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FOREST FIRE TRENDS AND MANAGEMENT PRACTICES IN THE HILLS OF NEPAL

Abstract: Understanding the trends and patterns of forest fires is critical for effective fire management. This study aimed to analyze forest fire incidences, trends, and management practices in the six different community managed and government managed forests in the Salyan district of Nepal. We analyzed active fire data for 2001–2017 using Moderate Resolution Imaging Spectroradiometer (MODIS), to understand the fire trend. Our results based on MODIS satellite imagery show that fires are common during the dry, windy pre-monsoon season which starts from March to May, with *Pinus roxburghii* forests being the most fire-prone, followed by *Shorea robusta*-dominated forests. Anthropogenic factors were identified as the primary cause of fire ignition. The fire management practices adopted by the Community Forest User Groups (CFUGs) have been effective in managing and preventing fires. These findings are valuable for prioritizing forest areas for fire control and management. We recommend close coordination and cooperation between CFUGs, governmental and non-governmental agencies to design and implement effective forest fire management strategies.

Keywords: anthropogenic factors, community forests, fire management, MODIS, wildfire

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Introduction

Wildfire is one of the major natural disturbances affecting the forest ecosystems in Nepal (Bhujel et al., 2018; Davies et al. 2014). It is reported that more than 30,220 fires are recorded in Nepal between 2000 and 2013 (Parajuli et al., 2015; Paudel et al., 2020). Most wildfires in Nepal are human-induced, and natural fires are very rare (Bajracharya, 2002). About 58% of fires are intentionally set by people for different purposes such as grass promotion for livestock, enhancing hunting conditions, and producing non-timber forest products. About 22% of fires are caused by negligence and 20% are accidental (Kunwar & Khaling, 2006; Timilsina et al., 2007).

Since fire can be both a useful management tool and a destructive force, understanding and managing it in forest ecosystems is complex. Fire with similar characteristics may benefit one ecosystem (for example, helps regeneration and nutrient recycling), while causing harm to other (damage flora and fauna and NTFPs); all these depending on the vegetation type, climate, hydrology, and fire intensity (Rowell & Moore, 2000; Thomas & McAlpine, 2010). Since fire poses both beneficial and harmful effects, its pattern and management practices need different implementations.

In his research, Bajracharya (2002) classified forest fire regimes according to vegetation types in Nepal. He noted that the Shorea robusta forest experiences annual surface fires, which consume leaf litter, seedlings, and other herbs and shrubs. While the large green trees and roots remain undamaged, the aerial parts of the trees get burnt. The *Pinus sps.* forests are greatly fragmented because of frequent burn due to their resin content. *Quercus semicarpifolia* forests are susceptible to extensive fire damage during the dry season, especially on windy days. Fire in alpine forests is acute from March to June every year, mainly due to human negligence caused while burning the area to get young shoots.

The preparation of Forest Fire Management Strategy 2010 is the only forest fire specific initiation of the Government of Nepal towards fire management (GoN, 2010). However, a few provisions on forest fire management have also been included in the forestry sector policies such as, the National Forest Policy, 2075, the Forest Act, 2019, and the National Parks and Wildlife Conservation Act, 1973 and their regulations (Bhujel et al., 2022). The Department of Forest (DoF) carries out fire prevention programs in priority districts under the National Forest Program (Sharma, 2006). Handling over forests as community forests to locals to manage and utilize has been proved to decrease the incidence of fires in Nepal (Kunwar & Khaling, 2006, Sharma 2006; Shrestha et al., 2010). The fire protection plan is included in the operational plan of the community forest in which they explain about different measures to apply before fire season and during the time of the fire.

Recently, remote sensing techniques have been widely used in forestry studies. Studies have demonstrated application of remote sensing data for estimating forest structural changes (Ryan et al., 2012), quantifying forest degradation (Bourgoin et al., 2020), land use land cover detection (Joshi et al., 2020; Sharma Banjade et al., 2023), monitoring forest structure (Rai et al., 2024), landslide susceptibility mapping (Shrestha et al., 2021), and drought monitoring (Bista et al., 2021). This is particularly relevant to recent findings suggesting changes in land use and land cover, including increased forest cover in the mid hills of Nepal (Joshi et al., 2020). As forest ecosystems evolve, they may become more susceptible to wildfires, which can have huge implications in biodiversity, carbon storage, and local communities.

Very few studies have been conducted in Nepal to analyze wildfire causes, consequences, management, and practices adopted in different locations (Bajracharya, 2002; Bhujel et al., 2022; Sharma, 2006; Parajuli et al., 2015). As a result, there exists a clear gap in understanding spatial patterns of natural and human-induced forest fire processes in different forest types and management regimes and appropriate management interventions to control them. We aimed to fill this knowledge gap through an analysis of forest fire trends and management practices adopted in different types of forest under different management regimes in the Salyan district located in the mid-hills of Western Nepal.

The primary objective of this research was to analyze the forest fire incidence trend and its management practice in two different forest management regimes (Community managed forests and government owned forests). Specifically, our study:

1. Analyzed the forest fire trend in Salyan district during 2001–2017;
2. Explored current forest fire management practices in selected community-managed and government-owned forests;
3. Assessed the opportunities and challenges for effective fire control and management in the district.

Materials and methods

Study area. The study was conducted in the Salyan District located in the western hills of Nepal. The district covers an area of 1,462 km^2, between the latitude 28°31' to 28°53' N and longitude 82°0' to 82°46' E in Karnali Province (Figure 1). Elevation ranges between 326 m to 2827 m above mean sea level. The district covers two physiographic regions i.e., Churia hills in the south and Mahabharat hills in the north. The climate varies from tropical to temperate. April to June is generally the hottest season with temperature ranging from 28°C to 35°C, while December to January is the coldest when the temperature ranges from 14°C to 27°C. Monsoon rains generally start from July and continue until the end of September with an average annual rainfall of 1,110 mm (District Development Committee Salyan, 2015).

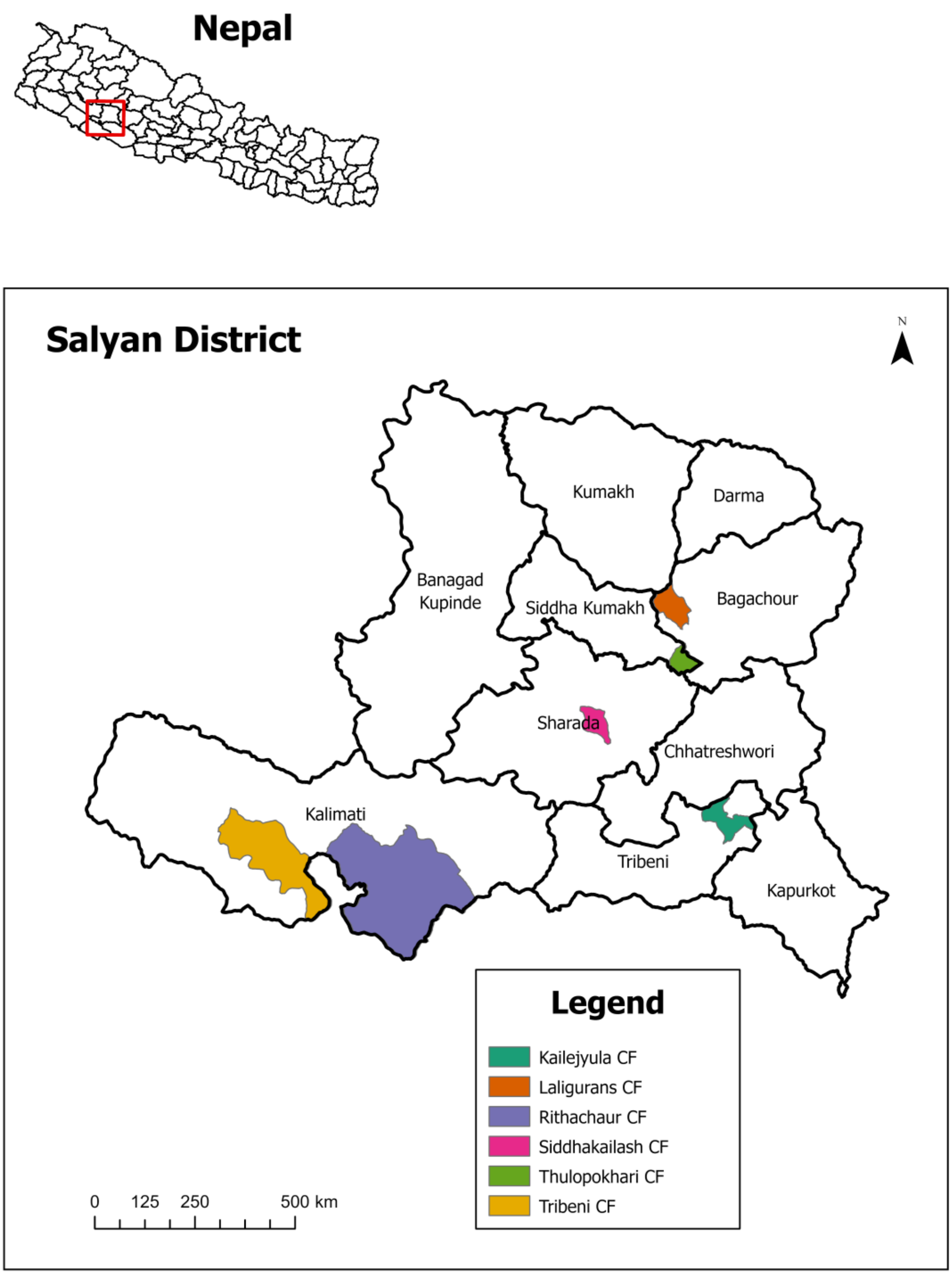

Figure 1. Map of studied community forest (CF) in the Salyan District
located in the western hills of Nepal prepared using ArcGIS
Source: own study

Forest covers 65.69% (128, 205 ha) area of the district. The majority (i.e., 67%) of the forest area is dominated by *Pinus roxburghii* forest. The forest resources in the district are managed through five approaches: government-owned forest (54%), community forest (CF) (45.14%), leasehold forest (0.86%), private forest (0.01%), and religious forest (0.003%) (District Development Committee Salyan 2015).

Satellite data collection. Active fire data from MODIS satellite Aqua and Terra for the 2001 to 2017 period were used for mapping forest fire occurrence and trend analysis. MODIS captures imagery of a given location four times daily, two images at day 1030 and 2200 h from Terra and two images at night 0130 and 1330 h from Aqua. This frequent revisit time allows for the detection of dynamic changes and provides a comprehensive view of the location across different times of day. To improve the analytical precision, we used MOD02-1KM data (MODIS calibrated radiances product: spatial resolution 1,000 m) and MOD03 data (geological location product), which are level 1B data of MODIS, and MOD09-HKM (atmospherically corrected surface reflectance data: spatial resolution 500 m) of MODIS Level 2 data. The downloaded MODIS satellite data were further analyzed using ArcMap 10.5.1.

Spatial distribution of the active fire points of 17 years was combined onto a single layer and converted into a raster dataset for density estimation through kernel density estimation tool (Serra-Sogas et al., 2008; Xie ZX et al., 2008) using Arc GIS. Kernel density model was used to find out the high, medium, and low forest fire risk zones in the district. According to Hardy (2005), fire risk is the probability of anthropogenic or natural ignition of the fire. Density estimation was necessary to know where the fire incidence is more concentrated. Kernel density calculates magnitude per unit area from a point using a kernel function to fit the smoothly tapered surface to each point (Vilar del Hoyo et al., 2011; Monjarás-Vega et al., 2020). Total fire occurrence for the 17 years, monthly, seasonal, and fire distribution according to forest types was analyzed in MS-EXCEL and the classification of fire risk zones was performed using Natural Breaks method in ArcGIS.

Fire management data collection. Primary information was collected by consulting with forest officers, rights holders, and stakeholders in forest management. A detailed checklist was designed to assess current fire management practices, challenges, and opportunities for fire control and management. Six CFUGs were visited to directly capture the perspectives, ideas, and views of stakeholders through key informant interviews where a total of 88 respondents were interviewed. These interviews conducted with Divisional Forest Officers (DFO), forest watchers, local herders and grazers, conservation workers, elderly people, Nepal army, and police officials were beneficial in revealing the help they gained in managing fires from the government and other stakeholders, and the constraints they faced. Further, consultations through focus group discussions were held with the executive committee and members of those six CFUGs.

Results

Fires in Salyan district. There were 1,092 forest fires from 2001 to 2017. The annual number of fire had a high variability and were greatest in 2016 (153) followed by the years 2014 (148) and 2012 (110) (Figure 2). Intra annual variability was also great. The majority of the fires were observed in April and May while March and June had very low records of forest fire (Figure 3, Table 1). The fall season especially August, September, and November contained no fires (Figure 3).

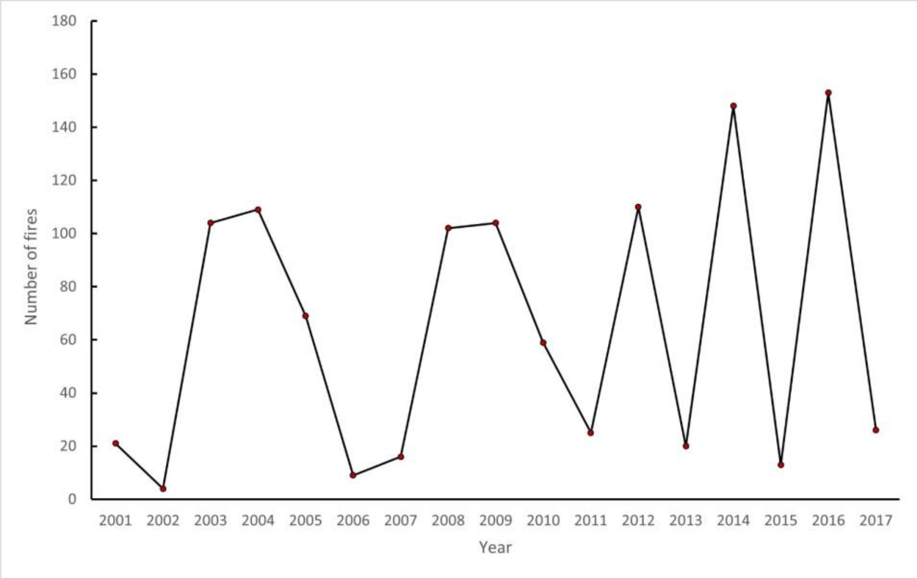

Figure 2. Number of forest fires recorded in Salyan district during 2001–2017, extracted from MODIS data
Source: own study

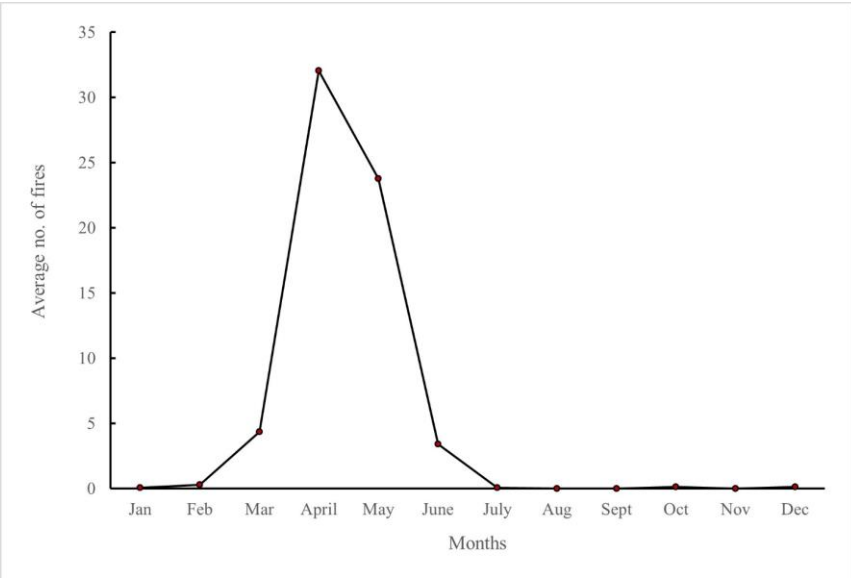

Figure 3. Average monthly occurrence of fire in the Salyan district from 2001 to 2017, derived from MODIS data
Source: own study

Table 1. Seasonal distribution of fire occurrences throughout 2001 to 2017, based on MODIS data

Season	Number of Fires
Spring (Mar-May)	1,019
Summer (Jun-Aug)	62
Autumn (Sept-Nov)	3
Winter (Dec-Feb)	8
Total	1,092

Source: own study

Forest type influence on fire occurrence. MODIS data was used to obtain information on forest fire frequency and the date of occurrence for each forest type. The average occurrence of forest fire was found to be highest in *Pinus roxburghii* forest (33 fires yr^{-1}) followed by *Shorea robusta* forest (15 fires yr^{-1}) and *Pinus roxburghii* and *Shorea robusta* mixed forest (14 fires yr^{-1}). *Quercus semecarpifolia* forest had the lowest fire occurrence with an average of two fires per year (Figure 4).

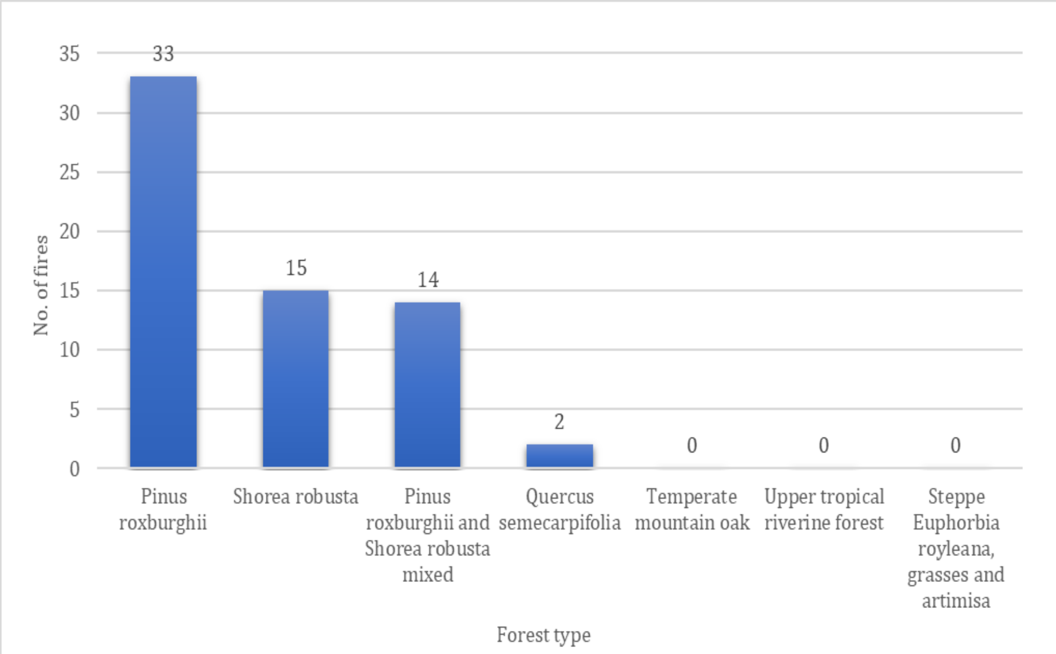

Figure 4. Average number of fires per year in different forest types in the Salyan district from 2001 to 2017
Source: own study

Fire risk zonation. We divided the study area into three fire risk areas: high, medium, and low (Figure 5). This division was categorized based on the number of times each area was burned over the time of the study period. We found that forest fires were scattered all over the study area and very few regions have never burned over the 17 years. High-risk areas (maximum fire concentration over 17-year) were in the western half of the study area (Figure 5). Bangad Kupinde Municipality and Sharada Municipality were under high forest fire risk while Kapurkot Rural Municipality and Darma Rural Municipality areas have the lowest risk (Figure 5).

Forest fires ignition source. Questionnaire survey with key informants revealed anthropogenic factors as the major cause of fire in the study area. 44% of the respondents believed that smokers are the major cause of forest fire while 18% of respondents believed that resin tapping causes forest fire. Harvesters visiting the forest for Non-Timber Forest Products (NTFPs) and firewood were also considered as significant (9%) cause for fire incidence (Figure 6).

Existing fire management practices in the district. Focus group discussions with Community Forest Users Groups (CFUGs) revealed that they have integrated fire protection plans into their operational plans (OP). This includes constructing fire lines around forests and routinely clearing these lines by removing bushes, dead leaves, and twigs that can fuel fires. CFUGs also conduct awareness-raising rallies and programs before and during the dry season to inform locals and facilitate planning.

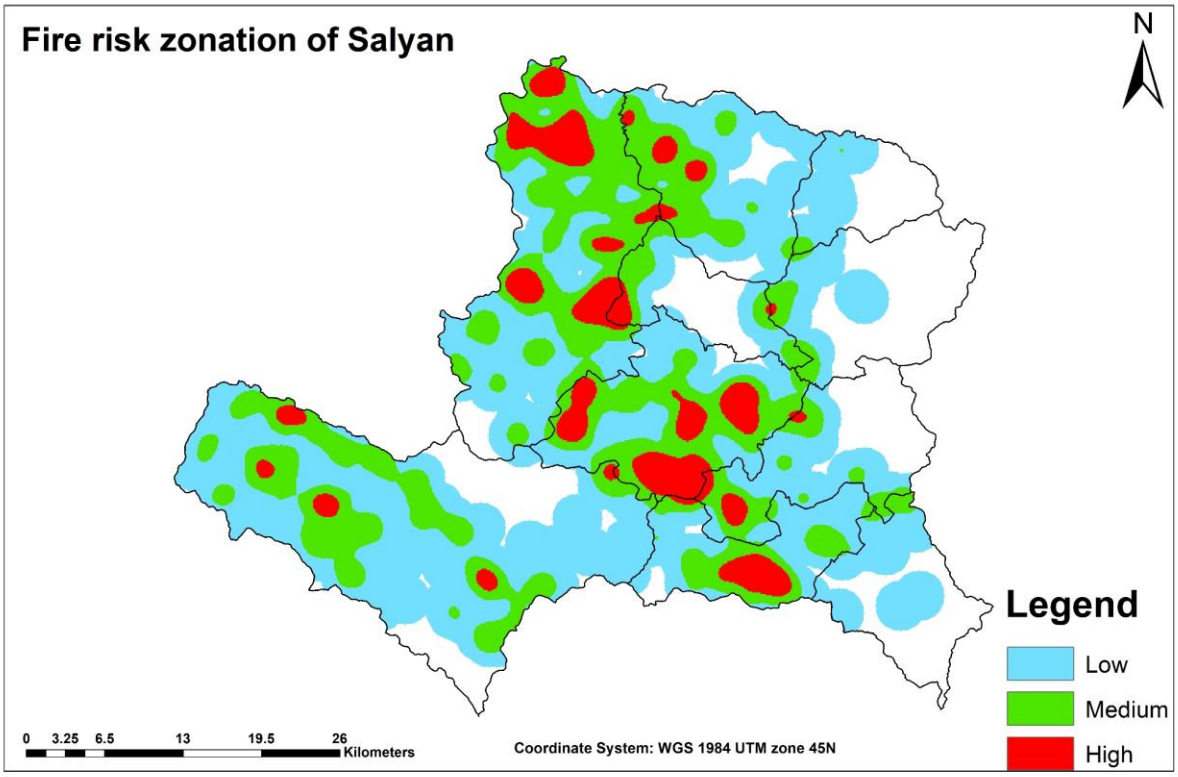

Figure 5. Fire risk in the Salyan district from 2001 to 2017 based on fire occurrence using MODIS data analyzed with ArcGIS
Source: own study

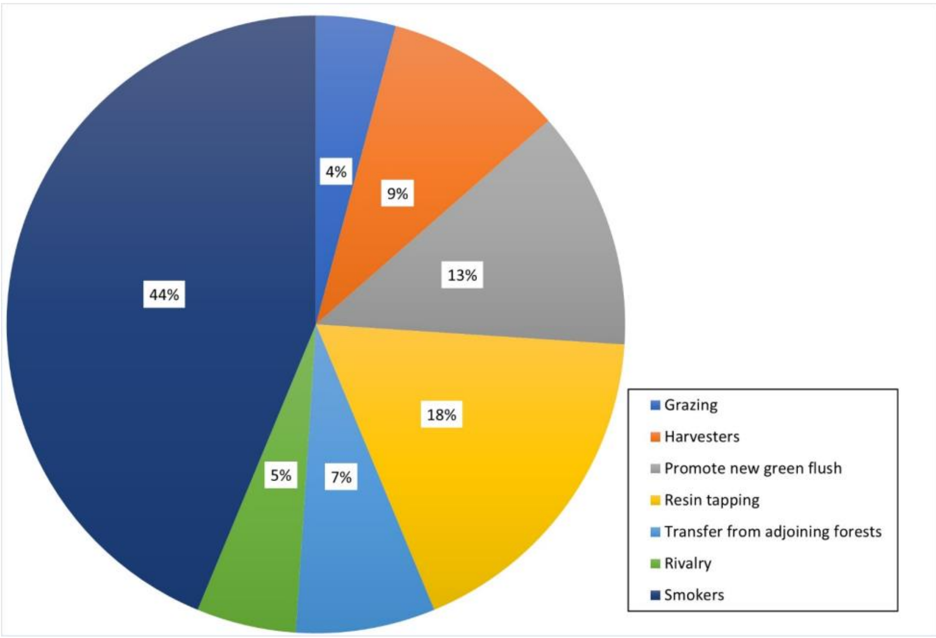

Figure 6. Perceived causes of forest fire ignition in the Salyan district based on responses from questionnaire survey
Source: own study

Fire-fighting techniques mostly involve the use of local materials like twigs, branches, and soil to suppress forest fires, primarily due to the lack of access to modern fire-fighting equipment. This shortage is often caused by limited funding, inadequate infrastructure, and the remote nature of the forest areas, which makes it difficult to transport and maintain advanced tools and machinery. Additionally, the absence of education and training on modern fire management practices further hinders the effective use of advanced technologies. A few community forests like Tribeni CF and Rithachaur CF have also used backfire techniques in recent years to control the spread of fire.

Key informant interviews with officials from the divisional forest offices indicated that the Division Forest Office (DFO) and its sub-divisions are responsible for fire control in government-managed forests. However, due to most accessible forests being managed under community forest management regimes, the DFO focuses on supporting communities and raising fire awareness. Initiatives include:

– FM radio broadcasts, newspaper articles, and the distribution of pamphlets and brochures to raise awareness.
– Training CFUGs on burning material management and decomposition.
– Assisting in constructing fire lines in community forests, such as in Duberichaur CF at Siddheswori in 2016.
– Building small water ponds for fire extinguishing in forests, with examples in Ranikot, Kotmaula, Khairabang, and Darim-jyula.
– Celebrating annual fire management week in the third week of March, involving local people in group meetings, training, coordination programs, and forest fire management workshops to enhance cooperation and trust among stakeholders.

Challenges for effective fire management. Key informant interview revealed that the extensive size of the Salyan district and its hilly terrain have posed significant challenges for effective and integrated fire management. Further, despite knowing the effects of forest fire, local herders and trespassers carelessly throw cigarette butts and leave fires on adjacent lands unattended making it a major challenge in forest fire control and management.

Interviews with key informants revealed a lack of essential skills and knowledge for effective fire management in the Salyan district, including limited understanding of fire behavior, poor training in suppression tactics, and no experience in fire risk mapping. This skills gap, worsened by the absence of formal training and technical resources, hampers both fire response and prevention. Building local capacity through targeted training and basic equipment is crucial to improving fire management in the region. Lack of documentation of the burned area, damage to crops, trees and wildlife has made knowledge on state of damage due to forest fire and preparation of fire management plans a major challenge for DFO.

Further, there is inadequate knowledge regarding the use of fire as a management tool, wildfire suppression methods, and effective wildfire prevention methods. Additionally, the budget for fire control is insufficient due to neither DFO nor concerned CFUGs have enough modern fire-fighting tools due to which management authorities and locals are confined to the use of local fire-fighting tools to suppress fire. This has further resulted in a lack of willingness of locals to participate in extinguishing fire for fear of injury and due to the lack of insurance mechanism. This reluctance was evident during field visits and community discussions, where several residents expressed hesitation to engage in fire suppression activities without proper safety gear or assurance of compensation in case of injury. Additionally, existing forest policy, legal procedures, and government plans lack proper guidance on forest fire management.

Apart from these gaps in knowledge and challenges in management, key informant further pointed out few ecological challenges in the district with steep slopes resulting in inaccessible terrain to control fire, water scarcity and strong winds throughout the year making it difficult to suppress wildfires. Further, the fact that more than 66% area of the district is covered with pine forest and pine needles and resin collection leftovers create favorable and most flammable fuel to ignite the fire has become a major challenge in managing wildfire in the district.

Discussion

The fire events detected from MODIS active fire data showed that most fires occur between March to May. This aligns with findings from other regions of the country, which report peak fire activity during the hottest period in the dry spring months (Bhujel et al., 2017; Bhujel et al., 2018; Parajuli et al., 2015). The seasonal consistency may be attributed to shared ecological conditions – such as similar forest types dominated by fire-prone species – and widespread management gaps, including limited prevention strategies and institutional capacities. The dry season facilitates fire occurrence through a combination of abundant, dry fuel loads – comprising fodder, grass, and leaf litter – and low moisture content in the undergrowth. These factors, combined with high temperatures, low relative humidity, minimal precipitation, and increased wind velocity, create ideal conditions for fire ignition and spread (Monjarás-Vega et al., 2020; Roy, 2003; Van Wilgen et al., 2004). These conditions reinforce the rationale behind observed fire patterns and emphasize the need for seasonally targeted fire management interventions.

The research shows that *Pinus roxburghii* forests have higher rates of fire followed by *Shorea robusta* forests. This is consistent with other results in the country that states that *Pinus roxburghii* forest has a higher rate of forest fire incidence in the middle mountain of Nepal (Bajaracharya, 2002) whereas *Shorea robusta* forests have frequent fires in the Terai and Inner Terai of Nepal (Khanal, 2018; Sharma, 2006). This result may have been amplified by the fact that the majority (i.e., 67%) of the forest area within our study area is dominated by *Pinus roxburghii* forest (District Development Committee Salyan, 2015). This could be due to the flammability of *Pinus roxburghii* forests, which contain resin while the *Shorea robusta* forests build up high fuel loads from falling leaves during the pre-monsoon summer, both of which increase fire risk (Bajracharya, 2002).

The results show that humans are perceived to be the major cause of fire ignition. This is consistent with the studies that states human activities as the major cause of forest fire in Nepal (MFSC, 2002; Monjarás-Vega et al., 2020). Research by Matin et al. 2017 recorded 41% of fires in Nepal are recorded within 1 km of a settlement and about 40%

of fire incidences were recorded within 1 km of a road. Further, Kunwar & Khaling (2006), stated in their research that 58% forest fire are caused by deliberate burning by grazers, poachers, and non-timber forest product collectors, with 22% are caused by negligence and 20% occur by accident assisting in justifying our result.

The information gained from focus group discussions and key informant interview revealed community forest users group to be the main source of fire management, with even the government sectors focusing on strengthening of community forest users group for the fire management practice. Kunwar (2006) presented the importance of local communities in preventing and suppressing harmful fires because they have clear understanding of local conditions and circumstances important for successful fire management. Further, Tshering (2006) stated that the active involvement of the local forest managers is necessary for effective forest fire management.

Furthermore, incorporating local knowledge and practices in forest fire management planning is crucial for effective forest fire management (Schultz et al., 2019). Study by WWF Nepal (2003) shows that after the initiation of community involvement in forest management, fire events reduction and management have improved in the community forests. Fewer fire events were recorded in community forests compared to the government-owned forest. Further, Kunwar & Khaling (2006) in their study writes that some CFUGs have developed concrete ideas about fire occurrences, the role of fire lines, the history of fire incidents, and the fuel loads they use to suppress forest fires. These might be the reason why DFOs, as seen in our result might have been focusing on forest fire management through the use and strengthening of CFUGs.

One of the major challenges in forest fire management as per the result of the research is the negligence of local people. This result was evident in other studies as well. One of the studies shows that about 58 per cent of forest fire is a result of deliberate burning by grazers, poachers, hunters, and non-timber forest product (NTFP) collectors; 22 per cent due to negligence and 20 per cent by accident in Nepal (Mathema, 2013).

The result from a key informant interview revealed inadequate policies related to forest fire. Other research also expressed this opinion stating that even though there are several policy provisions on fire and disaster risk reduction under different sectoral agencies, no other sectoral policy including the one on disaster risk reduction explicitly spells out forest fire management provision (Pandey et al., 2022; GoN, 2018). Further, the only government policy that focuses solely on forest fire management is the Forest Fire Management Strategy. However, its implication has been questioned stating that even though it envisions to facilitate integrating forest fire management contents in school-level curriculum and the government training courses (GoN, 2010). However, these are rarely translated into action except for a few sessions for in-service training for mid-level forestry staff. Likewise, finger count awareness activities are being conducted at the ground level to the selected community members.

Conclusions

Our study identified a total of 1,092 forest fires in Salyan District from 2001–2017, with a notable peak during the spring month (March-May); particularly in April. This highlights the need for effective monitoring and patrolling during these seasons to mitigate fire incidents. Among the forest types, *Pinus roxburghii* forest had the highest fire frequency followed by *Shorea robusta* forest and *Pinus roxburghii* and *Shorea robusta* mixed forest. Conversely, *Quercus semecarpifolia* forest experienced the lowest fire frequency.

Topographical challenges, including steep terrain and water scarcity, significantly impede fire control efforts in the district. Notably, many of the high-risk zones identified through our analysis overlap with areas characterized by difficult terrain and poor accessibility. Despite the DFO conducting various training and awareness campaigns, many Community Forest Users Groups (CFUGs) lack access to these resources. The effectiveness of fire management is further compromised by inadequate tools, communication gaps, and poor information flow, highlighting the need for enhanced social relations and greater trust among stakeholders.

To address the increasing fire ignition caused by high biomass accumulation, it is essential to provide accessible training on controlled burning and burning materials to all CFUGs. Effective fire management can be enhanced through stronger collaboration and coordination between CFUGs and governmental agencies, such as the forest department. The current lack of comprehensive forest fire management policies and the inadequate implementation of existing strategies highlight the need for more effective and actionable policies. Additionally, integrating insurance and compensation schemes for fire-affected communities can improve resilience and promote active participation in fire reporting and prevention. India's Forest Fire Prevention and Management Scheme, for example shows how compensation and community participation can be integrated into national fire management strategies. Adapting such mechanisms to local context can provide immediate support and promote long-term incentives for sustainable fire management.

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