería, 2006). Since the model was based on seven independent factors, the resulting fire risk map was validated using data from individual forest fire incidents. First, assuming that higher fire counts correspond to the higher risk rating in the designated category, archived fire counts were superimposed in each fire risk zone. Second, the outcomes of the fire risk model were compared using KDE (Parajuli

et al., 2020). By calculating event intensity as density estimation, KDE aimed to create a smooth density surface of point events across space (Serra-Sogas *et al.*, 2008). The VIIRS hotspots served as input for both validation techniques.

RESULTS

Areas most susceptible to forest fires

Altogether, 46,546 fire incidents were recorded in Bagmati Province between 2014 and 2024. 92.87 per cent of fire incidents were recorded in the pre-monsoon season from March to May, where April alone accounted for 52.67 per cent of fire incidents from 2014 to 2024. The highest number of forest fires was recorded in 2016 (11,044), followed by 2021 (10,381) and 2023 (7,341) as shown in the Figure 2.

At the district level, as represented in Figure 3, Chitwan was the most affected, with a staggering 12,480 fire incidents reported between 2014 and 2024. Similarly, Makwanpur also faces a high number of incidents, with 10,770 reported cases, followed by Sindhuli with 9,091 incidents. In contrast, urban districts such as Lalitpur, Kathmandu, and Bhaktapur report significantly fewer incidents, likely due to limited forest cover and better access to emergency services. Moderate fire activity was observed in Dhading, Kavrepalanchok, Sindhupalchok, and Nuwakot.

Forest fire risk zonation map

Approximately 34 per cent of the study area was identified as having a very high fire risk, followed by 56 per cent that are at moderate risk, and only 10 per cent falling into the 'very low risk' category. Sindhuli district recorded the largest burnt area, totalling 1274.12 km², followed by 965.91 km² in Ramechhap,

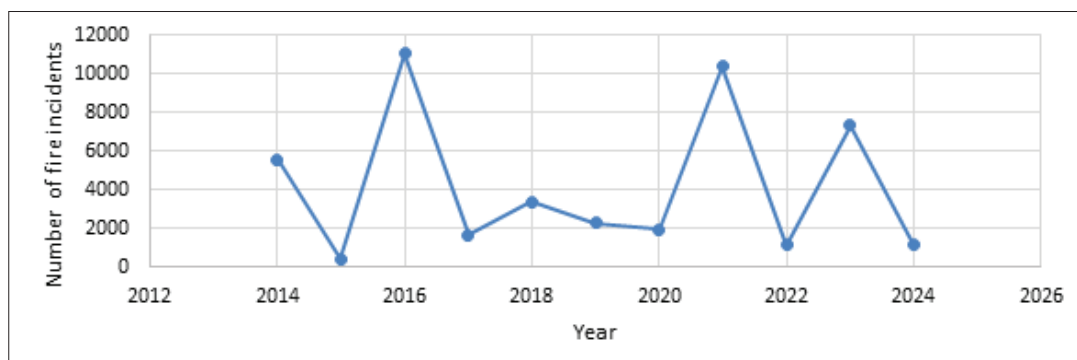


Figure 2: Trends of fire incidents in Bagmati Province from 2014 to 2024 (MODIS Data)

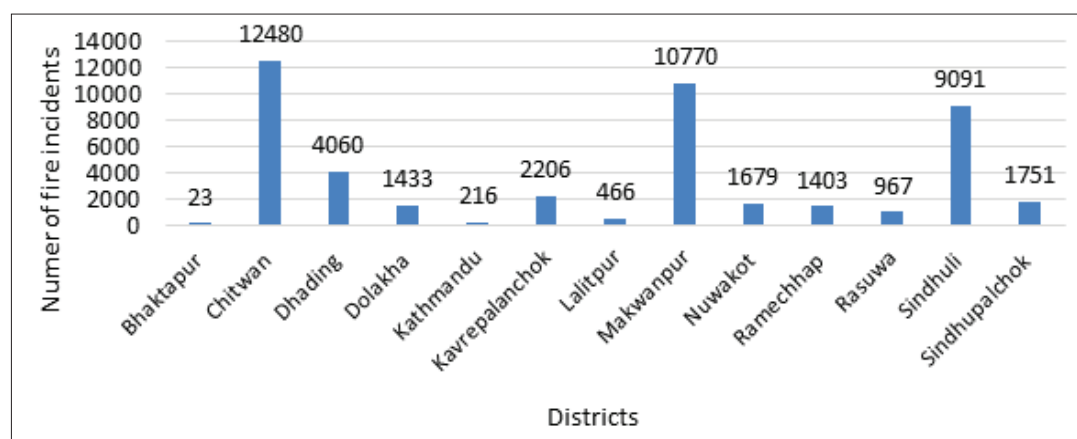


Figure 3: District-wise fire incidents (MODIS Data, 2024)

836.62 km² in Makawanpur, and 826.55 km² in Chitwan district. These burned areas largely correspond to zones identified as very high fire risk, as highlighted in Figure 4.

Among the districts, Ramechhap has the highest proportion of land area classified as very high risk of fire, at 55 per cent, followed by Sindhuli at 51 per cent. Chitwan also presents a significant concern, with 37 per cent of its land categorised as high fire risk. Similarly, 34 per cent of the land area in Dolakha, Kavrepalanchok, and Makawanpur falls within the high-risk category. Nuwakot has the largest proportion of land classified as moderate fire risk, with 72 per cent of its area falling into this category. This is followed by

Lalitpur, where 64 per cent of the district's land area is at moderate risk, and Makawanpur with 59 per cent of its land classified similarly. In contrast, Rasuwa shows a different pattern, with the largest proportion of land area (32%) classified as low fire risk, which is the highest among all districts of Bagmati Province.

Model validation

KDE has been widely applied as a validation tool for forest fire maps. According to Zhang *et al.* (2017), KDE can also serve as a useful component of decision support systems (Parajuli *et al.*, 2020). Very high-risk areas are nearly identical to those produced by the fire risk map, as demonstrated by the comparison

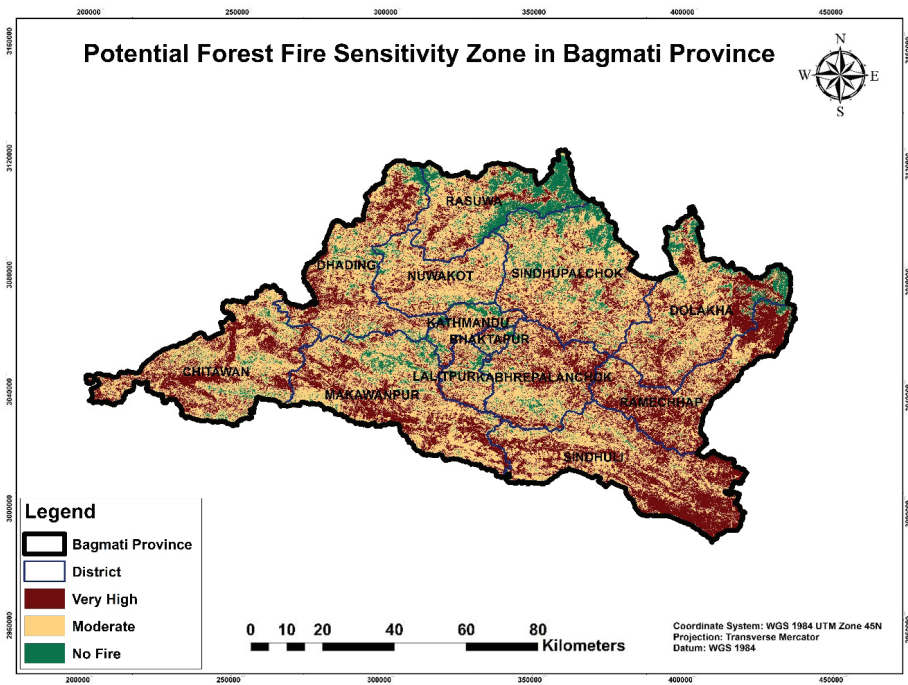


Figure 4: Forest fire-sensitive zones in Bagmati Province were developed by combining all influencing variables. *Source: MODIS/FIRMS (2024); GIS analysed*

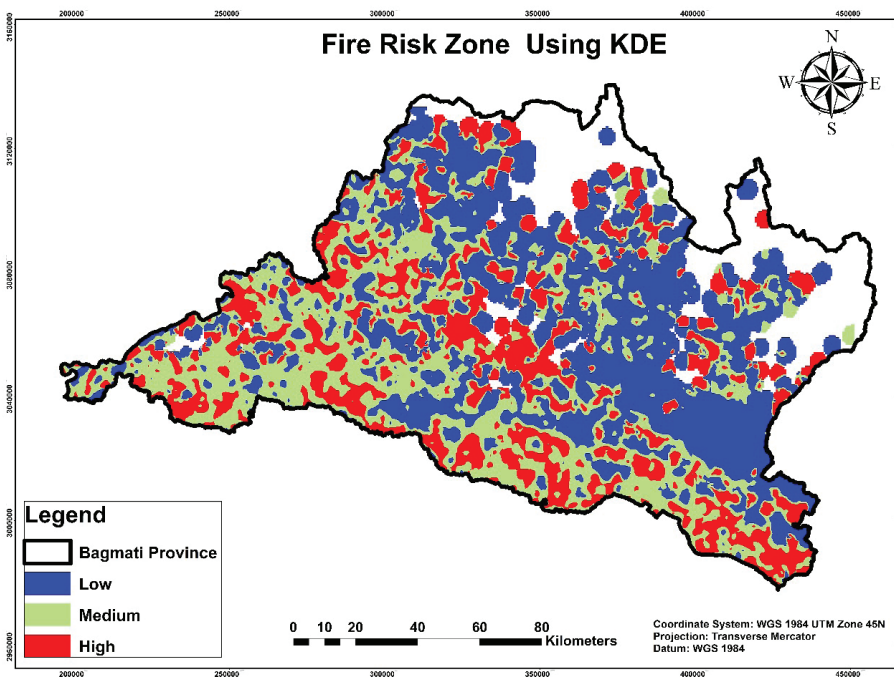


Figure 5: Fire risk map produced by the KDE Method from MODIS fire hotspots

of risk areas obtained through the validation of fire spots and KDE, as shown in Figure 5. On the other hand, KDE has expanded the low-risk zone. It might be as a result having fewer concentrated fire points.

In addition to spatial validation, perceptions of local people also highlight the evolving nature of fire risk. A majority (75%) of the interviewed participants reported an increase in forest fire risk over the past five years, highlighting rising concerns about the frequency and intensity of such events. Meanwhile, 18.8 per cent of respondents felt that there had been no significant change in fire risk levels during the same period. This suggests that while the majority perceive a growing threat, a small proportion of the population perceives that the situation has remained unchanged.

Major causes of forest fires in Bagmati Province

Figure 6 highlights human negligence as the most significant cause of forest fires in Bagmati Province, accounting for 75.86 per cent of the responses. This includes careless activities such as the improper disposal of burning materials like cigarettes. Agricultural practices represent the second most common cause with 24.13 per cent, including slash-and-burn techniques, the clearing of land

through controlled burns, and accidental fires spreading from farmlands to the nearby forests. Deliberate actions account for 13.8 per cent of the causes, primarily involving intentional fires set for land clearing or driven by vindictive motives. Natural causes account for the smallest share, at 3.45 per cent.

The results overall suggest a dominant perception among respondents that human activities are the primary drivers of forest fire incidences, with the “very high” category far outweighing the others. According to the Chairperson of Piple Pokhara CFUG (Makawanpur), personal or professional disputes can also trigger forest fires. He further noted that while forest cover has increased, the declining dependence of local communities on forest resources has contributed to fuel accumulation, making forests more susceptible to ignition during the dry season. As communities have become more independent from forest resources, local people's concern regarding forest fires has also decreased. Consequently, the reduced use of wood, timber, and other forest products over the years has contributed to an increased risk of forest fires. Similarly, the Chairman of Susheli CFUG emphasised that limited awareness and inadequate environmental education among residents remain key drivers of rising fire incidents. He explained that the adoption of alternative materials,

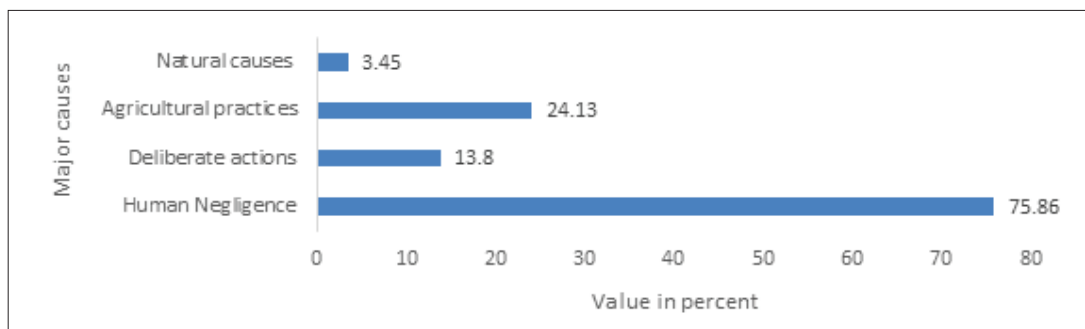


Figure 6: Major causes of forest fires (Note: The total percentage may exceed 100, due to overlapping categories)

such as metal furniture instead of wood and synthetic mats for livestock care, has reduced community dependence on forests. As a result, responsibility for fire prevention and forest management has increasingly shifted to the CFUGs alone.

Existing forest fire management practices employed in the Bagmati Province

Figure 7 represents that forest fire management in Bagmati Province is predominantly community-led, with CFUGs playing a central role in fire suppression and prevention. The use of water for firefighting is the most widely practiced method, reported by 90 per cent of respondents, followed by community education and awareness activities (75.86%), underscoring the importance of public engagement in reducing fire risk. The establishment of firebreaks and firelines is also commonly practiced by CFUGs and forest officers (72.41%), indicating their widespread adoption as a preventive measure (Figure 7).

At the community level, CFUGs primarily rely on basic hand tools and traditional knowledge, including backfiring and locally constructed firelines. In contrast, the Forest

officers focus on controlled burning, seasonal patrolling, and awareness-raising programs. Fuel load reduction through leaf litter collection is additionally practiced to limit fire intensity.

Local governments support fire response by coordinating with DFOs and providing firefighting equipment. Despite these efforts, the use of early warning systems remains limited. Only a small number of respondents reported receiving fire alerts based on MODIS satellite data, which were widely perceived as ineffective due to the lack of supporting technical infrastructure. Fire-related information is largely communicated through informal channels, particularly mobile phone calls. Forest officials and CFUGs representatives further noted that MODIS alerts often fail to align with the actual timing of fire ignition, frequently occurring at night, thereby reducing their effectiveness for timely response and suppression.

Preparedness

The absence of a “very well prepared” response indicates a lack of perceived readiness for forest fire events among respondents, attributed to limited resources and ongoing

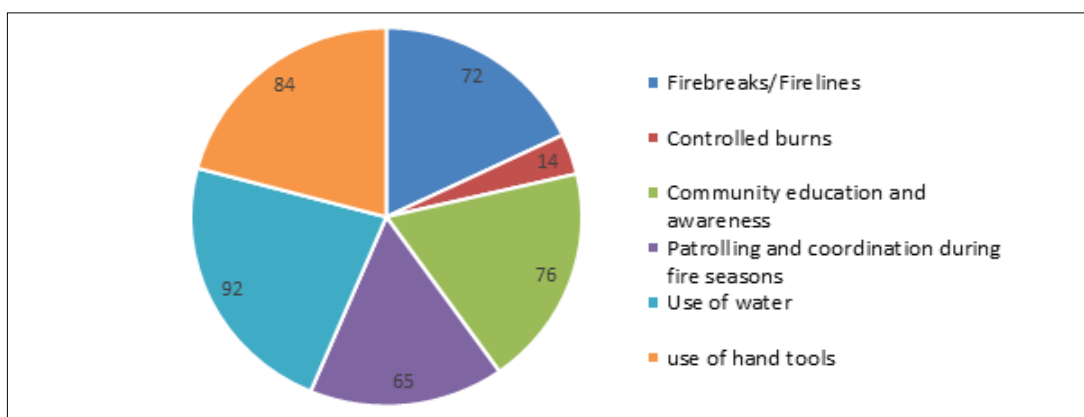


Figure 7: Existing management practices (in %) (Note: the total percentage may exceed 100, due to overlapping categories)

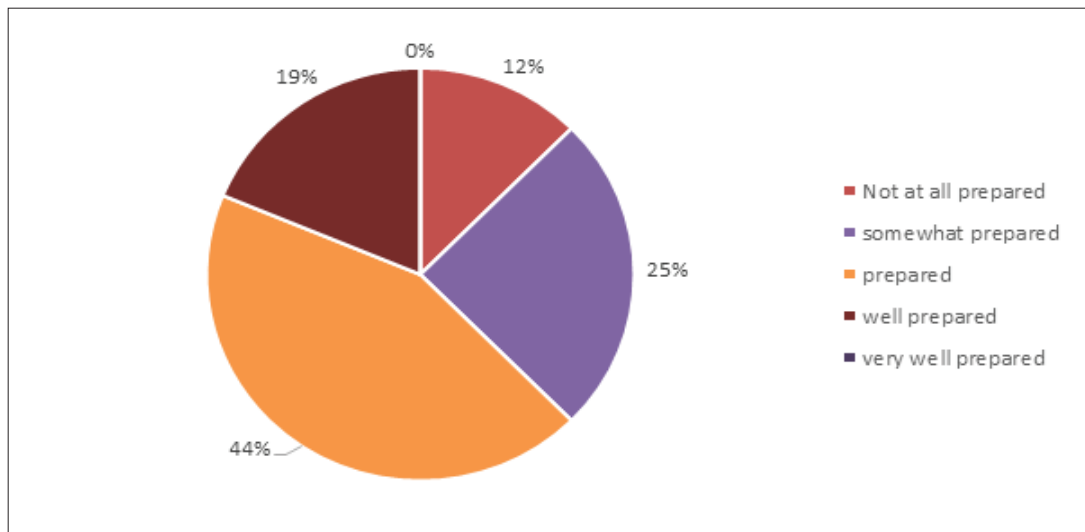


Figure 8: Area's preparedness for forest fires from interviews

vulnerabilities (Figure 8). A member of Susheli Community Forest (CF) noted that preparatory measures are minimal, mainly limited to discussions, with no effective prevention or response mechanisms in place. Further, he added key challenges, including adequate budget allocation, insufficient funding, and a lack of proper firefighting equipment.

Gaps in existing management

The existing management of forest fires in the study area reveals significant gaps, particularly in coordination and communication between CFUGs and government bodies. While forest officers often report that there is regular collaboration with local communities, many CFUG members express a contrasting experience, citing a lack of timely support and proactive engagement from local governments or the DFOs. For instance, *"We were given training after the fire took place, and it is quite difficult to complain and punish someone within our community if found igniting the fire,"* said a member of Bandevi Shanti CF. Furthermore, the absence of dedicated fire

control committees in some areas points to poor coordination and inadequate planning, ultimately undermining efforts to prevent and manage forest fires effectively.

Beyond coordination, limited capacity building is another critical barrier to successful forest fire management. A large proportion of respondents reported inadequate or completely unavailable resources for fire control, including essential equipment and financial support. The lack of budget allocation within CFUGs, primarily due to insufficient income sources, has made it difficult to invest in vital components such as training programs and hiring forest watchers. This situation is worsened by limited public awareness and a general lack of interest in fire management among residents. As pointed out by CFUG leaders, community members are often more motivated by training allowances than by a genuine commitment to forest protection. This disconnect between people and the forest, driven by minimal engagement and economic constraints, poses a major obstacle to building a resilient and participatory fire management system.

Role of community involvement and local knowledge in mitigating forest fires

The role of community involvement and local knowledge is central to effectively mitigating forest fires in the region, as highlighted by both CFUGs and forest officials. CFUG emphasises that meaningful participation in activities such as fire prevention campaigns, budget planning, and coordination meetings is essential for strengthening collaboration between local communities and government bodies. They argue that engagement should go beyond formalities, such as being rooted in practical, on-the-ground involvement. They further believe that the responsibility for forest protection should be more widely shared, including among local governments, rather than resting solely with forest departments or federations like FECOFUN.

In addition, improvements in infrastructure and livelihood alternatives are viewed as vital strategies for forest fire management. There is a strong demand for better firefighting tools, equipment, and protective gear. Forest officers' emphasise the need for enhanced training and a dedicated budget for fire management. Additionally, providing insurance for local people involved in fire control would offer protection and encourage more active participation in firefighting and rescue operations. These infrastructure improvements would increase community capacity and reduce risks during fire incidents.

Another important aspect is the need for sustainable livelihood alternatives. CFUGs believe that the collection of forest litter and waste, often a major fuel source for fires, could be integrated with income-generating activities such as compost production. Providing financial incentives to community members for these activities could not

only help manage forest waste but also support vulnerable households, creating a mutually beneficial solution for both forest conservation and community development.

DISCUSSION

Forest fire incidence in Bagmati Province is attributable more to a combination of climatic stressors, user behaviour, and governance limitations than biophysical factors alone. Drawing on Ostrom's SES framework and CAT, this study demonstrates that forest fires are produced through mutually reinforcing feedbacks among the resource system (dry and fuel-rich forests), resource users (local communities), and governance systems (community forestry institutions and state agencies). These interactions explain the persistence and intensification of fires despite the expansion of community forestry and existing management interventions. From a SES perspective, fire is a disturbance that arises when poor governance, ecological sensitivity, and deteriorating collective action come together, and CAT explains why cooperation does not materialise at the size and speed necessary for effective prevention and response.

Seasonal climate variability, particularly the dry pre-monsoon period, functions as an enabling condition rather than a causal driver of forest fires in Bagmati Province. Consistent with national-level studies, our analysis confirms that the majority of fires occur between March and May, when high temperatures, prolonged dry spells, and low humidity increase fuel flammability (Matin *et al.*, 2017; Kalawar, 2022; Mishra *et al.*, 2023). Approximately 92.87 per cent of recorded fires occurred during this period, closely aligning with earlier estimates that around 89 per cent of fires in Nepal happen in the dry season, alongside an annual

increase of approximately 0.6 per cent in burned area (Matin *et al.*, 2017; Mishra *et al.*, 2023). The SES theory emphasises that ecological susceptibility alone does not produce disturbance events unless it is triggered by human activity and governance failures. Comparative studies from India and Southern Europe show that similar climatic conditions result in divergent fire outcomes depending on land-use practices, institutional capacity, and enforcement effectiveness (Somlai *et al.*, 2018; López-Rodríguez *et al.*, 2021). The sharp decline in fire incidence during COVID-19 mobility restrictions in Nepal, marked by a 4.54 per cent decrease in fire events and an 11.36 per cent reduction in fire radiative power, further confirms that climate stress becomes consequential only when coupled with human activity, as documented by Paudel (2020). Human ignition emerged as the most immediate and decisive driver of forest fires in Bagmati Province, underscoring the central role of resource users within the SES. Negligent activities, intentional burning, agricultural practices, and grazing-related practices dominate ignition sources, indicating that user behaviour frequently overrides biophysical constraints. This aligns with findings from Mediterranean Europe, where anthropogenic ignitions account for over 90 per cent of wildfire events (Moreno *et al.*, 2021) and are increasingly dominant across South Asia (Doerr and Santin, 2016). In Nepal, Tiwari *et al.* (2022) link increasing fire incidence to livelihood transitions, declining forest dependence, and reduced incentives for stewardship. From the SES perspective, this reflects a weakening feedback loop between resource users and the resource system: as economic and cultural reliance on forests diminishes, so does collective responsibility for protection. Similar dynamics have been documented in Ethiopia and Southeast

Asia, where livelihood diversification erodes shared norms and collective monitoring, increasing fire risk (Somlai *et al.*, 2018). The convergence of these findings suggests that human behaviour constitutes not merely any driver of contemporary wildfire regimes, but a structural one.

The spatial distribution of forest fires in Bagmati Province further illustrates how socio-institutional processes shape fire risk beyond environmental determinants. High-risk zones were concentrated near settlements, roads, and forest-agriculture interfaces, reflecting patterns of human access and land-use intensity. While slope, vegetation type, and fuel load influence fire spread, they do not fully explain spatial clustering. Comparable studies from Europe and Australia consistently show that proximity to infrastructure and human access outperform biophysical variables in predicting fire occurrence (Doerr and Santín, 2016; Charnley *et al.*, 2020). Within the SES framework, these interface zones represent areas where interaction between resource users and the resource systems is most intense, yet governance oversight is often weakest. The KDE-based spatial validation applied in this study identifies zones of intensified interaction between resource users and the resource system, where governance oversight tends to be weakest. It further corroborates this interpretation by delineating low-risk zones in areas with less concentrated human activities, thereby illustrating that fire risk is socially produced and spatially mediated through governance gaps.

Institutional capacity within the governance system critically mediates the extent to which human ignition escalates into large-scale fire events. Despite Nepal's progressive forest policies, including community forestry, fire management remains under-resourced

and weakly enforced. Less than 0.5 per cent of the forestry budget is allocated to fire management, severely constraining investments in training, equipment, and early warning systems (Pandey *et al.*, 2022). Evidence from decentralised governance systems suggests that increased local responsibility without adequate institutional support often leads to management failure (Laschi *et al.*, 2019). In Bagmati Province, decentralisation has expanded the number of actors involved in fire management but has not strengthened coordination or accountability, resulting in delayed responses and ineffective prevention. As Kirschner *et al.* (2023) demonstrated, inclusive governance enhances the collective capacity to manage wildfire risk, suggesting that institutional design, rather than decentralisation alone, is decisive.

This study further reveals how weak collective action exacerbates institutional limitations. CFUGs reported insufficient firefighting tools, a lack of standardised training, and an inability to hire forest watchers due to financial constraints. From a CAT perspective, deficiencies in communication and coordination are particularly salient: fire response remains informal and reactive, often relying on phone calls, which delays mobilization and reduces effectiveness (Sapkota *et al.*, 2015). While the ICIMOD web portal demonstrates the potential of digital early warning systems, detecting and communicating fire events within approximately 20 minutes (Thapa *et al.*, 2021), its limited uptake underscores persistent investment and capacity gaps. The reported tendency for fires to ignite at night, when alert systems and coordination mechanisms are weakest, further exposes temporal mismatches between risk and response capacity. These findings are consistent with Charnley *et al.* (2020), who

documented that insufficient institutional support undermines local wildfire governance, as well as with Oslon's (2012), who argues that collective action tends to fail when individual costs outweigh shared benefits.

Declining trust and reciprocity, central to CAT, further weaken cooperation between communities and state institutions. Livelihood insecurity, limited incentives, and weak state presence reduce voluntary participation in fire prevention and suppression, reinforcing a cycle of disengagement. Similar issues are highlighted in the studies by Pandey *et al.* (2022) and Tiwari *et al.* (2022), suggesting that Bagmati's challenges reflect broader governance failures in managing fire as a common-pool risk rather than isolated local shortcomings. To address this, the study suggests innovative solutions like providing insurance mechanisms for individuals involved in fire control, a recommendation that aligns with findings from earlier research (Bhattarai *et al.*, 2022). This offers a promising avenue to rebalance risk and incentives, aligning individual participation with collective benefits.

Overall, the interplay of climate stress, human ignition, institutional weakness, and collective action capacity perpetuates a feedback loop that heightens forest fire risk in Bagmati Province. This cycle, observed across diverse socio-ecological contexts, combines heightened ecological vulnerability within anthropogenic fire use and inadequate governance, progressively eroding trust, coordination, and motivation. Effective strategies to mitigate this risk must involve behavioural modification, improved institutional coordination, and re-engagement of community–state collaboration, rather than just focusing on ecological restoration or fire suppression alone. Embedding fire management within a robust SES-informed

governance framework, supported by incentives that enhance trust and reciprocity, is essential for fostering long-term resilience to forest fires in Bagmati Province and similar socio-ecological systems.

Despite the analytical strengths of this study, several limitations should be acknowledged. The large geographical extent and complex topography of Bagmati Province constrained field access, potentially leading to the underrepresentation of remote forest areas. The analysis relies on data from NASA's FIRMS and other secondary sources, which are subject to limitations including the omission of small fires, cloud cover interference, and reduced detection accuracy in dense forests. Additionally, the use of a 90m DEM, rather than higher-resolution data (e.g., 30 m), may have constrained the precision of topographic variables in fire risk zonation. The exclusion of wind as a parameter, despite its known influence on fire spread (Weise and Biging, 1997), may have further affected the accuracy of the zonation results.

CONCLUSION

This study addressed two research questions by examining the spatial-temporal patterns and causes of forest fire in Bagmati Province and assessing how community knowledge and institutional capacity influence fire management. By integrating GIS-based analysis with community-level insights, the study shows that forest fire risk in Bagmati Province is highly uneven and strongly seasonal. Approximately 34 per cent of the province is classified as being at very high fire risk, primarily concentrated in Chitwan, Makwanpur, and Sindhuli, where most fires occurred during the pre-monsoon season. These findings reinforce the discussion that anthropogenic factors such as negligence, agricultural burning, and intentional fires outweigh biophysical drivers alone. Further

studies demonstrate that while community forestry institutions play a central role in fire management, their effectiveness is constrained by limited financial and technical capacity, weak coordination, insufficient training, and the absence of reliable early warning systems. From social-ecological systems and collective action perspectives, these institutional gaps undermine cooperation, delay response, and intensify fire impacts, especially in areas with high human-forest interaction.

The unique contribution of this study lies in its integrated approach, combining long-term satellite-derived fire data with community-level experiences to produce a validated fire risk map while simultaneously diagnosing governance and collective action challenges. Future efforts should prioritize strengthening institutional coordination, expanding technology-based early warning systems, and linking livelihood incentives with fuel management.

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