Received 9 February 2025, Revision accepted: 8 June 2025
Himalayan Biodiversity 2025. 10: 70- 83 **DOI: https://doi.org/10.3126/hebids.v10i1.85810**
ISSN: 2382-5200

Forest Fire Hotspots, Distribution and Management in Lowland of Tarai, Nepal

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ABSTRACT

Spatial mapping, impact assessment and sustainable management of forest-fire in Nepal through participatory processes are urged in national policies; however, such attributes including identifying forest-fire hotspots and the management practices are handful in Nepal. This study aimed to provide the field-level information of forest-fire of Rautahat and Bara districts of Central lowland Tarai region that is helpful in mapping fire-hazardous areas and the related challenges, and developing management measures applying both GIS and participatory approaches. We used literature review, expert consultation, surveys with key informants and local communities, and integration with geocoordinate vector layers of seven variables (land use land cover, forest/vegetation type, aspect, slope, fire occurrence, proximity to settlement, and proximity to road) for GIS mapping and modeling of forest-fires. Results showed that forest-fire incidences are varied at spatio-temporal scales where annual forest-fires are increasing and influenced by human interferences. Forest-fire hotspots found in this study are closer to the built-up areas and villages, and prevalent in the northern part of villages, close to the Churia-Siwalik range and east-west highway. The northern parts are also associated with frequent open spaces abraded by invasive species, big shrubby patches, and dry, disturbed hardwood and mixed Sal forests that are annually burned by villagers for sprouts. Provided the warm and humid weather together with heavy pressure on forests for timber and non-timber forest products collection, the Sal forests of the villages and northern parts are under high risk of forest-fire. Engaging local communities in sustainable forest management measures and emphasizing and incentivizing forest-fire management interventions are some of the plausible ways forward.

Keywords: Climate change, Chure, forest-fire, hazard mapping, hotspots.

INTRODUCTION

Nepal Disaster Risk and Management Act (2017) recognizes earthquakes, forest fires, floods, landslides, heavy rainfall and drought as major disasters of the country (MoHA, 2019). Among them, forest-fire is the second most crucial threat worsening the forest ecosystem in Nepal (MoFSC, 2014). According to Reddy *et al.* (2019), annually about 30% of the forest areas likely catch forest-fire. The Forest Monitoring and Detection System Nepal recorded 5,626 forest-fire incidents across the country from November 2020 to April 2021 (Mandal, 2021). Over 55,000 active forest-fires were observed in 20 years between 2000 and 2020 (ICIMOD, 2021). Forest-fires in Nepal burned around 0.172 million ha of forests annually, leading to 7.07 million tones of biomass loss and 3.3 million tones of carbon emission (Bhujel *et al.,* 2022). Frequent and recurrent forest-fires severely damage and prohibit the regeneration and growth of seedlings, destroy non-timber forest products, and promote invasive species (Baral *et al.* 2017; Paudel, 2022).

A total of 1,863 forest-fires were recorded in 2001 and almost double, 3,830 in two decades in 2019, which indicates that the frequency of forest-fires is increasing (Matin *et al.,* 2017; DFRS, 2015; Khanal, 2015; Parajuli *et al.,* 2015; Paudel *et al.,* 2020). Kunwar and Khaling (2006) reported an increase in forest-fires in the lowland Tarai region of Nepal due to increasing human-forest interface. Until 2000, up to 90% of the forests of Rautahat district were destroyed, and almost all of the broad-leaved forests of the district were dilapidated (Goldammer, 1993; Sharma ,1996; Sharma and Goldammer, 2010). Occasionally, embers from forest-fires cause fires in nearby villages, especially in the Tarai region, resulting in loss of lives and properties (Parajuli *et al.,* 2015). Fires in Tarai, however, are mostly surface fires that do not necessarily destroy forests. It also helps maintain the habitat of the fire-adapted ecosystem; for example, the broadleaved Sal forests in Tarai show a remarkable adaptation to fire as it cleans the forest floor and helps seed germination (Webb and Sah, 2003).

Fire is an ecological process that supports the forest ecosystem if appropriately managed. However, it can often pose significant loss when out of control (Martell, 2015). In Nepal, forest-fire is considered one of the considerable causes of forest destruction and degradation (Matin *et al.,* 2017). The forest-fires are getting severe in Nepal and are limiting sustainable forest management (DoF, 2010) and sustaining the local economy. It has surmounted the challenges at both national and community levels. Consequently, massive loss of bioresources and physical properties has been experienced, so forest-fires have been counted as drivers of deforestation and forest degradation (MoFSC, 2015). Forest-fire wipes out considerable forest resources every year, resulting in the loss of biodiversity and deterioration of forest conditions (Kunwar and Khaling, 2006). Recurrent uncontrolled forest-fires severely negatively impact biodiversity, rural livelihoods, and the natural environment, including regional climate (Parajuli *et al.,* 2015).

Since uncontrolled fire seriously impacts biodiversity and livelihood, it is essential to map and identify fire risk before planning and implementing effective forest-fire management (Jaiswal *et al.,* 2002) as fire is a patchy phenomenon, different parts of the landscape burn at various severities and frequencies, leaving some areas unburned depending upon their driving factors (Bond, 2005). This results in temporal and spatial heterogeneity in the landscape (Turner, 1987). Understanding the causes and spatiotemporal patterns of forest-fires in a landscape is vital to developing effective fire management plans (Parajuli *et al.,* 2015, Matin *et al.,* 2017). Therefore, our study addresses this gap by mapping and finding patterns of forest-fires and their causes in lowland Tarai, which will help understand the relationship between forest-fires, humans, and surrounding forests. It aims to document and quantify forest-fire risk and consequences on livelihood and biodiversity in Bara and Rautahat districts of the Tarai region of Nepal. Results from this study can be referred to the forest managers, local communities, and related organizations for better forest management strategy considering the geographical sites.

MATERIALS AND METHODS

Study area

Rautahat and Bara districts were selected in this study for assessment since the districts are forest-fire hotspots in Madhesh province next to Parsa district (Badal and Mandal, 2021). Study area (Figure 1) covers Ratanpuri (Nijgadh Municipality, Bara - 27.2 N, 85.12 E) and Chandranigahpur (Chandrapur Municipality, Rautahat – 27.3 N, 85.37 E) villages of Central Tarai. Rautahat and Bara districts spread south from the ridge of Chure, representing tropical and sub-tropical climates. The districts receive about 243.84 millimeters of precipitation annually and yearly temperature is 28.23ºC which is 6.23% higher than Nepal's averages. The selected villages are characterized by semi-arid bioclimate, mainly dominated by Bhavar (Chure foothills and submerged spring canals) composed of tropical riverine vegetation. There are emerging and expanding urban settings along the East-West Highway in both districts named Chandrapur (Rautahat) and Nijgadh (Bara), which have created increasing pressure on the forests. Provided the warm and humid climate together with the mobility of the East-West Highway and heavy pressure on different forest types for timber and non-timber forest products collection, the forests of the districts are under high pressure of anthropogenic disturbances, including forest-fire. Forest-fire incidents are increasing by virtue of increasing heat, shrinking water bodies and prolonged heat waves.

Ratanpuri village is situated between Nijgadh (now Municipality) and Amlekhgunj. It borders the ridge of Chure (Makwanpur) in the north and Simra and Dumarwana village in the south. Chandranigahpur of Rautahat also has a similar climate and topography, ranging between 80 m and 181 m above sea level. It borders the Bagmati River to the east and the Dhansar River to the west. Chandranigahpur lies at the center of northern Rautahat and is bisected by East-West Highway. Most of the areas of the site lie in the *Tarai-Bhabar* zone (south of the Churia-Siwalik hill), characterized by a semi-arid and dry climate. The *Tarai-Bhabar* has a tropical environment with the forest type comprised of Sal (*Shorea robusta*) with smaller proportions of moist evergreen forest, dry deciduous forest, and Khair-Sisoo (*Acacia catechu-Dalbergia sisoo*) forest along the riversides. In this region, the accumulated glabrous Sal leaf litter is burned annually, and naturally regenerated Sal seedlings and other herbs and shrubs are burned during the process. The Chure-Siwalik hill and the Dune valleys north to the sites are characterized by a subtropical climate. Isolated Broad-leaved and hardwood forest patches are interspersed with human settlements, triggering frequent forest-fire transmission from the villages to forests and *vice-versa*.

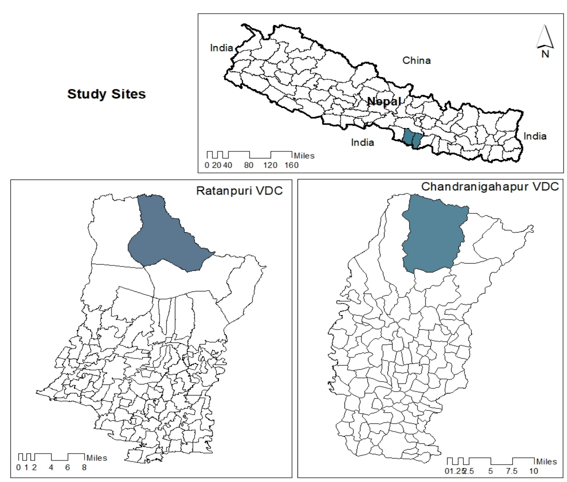

Figure 1. Map showing study villages (Ratanpuri, Bara and Chandranigahapur, Rautahat)

Study methods

Literature review, field observation, group discussion, key informant consultations, and GIS mapping and modelling were the primary methods adopted in this study. Published and unpublished reports, government periodicals, and related literature pertinent to forest-fires in the study area and adjoining areas, including climate change vulnerability assessment reports, District Forestry Sector Plans (DFSP), forest-fire hazard feasibility studies, and forest-fire maps, were reviewed. A national database of forest-fire was also reviewed. Although few studies have been conducted on forest-fires in Nepal (Paudel *et al.,* 2020), the study benefited from international experiences and knowledge sources.

Two field observations were carried out in Ratanpuri and Chandranigahpur of Bara and Rautahat districts in 2015 during premonsoon season (May-June). A total of ten consultations at different levels were organised to help generate necessary information on fire hazards in the area, to verify the acquired data and their underlying causes and build consensus in zoning criteria for forest-fire hazard mapping. Consultation with government staff- Department of Forests, District Forest Office, local police office, Nepal Red Cross Society, Federation of Community Forest Users Nepal (FECOFUN), Community Forests User Groups (CFUGs), Collaborative Forest User Groups within the villages and with experts of International Centre for Integrated Mountain Development (ICIMOD) and Department of Forest's Fire Detection and Monitoring Units were done. Meetings with Division Forest Officers and FECOFUN Officers were organized to know the practical usage of SMS text alerts sent by ICIMOD's Fire Detection and Monitoring Unit, and associated data was analyzed for the detection, mapping, and monitoring of forest-fire. Focus group discussions were conducted for generating distribution and management information on fire hazards in the study area. Ten group discussions and global positioning system (GPS) point collection sites were sorted out following participatory shared learning dialogues and discussions. The GPS points collected were used to triangulate and verify data generated through Geographic Information System (GIS).

Data acquisition, modeling and analysis

Forest-fire hazard map was prepared using the latest land-sat images (30 m resolution LandsatTM, 2015; https://www.usgs.gov/landsat-missions/landsat-data-access), processed data, and available Land cover (1:25000 m, Survey department, 1996) and vegetation/forest type map (Land Resource Mapping Project, Survey Department, 1886) of both sites. The buffered map was rasterized and overlaid with the other seven layers of information to derive the final fire hazard map. The predictor variables (i) Land use Land cover Type, (ii) Forest Type, (iii) Aspect, (iv) Slope, (v) Frequent Fire Occurrence Zone, (vi) Proximity to Settlement and (vii) Proximity to Road (Table 1) selected for mapping forest-fire hazard were adapted from Jaiswal *et al.* (2002), Ghobadi *et al.* (2012) and Matin *et al.* (2017). Their weights were used to scale the final map. The overlaying of seven raster layers was weighted based on its impact, assigning a higher weight to the variable with a higher fire hazard effect. Although subjective weights were based on expert judgments, to improve the results, consensus from stakeholders and previous models and studies were considered for weightage. The resulting maps were then classified into four risk categories: low, medium, high, and very high. The categorization was based on "Multi-Criteria Analysis (MCA) for Fire Sensitive Mapping” (Table 1).

Table 1. Multi-Criteria Analysis for Fire Sensitive Mapping

Parameters	Parameters code	Classes	MCA Rank	Fire Risk Rating (1-lowest to 5-highest)	Overall Weightage
Land use Land cover Type	A	Ice/Rock/Glacier/Water Body/Sand/Landslide/Pond/ Lakes/Airport/Institutions	0	1	20 % influence on mapping
		Forest Land	1	5	
		Bush/Shrub Land	2	3	
		Grass Land	3	4	
		Cultivated Land/Orchard/ Nursery	4	2	
		Waste/Barren Area	5	1	
		Built-up Area	6	1	
Vegetation/ Forest Type	B	Others	0	1	20 % influence on mapping
		Sal Forest	1	5	
		Hardwood Tropical Forest	2	4	
		Hardwood Sal-Sissoo Forest	3	3	
		Coniferous Forest	4	4	
		Mixed Forest	5	2	
		Grazing	6	4	
		Shrub	7	3	
		Cultivated Land	8	1	
Slope	C	Flat (0-5^0)	1	1	5 % influence on mapping
		Gentle Slope (5-10^0)	2	2	
		Medium Slope (10-25^0)	3	4	
		High Slope (25-35^0)	4	5	
		Steep Slope (35-45^0)	5	4	
		Extreme Steep Slope (>45^0)	6	4	
Aspect	D	Flat	1	1	5 % influence on mapping
		North	2	2	
		East	3	3	
		South	4	5	
		West	5	4	
Fire Occurrence Zone (distance from fire incident)	E	<200 m	1	5	20 % influence on mapping
		200 – 400 m	2	4	
		400 – 600 m	3	3	
		600 – 800 m	4	2	
		800 – 1000 m	5	2	
		> 1000 m	6	1	

Parameters	Parameters code	Classes	MCA Rank	Fire Risk Rating (1-lowest to 5-highest)	Overall Weightage
Proximity to Settlement	F	< 500 m	1	5	20 % influence on mapping
		500 – 1000 m	2	4	
		1000 – 1500 m	3	3	
		1500 – 2000 m	4	2	
		2000 -2500 m	5	1	
		> 2500 m			
Proximity to road	G	<200 m	1	4	10 % influence on mapping
		200 – 400 m	2	5	
		400m – 600 m	3	4	
		600 – 800 m	4	3	
		800 – 1000 m	5	2	
		> 1000 m	6	1	

Calculating Composite value: Composite value of a particular area was calculated by using the following formula [A * 20% + B *20% + C * 5% + D * 5% + E * 20% + F * 20% + G * 10% = Low(1), Low medium (2), Medium (3), High (4), Very High (5)]

The study team ranked the variables by adopting results from various similar kinds of literature, the environmental characteristics of the study area, and results from group discussions and expert consultations. We verified GIS maps using ground-truthing (rapid GPS location survey method on the ground and consultations with divisional forest officers). Group discussions were meant to approximate the forest-fire hotspots and human commuting trails/roads. These roads/trails and hotspots/ hazard zones were then verified in a GIS map using the GIS tool (ArcGIS 10.8). Buffer distances (the fire proximate area) at the interval of 200 m (up to 200 m, 200-400 m, 400-600 m, 600-800 m, 800-1000 m, and > 1000 m) were established from the main roads and trails, considering the center of the roads or trails as starting point. The buffered map was rasterized and overlaid with the other layers of information to map the final fire hotspots. Total five fire incidences (three in Rautahat and two in Bara) were recorded during field study in May-June 2015. Delphi method (Turoff and Linstone, 2002) was used to verify the acquired data and their underlying causes and build consensus in zoning criteria for forest-fire hazard mapping.

RESULTS AND DISCUSSION

Forest-fire and its causes

A total of 88 forest-fire incidences in Rautahat and 118 in Bara were recorded between 2012 and 2015. Among these, 27 and 9 incidences of forest-fire were reported from Chandranigahpur, Rautahat and Ratanpuri, Bara, respectively. The less forest-fires in Ratanpuri could be a result of higher forest cover (~70%) and water bodies (6.7% of the village's total land area). The villages have around 15% built-up area and agricultural lands (Figure 2).

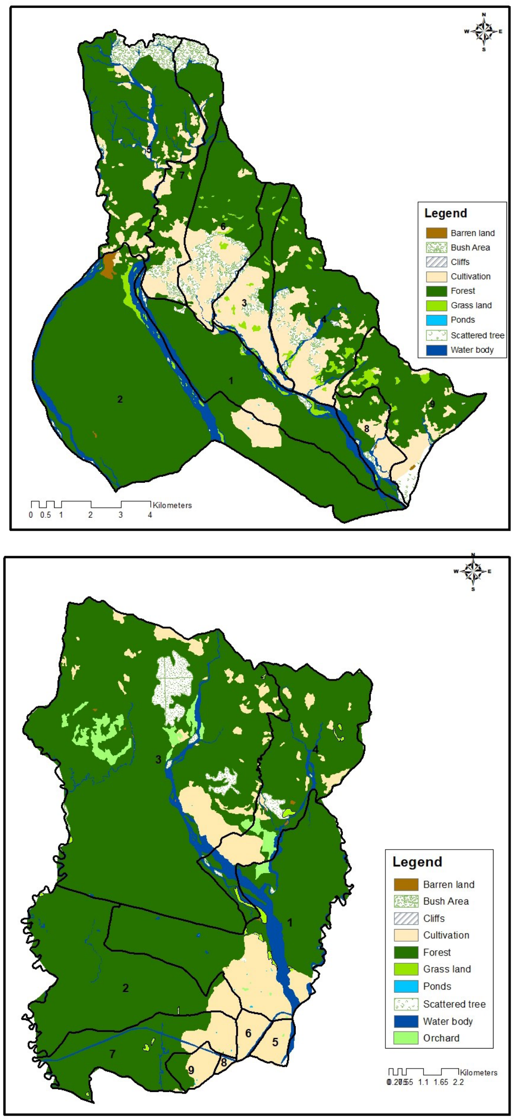

Figure 2. Land use map of Ratanpuri (left) and Chandranigahpur (right) villages

Over 20 years, between 2000 and 2019, 443 (22.1/ yr) and 634 (31.7/ yr) forest-fires were recorded in Rautahat and Bara districts, respectively, with an annual average of 53.8 for both districts. However, the incidence and casualty of forest-fires have been increasingly rampant in Tarai. Data of the last decade (2015-2024) shows that the annual average of forest-fires in Rautahat is 64.6 and that of Bara is 72.3 with 136.9 for both districts which is quite bigger number than that of the annual average of 2000-2019. The districts of central Tarai experience more forest-fire incidences than those of hills (Matin *et al.,* 2017). The Madhesh province exhibited an overall increase in forest fire susceptibility over the period of 20 years between 2000 and 2020 (Dahal *et al*., 2025).

We observed about 25% of total forest-fires recorded in the country was from Madhesh province in the last decade (2015-2024). Increasing fire events have been identified as one of the impacts of climate change (Karki *et al.,* 2021). According to ICIMOD, year 2009 and 2016 experienced a higher number of forest-fires (ICIMOD, 2021; Badal and Mandal, 2021), which was higher than the annual average (3,098) (Bhujel *et al.,* 2022). The higher number of forest-fire incidences in the year 2009 corresponded with the driest year, experiencing 50% less rainfall than average during the winter season (Wang *et al*., 2013). Global Wildland Fire Fatality Report accounted for 49 human casualties in Nepal in 2009 due to wildland forest-fires (GFMC, 2010). According to Sharma and Goldammer (2010), earlier in 2010, 90% of the forest areas of Rautahat were observed to have been burned (Sharma and Goldammer, 2010). Higher total forest loss and tree cover loss were reported in these years (Pandey *et al.,* 2022). The data available at bipadportal.gov.np (2015-2024) shows that 2023 was the hottest year in the record followed by 2018-2019.

Forest-fire in Tarai, Nepal, is typical during the dry season, which starts in March. In Tarai, the fire problems are acute for three to four months during the dry period between March and June yearly (WWF Nepal, 2003; Matin *et al*., 2017). Human-induced forest-fires were the most common in both districts, mainly due to negligence or accidental. Total 58.06% of forest-fires were induced by deliberate causes, 20% accidental, and 22% by negligible causes. More than 50% of forest-fires were due to people's negligence while they made small fires to fulfill their household purposes, such as fires for religious and cultural practices and for burning agricultural residues to fertilize soil.

The northern part of study area was associated with frequent open spaces abraded by invasive species (*Lantana camara, Chromolaena odorata, Bidens pilosa*), big shrubby patches, and dry, disturbed hardwood and mixed Sal forests, which are annually deliberately burned by villagers for forage and firewood. Such fire is attributed to local agropastoralists, who practice short-term grazing and rotation (Paudel *et al.,* 2020). Slash-and-burn practices also led to some of the fires from the northern Chure region. Some forest-fires originated from human settlements, persisted over a week/fortnight, and expanded to the north. The accidental fires were transmitted from the houses with the thatched-grass roofs. We found that 41% of the fires in the villages are recorded within 1 km of the settlement area, and the areas closer to the human settlements were more prone to forest-fires (Figure 3). The result was substantiated as unattended smoked cigarette stub was the primary cause of forest-fire in Bara and Rautahat district (Badal and Mandal, 2021). Given the increasing temperature and pressure on forests and close to settlement areas, both the settlement and Sal forests of the villages are under severe vulnerability.

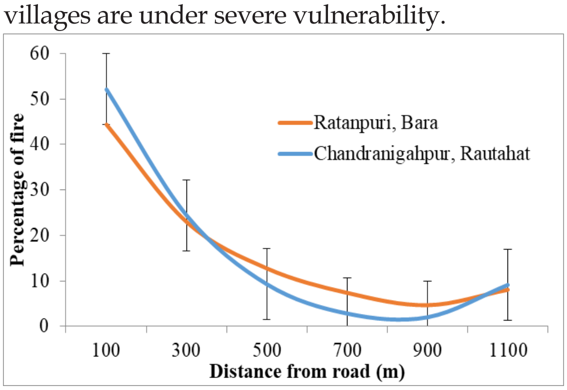

Figure 3. Fire risk areas and distance from roads

NTFP collectors, smokers, loggers and smugglers, and livestock grazers were prominent actors inducing deliberate fire in forests for collecting NTFPs. Thus, the study area's human factor (population, distribution, and human interventions) and natural conditions synergistically fomented the forest-fire incidences. The fire continued in areas where fuel accumulation was higher, particularly in inaccessible areas, leading to high-severity fires where high geographical challenges interrupted the control of fire spread (Matin *et al.,* 2017). The climatic conditions, such as prolonged dry seasons and deficient winter rainfall in recent years due to global climate change, caused some forest-fires (Das, 2012). The shortfall of winter rain leads to a catastrophic impact on food production and food security, curtailing the livelihood of local people.

Forest-fire hotspots

Around 40% of the area of the villages was under a high-risk zone, while the least (< 5%) was under a low-risk zone (Table 2). However, forest-fire distribution varied at the village level, and Ratanpuri was under severe risk. Most fire risk areas were from Ward number 3, Chandranigahpur, and all Wards of Ratanpuri village. Rivers and tributaries of the villages help hold the soil moist, offset the fire rage, and lessen the frequency.

Integrated analysis and overlaying of all seven variables of two sites showed that in both sites, over 50% of the forest area was under low-medium risk of fires (71.08% for Chandranigahpur and 52.65% for Ratanpuri). Over 45% of the forest area was under the high to very high-risk category in Ratanpuri Bara, followed by < 30% in Chandranigahpur, Rautahat, revealing that the Tarai region of Nepal is a forest-fire hotspot.

Table 2. Fire risk classification and area of Chandranigahpur and Ratanpuri

Level	Fire Hazard type and value	Chandranigahpur, Rautahat		Ratanpuri, Bara	
		Area (ha)	Percent	Area (ha)	Percent
1	Low medium (2)	42.507	0.58	459.822	4.73
2	Medium (3)	5172.650	70.50	4656.507	47.92
3	High (4)	2088.137	28.46	3623.664	37.29
4	Very High (5)	33.457	0.46	976.585	10.05
Total		7336.750	100.00	9716.578	100.00

Most of the forests of Tarai region are under high and very high-risk categories, situated in the northern part of both villages close to the Chure-Siwalik hills (Figure 4). Chure-Siwalik connects Tarai in the south and the Himalayas in the north. It is a fragile and young mountain in Nepal that is rich in tropical biodiversity (Chaudhary and Subedi, 2019). Consistent with our findings, the maximum number of forest-fires (37%) were recorded from the Churia-Siwalik region, and 80% were reported from the tropical broad-leaved forests by Matin *et al.* (2017). We found that the fire-risk regions are closer to the built-up areas and villages, supporting the results of Parajuli *et al.* (2023). Sibanda (2011) suggests that roads and trails increase the chances of forest-fires, and our study also found that more fire-risk zones are closer to roads. The incidence of fire near the streets corresponds to the physical activity of the passersby.

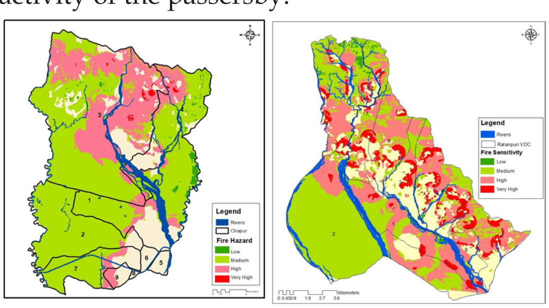

Figure 4. Fire risk map of Ratanpuri village, Bara district (left) and Chandranigahpur village, Rautahat district (right)

Consequences of forest-fire

Forest-fire incidences not only persisted in the northern parts of study sites but also spread all over the district where fuel accumulation was high and access was relatively difficult. The forest-fires affect health of both vegetation and human communities. Of the seven forest and habitat types reported from the villages (Table 3), River banks and Sissoo-Khair forests were less assaulted by forest-fire. Bamboo breaks, shrubby patches, vines, and invasive species were often burnt, but the giant trees were usually spared. Forest-fires promoted invasive species and vice-versa. Forest-fires in these districts burned forests enriched with timber, NTFPs, and various ecosystem services. Similar observation was made by Acharya *et al.* (2020) in Chure area of Nepal. Recurrent forest-fires severely damaged and prohibited the regeneration and growth of tree seedlings and destroyed non-timber forest products (MFSC, 2010). The consecutive district forestry sector plan of Bara and Rautahat reported the damage of hundreds of hectares of forests annually by forest-fires. Discussions concluded the maternal health and pregnancy problems triggered by forest-fires.

Table 3. Forest and habitat cover in Bara and Rautahat districts

Forest and habitats	Bara District		Rautahat District	
	Area covered (Ha)	Percentage	Area covered (Ha)	Percentage
Sal (*Shorea robusta*)	2051.9	7.9	4886.5	16.62
Sal Tarai Hardwood (STH)	11549.7	44.49	5408.1	18.39
Tarai Hardwood (TH)	11307.3	43.56	8379.5	28.5
Sisoo Khair (SK)	495.2	1.91	8.8	0.29
Teak Forest	200.7	0.77	-	-
River Banks	-	-	1280.3	4.35
Open space in forest area	354.3	1.36	40	0.6

As surface fire is common in Tarai (Kunwar and Khaling, 2006) and selective burning for non-wood species is persistent, tree species, particularly the Sal (*Shorea robusta*) trees, were spared. However, fire-induced soil erosion, floods, and landslides were observed at the foothill of Chure in both study sites as an aftermath of the destruction of natural vegetation (Karki *et al.*, 2013; Paudel *et al.*, 2020).

Forest-fire management

This problem will be worsened under the projected climate change and uncertain wildfire hazards (Sullivan *et al.*, 2022). Preventing deliberate forest-fires is a severe challenge to sustainable forest management. Both districts have applied local and participatory management measures to control fires caused by both intentional and negligence. It was good to see that the local communities were aware of the consequences of forest-fires and were investing their efforts to combat them in both sites. In the community forest's operational plans, some provisions such as plantation and afforestation of fire-resistant tree species (*Phoenix species, Butea species*), water hole maintenance, and fire lines and forest roads for forest-fire control have been employed to control fire. However the identification of fire-resistant and fire-sensitive species is important *in-priori*. Collection of leaf litter, dead logs and weeds, preparation of firelines and production of biomanure is trade-offs of the participatory fire management strategy.

In Rautahat, 127 km of fire lines have been constructed and maintained, whereas in Bara, only 22 km of fire-line forest roads have been built to control forest-fires. Local people used to collect litter and fuelwood while maintaining firelines. In some villages, compost trenches were initiated where poor people of the forest users committee were allowed to collect forest litter and dump it in the trenches to produce biofertilizer. We considered this initiative significant as it reduces litter and fuel accumulation, helps engage forest users in forest conservation and income-generating activities, and lessens fire risks and incidences. To extend and strengthen public awareness of fire safety, behavior, consequences, and forest management, the members of local forest user groups are to be involved in several field-level training. Engaging local communities in sustainable forest management measures and emphasizing and incentivizing forest-fire management interventions would be some plausible ways forward.

Despite forest-fire is a chronic problem in study site, the response to the forest-fire from the government level needs to be revised and more efficient. Annual periodic government plans have proposed fire management activities, which are based on past experiences. Moreover, inadequate tools and techniques to control fire yield the less effective fighting operation (Koirala *et al.,* 2014). The capacity of the division forest office needs to be improved in terms of equipment, technology, institutional, policy, and legal frameworks, and it faces financial and human resources challenges that hinder the effective management of forest-fire. Forest-fire Management Strategy, 2010 is the only document for wildfire management in Nepal with limited fire management policy provisioned (Karki, 2014; DoF, 2014), which is imperative to be updated as forest fire regimes are aggravated by climate change. Given the constraints, the divisional forest offices of Rautahat and Bara have recently been mobilizing their resources to respond better to forest-fires in the districts (DFO Bara, 2017; DFO Rautahat, 2017). In this constraint, the village-level risk maps will help district managers develop strategies for fire management within the district and prioritize areas for resource distribution based on higher fire risk zones. National level climate change adaptation plan (GoN, 2021) and biodiversity strategy and action plan (MoFSC, 2014) are supportive in offsettingthe fire risks.

CONCLUSIONS

This study found that both Rautahat and Bara districts are more vulnerable to both natural and anthropogenic forest-fire hazards. Fire hazard areas are more prominent at the vicinity of settlements and the northern parts of the districts substantiating that human-induced forest-fires are common in both districts. Local communities put on fires to fulfill their household purposes, such as fires for religious and cultural practices and for burning agricultural residues to fertilize soil. The northern part of study area was associated with frequent open spaces abraded by invasive species, big shrubby patches, and dry, disturbed hardwood and mixed Sal forests are annually deliberately burned by villagers for forage and firewood. As increasing warm and humid weather together with rising pressure on forests for timber and non-timber forest products collection, the forests nearby settlements and northern parts are under high risk of forest-fire. The initiatives significantly reduce litter and fuel accumulation, help engage forest users in forest conservation and income-generating activities, and lessen human-induced fire incidences are important. Raising awareness, strengthening capacities and engaging local communities in sustainable forest management measures and emphasizing and incentivizing forest-fire management interventions would be some plausible ways forward.

ACKNOWLEDGMENTS

We acknowledge the Global Environment Facility through Sustainable Land Management in Chure Range, Nepal project, WWF Nepal for providing the technical and financial support.

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