Chapter 8
Forest Fire Detection and Monitoring

**Sunil Thapa, Vishwas Sudhir Chitale, Sudip Pradhan,
Bikram Shakya, Sundar Sharma, Smriety Regmi,
Sameer Bajracharya, Shankar Adhikari, and Gauri Shankar Dangol**

8.1 Introduction

8.1.1 Forest Fire Across the World

Forest fire is one of the major global environmental issues, causing havoc in places as disparate as cold Siberia, tropical Amazon, and the temperate HKH region (Fig. 8.1). Recent mega fires in Australia (Nolan et al. 2020), Brazil (BBC 2019), the United States, Greece (CNN 2020; Smith et al. 2019), and Indonesia have not only destroyed ecosystems but have also triggered climate change through carbon emission (Mannan et al. 2017). A rise in global temperature by 2 °C has contributed to increased frequency of forest fire, though only 3% of all forest fires have been caused naturally (Hirschberger 2016)—the majority of them have been sparked off by anthropogenic activities (FAO 2007).

HKH, known as the Third Pole, or the Water Tower, is likely to face an increase in the frequency of forest fires as it is a region sensitive and vulnerable to climate change. The region is currently experiencing an annual increase in temperature by 0.03–0.07 °C (IGES and ICIMOD 2013; Wester et al. 2019; Zomer et al. 2014). Climate change has had an impact on the increasing number of hot and dry days, thereby aggravating the risk of fire (Hirschberger 2016). Also, climate change and forest fire are interrelated and can have an impact on both—while forest fires can cause climate change through carbon emission (Joseph et al. 2009), an increase in

S. Thapa (✉) · V. S. Chitale · S. Pradhan · B. Shakya · S. Bajracharya · G. S. Dangol
International Centre for Integrated Mountain Development, Kathmandu, Nepal
e-mail: sunil.thapa@icimod.org

S. Sharma · S. Regmi
Department of Forests and Soil Conservation, Ministry of Forests and Environment, Kathmandu, Nepal

S. Adhikari
REDD Implementation Centre, Ministry of Forests and Environment, Kathmandu, Nepal
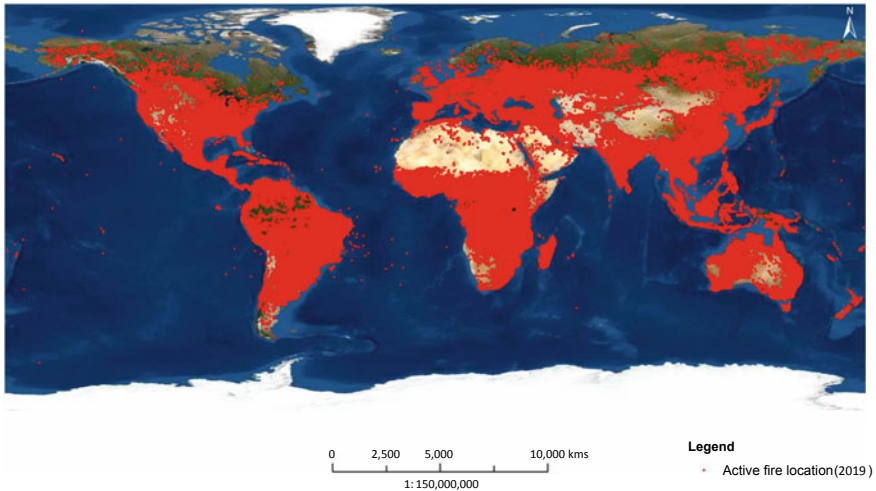
Fig. 8.1 Global distribution of active fires from January to December 2019, as detected by MODIS. *Source* NASA

temperature due to climate change can cause forest fires. Forest fires are a major driver in the destruction of biodiversity and habitats of many endangered species in the region and a key factor in environmental transformation by the infusion of substantial amount of greenhouse gas (FAO 2007; Volkova et al. 2019). Besides, vegetation cover and its moisture content are two of the major factors that significantly influence forest fire as it holds fuel (Ajin et al. 2016; Matin et al. 2017). Areas with dry and dense vegetation are more prone to forest fires than those with moist and sparse vegetation (Stevens et al. 2020). It has also got to be noted that forest fires are beneficial for nutrient recycling and vegetative succession (Chuvieco et al. 2010), but an increase in their intensity and frequency could lead to desiccation and death of trees.

8.1.2   Need for Forest-Fire Risk Mapping and Fire Monitoring

Forest fire not only causes ecological, economic, and material damages but also destroys the forests which are an irreplaceable sink of carbon. In order to support foresters, government authorities, and firefighters in developing efficient fire-risk management plans and to properly monitor and identify the risk areas, it is also crucial to understand the relationship between climate and fire regimes. Forest-fire risk mapping is an essential component in fire management (Sivrikaya et al. 2014) and depends on various factors like temperature, topography, vegetation type, land cover, and distance from settlements and roads (Carmel et al. 2009). A forest-fire

risk map helps to identify and locate the vulnerable zones and can assist in formulating a pre-management plan that can help in averting risks (Matin et al. 2017). It is essential to obtain quantitative information on forest fires in order to understand the phenomenon and its spatiotemporal characteristics and manage them (Hua and Shao 2017). Reliable and near-real-time fire detection and monitoring systems can provide vital information to resource managers for prioritizing technical and economic choices for fire prevention and suppression, thereby playing a key role in forest fire management. Several methods and statistical models, like multi-criteria decision analyses (MCDA), Frequency Ratio (FR), Analytical Hierarchy Process (AHP), and machine-learning and ensemble systems, integrated with GIS, have been successfully applied worldwide in developing forest-fire risk maps (Kayet et al. 2020; Naderpour et al. 2019).

8.1.3 RS and GIS Application in Forest Fire Detection and Monitoring

EO data and various RS techniques have been broadly applied in forest-fire monitoring, risk mapping, and in identifying the potential zones. Besides, high-resolution satellite imagery has gained importance in accurately assessing and monitoring the health status of forests (Matin et al. 2017). Since the 1970s, EO satellite sensors have been used to detect changes in the emission of energy. Moreover, a new generation of satellite sensors and Unmanned Air Vehicle (UAV) technology have brought in a superior synergy of present and future RS technology, leading to enhanced monitoring of the extent and frequency of forest fires (Fuller 2000; Hua and Shao 2017; Joseph et al. 2009). Owing to their large-area repetitive coverage and low cost, satellite data sets are helpful in near-real-time fire detection, monitoring, and in the assessment of the burnt areas (Kaufman et al. 1998; Leckie 1990). The availability of high resolutions and more spectral information via Sentinel-2 and Landsat-8 have also widened the opportunities in detecting active fires and in developing new indices for burnt-area mapping (Filipponi 2018; Pádua et al. 2020; Salvoldi et al. 2020; Schroeder et al. 2016). Moreover, fire-monitoring products from MODIS are being used worldwide because of their high temporal resolutions. The MODIS sensors onboard the Terra and Aqua satellites of NASA are commonly used in active forest-fire detection and monitoring across the globe; they provide the location information on the fires occurring across the globe. In 2017, a study by Rahman and Chang (2017) also demonstrated the reliability and robustness of MODIS data in mapping fire severity and the seasonality of vegetational response. With the advantage of EO applications for assessing the fire dynamics, global, regional, and national initiatives have been rolled out, such as the MODIS Rapid Response System global fire maps, GlobScar, the European Forest Fire Information System (EFFIS), Web Fire Mapper, the Canadian Wildland Fire Information System, the Indian Forest Fire Response and

Assessment System (INFFRAS), and Nepal's Forest Fire Detection and Monitoring System (Joseph et al. 2009; Matin et al. 2017). In the case of EFFIS, well-known for its comprehensive monitoring of forest fires, it is based on RS and GIS, and integrated with components like fire-danger forecast, fire detection, forest-fire events, burnt-area maps, land-cover damage assessment, emission assessment, potential soil erosion estimation, and vegetation regeneration (San-Miguel-Ayanz et al. 2012).

8.1.4 Forest-Fire Impacts During the Last Decade in Nepal

In Nepal, active fire incidents and burning days have been increasing annually and more than half of the forest areas experience frequent fires (Fig. 8.2) during the dry season (Parajuli et al. 2015). In Nepal too, anthropogenic activities are considered to be main drivers of forest fire (Khanal 2015). From 2001 to 2019, more than 38,000 fire incidents were reported from Nepal (MODIS archive data: https://earthdata.nasa.gov/firms). The years 2009 and 2016 were the worst, with several disastrous forest fires being reported; in 2016, more than 12,000 community forests in 50 districts were damaged by forest fires, killing 15 people (CIFOR 2017; SERVIR Global 2018). In March 2009, high-intensity and disastrous fires engulfed 48 places in Nepal, including several listed PAs, namely, Langtang, Makalu Barun, Chitwan, Shivapuri-Nagarjun, Bardia and Parsa national parks, Kanchenjunga and Manaslu Conservation Areas, and the Dhorpatan Hunting Reserve (BBC 2012). Earlier, in 1995, about 90% of the forests in Terai had been affected by fires (Sharma 1996), while in April 2009, NASA listed Nepal as a country "most vulnerable to wildfires" having registered the highest number in a day of 358 blazes (The Kathmandu Post 2016). In 2012, more than 70% of Bardiya National Park was engulfed by fire, leading to the loss of 40% of small mammals, 60% of insects, and a substantial number of birds (BBC 2012). In this regard, our study focuses on the efforts in mapping forest-fire risk, and on monitoring and identifying the fire zones in Nepal which could help decision makers in enhancing preparedness and responses during such fires.

8.1.5 Collaborations and Partnerships for Forest-Fire Management in Nepal

Based on the demand from the country partners, in 2012, SERVIR jointly developed a forest-fire detection and monitoring system for Nepal with its Department of Forests and Soil Conservation (DoFSC). In 2019, the system was upgraded in collaboration with the DoFSC in Nepal to include a feedback module for getting information on incidents and damages from the field. Also, a fire-risk analysis and

Fig. 8.2 Forest fires are common during the pre-monsoon season in Nepal. Photo by Birendra Bajracharya

reporting mechanism was incorporated into the system. The DoFSC played a crucial role in the uptake of these products in the planning process in a few districts, starting with Province 1. Besides ICIMOD, other partnerships and programs like the Australia Capital Territory (ACT), Global Fire Monitoring Center (GFMC), Japan International Cooperation Agency (JICA), Korean Forestry Services (KFS), Nepal Forest Fire Management Chapter (NFFMC), Thompson Rivers University (TRU), USAID, and WWF also collaborated with the relevant Nepali agencies in forest-fire governance and management (Sombai et al. 2018). This chapter describes the methodologies and the implementation processes of the fire monitoring system and its components, including about fire-risk analysis and fire-alert monitoring mechanisms.

8.1.6 Objectives of the Forest-Fire Detection and Monitoring System

The forest-fire detection and monitoring system in Nepal, with the help of the DoFSC, aims to support forest officials, local decision makers, stakeholders, and community forest user groups in fire monitoring, analysis, and in the action required to minimize fire impacts. In addition, there's a forest-fire monitoring web tool that

supplies visual information on historical forest fires as well as on near-real-time fire incidents and fire-risk areas.

8.2 Methodology

8.2.1 Fire-Risk Mapping

Several indices have been used and suggested to assess fire risks using natural and anthropogenic parameters (Matin et al. 2017; Sivrikaya et al. 2014; Zhang et al. 2014). In this study, we used vegetation type (land cover), elevation, slope, and surface temperature, as the natural parameters, and proximity to settlements and roads as the anthropogenic factors to compute the fire risk index (FRI). The FRI is expressed as shown in Eq. 8.1 (Matin et al. 2017):

$$\text{FRI} = \sum Wi \times Ci \tag{8.1}$$

where Wi is the relative weight of a variable and Ci is the rating for different classes within each variable.

The relative weights for variables were selected on the basis of literature (Adab et al. 2013; Matin et al. 2017) and the ratings of the different classes for each variable were selected on the basis of historical data analysis (Matin et al. 2017). Higher ratings were assigned to classes with relatively higher occurrence of historical fire incidence within that class compared to other classes.

$$\text{FRI} = 10\,\text{LCR} + 6\,\text{TR} + 4\,(\text{SDR} + \text{RDR}) + 2\,(\text{ER} + \text{SLR}) \tag{8.2}$$

where,

LCR = land cover rating
TR = temperature rating
SDR = settlement distance rating
RDR = road distance rating
ER = elevation rating
SLR = slope rating

The exploratory data analysis method was used while assigning the ratings for the variables.

Vegetation cover and its moisture content is one of the key factors that significantly influence forest fire as it holds the availability of fuel (Ajin et al. 2016; Matin et al. 2017; Roy 2003). Areas having dry and dense vegetative cover are more prone to forest fires than those with moist and sparse cover. The ratings for these variables were assigned as below (Table 8.1), a method adopted by Matin et al. (2017).

**Table 8.1** Weights and ratings for different variables and classes

S. no.	Variables	Weight	Classes	Ratings	Fire risk
1	Land cover	10	Broadleaved closed forest	10	Very high
			Broadleaved open forest	6	High
			Shrub land	4	Moderate
			Grassland	4	Moderate
			Needle-leaved closed forest	2	Low
			Needle-leaved open forest	2	Low
			Other land cover	0	Not considered
2	Average summer land surface temperature	6	>30 °C	6	Very high
			25–30 °C	4	High
			20–25 °C	2	Moderate
			<20 °C	1	Low
3	Distance from settlement	4	<1,000 m	6	Very high
			1,000–2,000 m	4	High
			2,000–3,000 m	2	Moderate
			>3,000 m	1	Low
4	Distance from road	4	<1000 m	6	Very high
			1,000–2,000 m	4	High
			2,000–3,000 m	2	Moderate
			>3,000 m	1	Low
5	Elevation	2	<1,000 m amsl	6	Very high
			1,000–2,000 m amsl	4	High
			2,000–3,000 m amsl	2	Moderate
			>3,000 m amsl	1	Low
6	Slope	2	<15%	6	Very high
			15–30%	4	High
			30–35%	2	Moderate
			>35%	1	Low

8.2.2 Fire Monitoring

8.2.2.1 MODIS Fire-Detection Process

MODIS active fire products are used worldwide as it provides the location information on fires occurring across the globe. In our study too, MODIS products were used because they have high-temporal, high-spectral (36 spectral bands), and moderate spatial resolutions (250, 500, and 1000 m); they are also freely available compared to other easily available sensors products (Rahman and Chang 2017). Besides, MODIS products are reliable and have proven their effectiveness in fire detection. Each active fire corresponds to the center point of a 1 × 1 km pixel and represents one or more fire incidents occurring within that 1 km² area (Fig. 8.3).

The active fire incidents were identified using a contextual fire detection algorithm that classified each pixel of the MODIS swath as missing data, cloud, water, non-fire, or unknown. Firstly, the pixels without a valid value were classified as missing data where cloud and water pixels were identified using cloud and water masks, respectively. The algorithm then looked at the remaining land pixels for identifying fire. For each potential fire pixel, the algorithm used its brightness temperature from the MODIS 4 and 11 µm channels and those of its background non-fire pixels to determine the fire pixels. The size of the background non-fire pixels may vary from a 3 × 3 pixel square window to a maximum of 21 × 21 pixel square window such that at least 25% of the pixels within a window are valid and
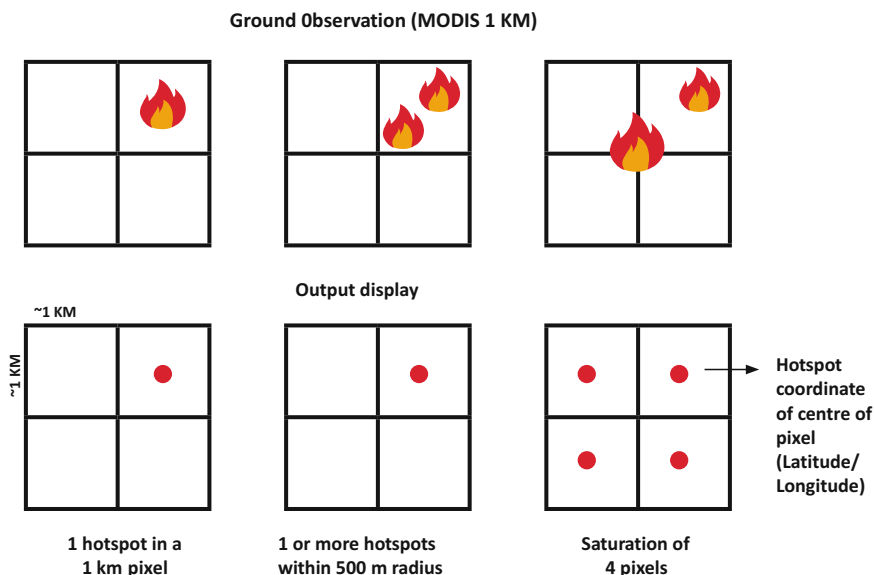
Fig. 8.3 Concept of fire detection in MODIS image. *Source* https://earthdata.nasa.gov/faq/firms-faq

the number of the valid pixels is at least eight. The algorithm identifies a potential fire pixel as a fire pixel if it has a very high brightness temperature of 4 μm or if the brightness temperature difference of 4 and 11 μm depart substantially from that of the non-fire background non-pixels (Giglio et al. 2003).

8.2.2.2 Data Processing Workflow

The MODIS data are downloaded every 24 h from NASA from: https://earthdata. nasa.gov/earth-observation-data/near-real-time/firms/active-fire-data. The active fire data are then clipped to Nepal's boundary to know about the fire incidents occurring within the country. Major information related to administrative units (i.e., whether district, rural/municipality, division, subdivision or ward), PAs, land cover, elevation, and slope are then added to the active fire data before they are stored in the fire database (Table 8.2; Fig. 8.4).

8.2.2.3 Web Application for Fire-Alert Dissemination

ICIMOD has developed a web portal/application and this system publishes the stored fire data as a map service so that the locations of fire incidents can be viewed on any given date and filtered at the levels of province, district, subdivision, and protected areas. The portal also includes a damage-assessment form which is only

Table 8.2 List of data used in this study

Name (code)	Platform	Data product	Source
MCD 14 ML (MOD14/ MYD14)	Combined (Terra and Aqua)	MODIS/Aqua+Terra thermal anomalies/active fire	https://firms.modaps.eosdis. nasa.gov/download/
Boundary		Administrative boundary (district, rural/municipality, division, subdivision, and ward)	Survey Department, Government of Nepal
		Protected area	Department of National Parks and Wildlife Conservation (DNPWC, Nepal)
Land cover		2010 land cover	ICIMOD (http://rds.icimod. org/Home/DataDetail? metadataId= 9224&searchlist=True)
Topography		Elevation, slope, and aspect	http://srtm.csi.cgiar.org/
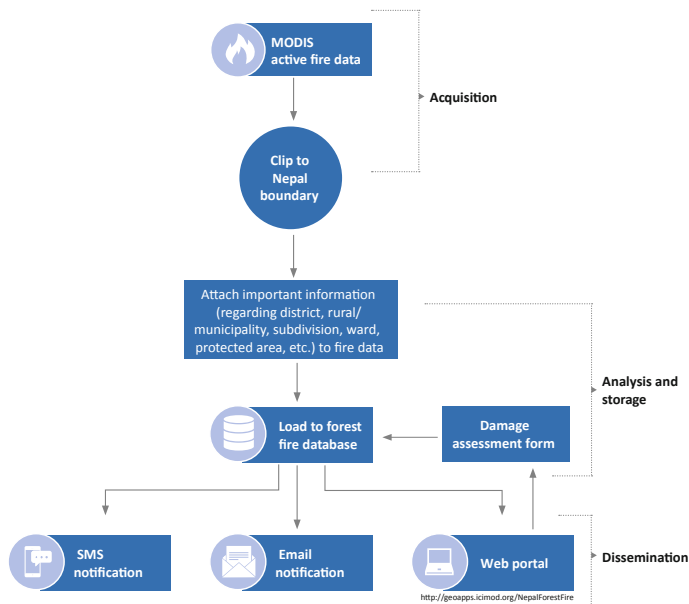
Fig. 8.4 Workflow diagram

accessible to the authorized users. The form is in the Nepali language and it allows entry of data about any damage to a forest or other property by fire, which is then stored in a central database system.

8.2.2.4 Alert Generation and Distribution

When one or more fire incidents are detected in a district, the system sends out SMS alerts containing the location details of those fires to individuals who are subscribed to the SMS fire alert for that district. These alerts, delivered within 20 min of detection, have the ability to reach hundreds of divisional forest Officers and local community representatives from all districts in Nepal. The SMS fire alert contains the following information:

a. District name
b. Location details of individual fires in terms of latitude and longitude
c. Rural/municipality name, and ward number
d. Forest division/subdivision name
e. Protected area identification in case fire is detected within a protected area

The information about all the fire incidents occurring in a district is combined to create one SMS which is then sent to individuals who have subscribed from that district. Due to the restriction on the number of characters that can be sent in one

single SMS (160 characters), the fire alert may be received by the subscribers as multiple SMSs in cases when there is a large number of fire incidents within a single district. And to avoid false alarm, the notification on individual fire incidents is included in the SMS only if the "confidence" level of the active fire is greater than 70% and only if it has occurred in forest, shrub, or grassland.

8.2.2.5   Email Alerts

The system also sends email notification on active fires throughout Nepal to all the subscribers, which comprise divisional forest officers and other decision makers in the country. These notifications contain the following detailed information on individual fires:

a. Location details of individual fires in terms of latitude and longitude
b. District, rural/municipality name and ward number
c. Protected area identification in case fire is detected within a protected area
d. Elevation (in meters)
e. Slope (in percentage)
f. Confidence (in percentage)

8.2.2.6   Fire-Incidence Maps and Feedback from Field

The system allows registered users to download maps with forest fire incidents on any given day. The fire-incidence maps were generated on the basis of fire occurrence data of over 50% confidence level recorded by MODIS. To avoid wrong identification, incidence levels of less than 50% were filtered out. The system also allows the user to view and select any information provided on this web platform.

A mobile application, "Nepal Forest Fire Detection and Alert", has also been deployed to support citizens in reporting forest fires in Nepal. Through the use of this application, members of CFUGs and forest department officials can now respond more quickly to fire dangers. Moreover, a damage assessment form has been integrated into the web-based system that allows DoFSC officials to capture information on reported fire incidences, estimated damages, and on fatalities.

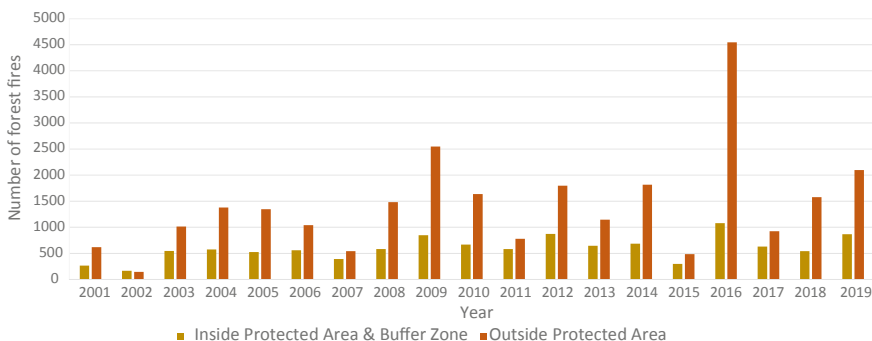### 8.2.3   Temporal Distribution of Forest Fires in Nepal

A total of 38,248 active fires with a confidence level of 50% or more were recorded in Nepal by MODIS sensors from January 2001 to December 2019. The maximum number of fire incidents occurred in the year 2016 (Fig. 8.5), which were almost 15% of all the total fire events that took place from 2001 to 2019; the second highest (9%) took place in 2009, followed by instances in 2019 (8%). A study by
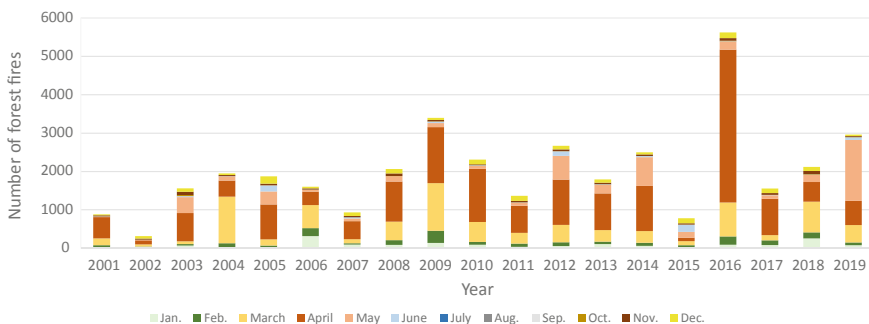
Fig. 8.5 Annual and monthly forest fire in Nepal

Bhujel et al. (2017) reflects the increasing trend of forest fire in the last two decades, with the plains of Terai recording the highest density and the highest burnt area per square kilometer in 2016. And, the years 2009 and 2016 were considered as drought years as they experienced severely dry weather during the summer. Besides, an analysis of the monthly patterns of forest fires from 2001 to 2019 shows that usually such events start during the winter months of October to January and reach the peak in April when more than 45 of forest fires occur. We also observed a change in the peak month of occurrence of forest fire, which is shifting from March to May, perhaps attributable to phenological changes and the vegetation's responses to climate change. Here, it has to be noted that negligible or almost no fire incidents took place between June and September which constitute the monsoon season.

About 71 of the fire incidents occurred outside the PAs, whereas 29% took place inside the Pas (Fig. 8.6). Within the PAs, approximately 75% of fires occurred in national parks, followed by 13% in buffer zones (Fig. 8.7). In analyzing the forest fires from the years 2001 to 2019, we found more instances of fires—almost 20% each—in Bardia and Chitwan national parks, followed by Parsa National Park at 15% (Fig. 8.8). All these three national parks are located in the lower elevation in

**Fig. 8.6** Distribution of forest fire inside and outside protected areas (2001–2019)
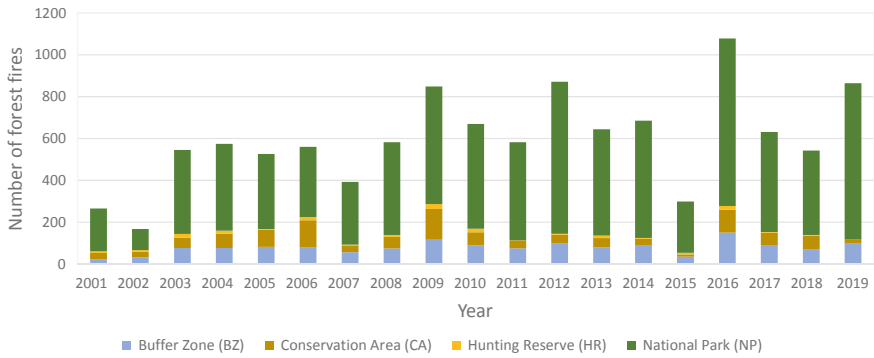
Fig. 8.7 Distribution of forest fire in different types of protected areas (2001–2019)
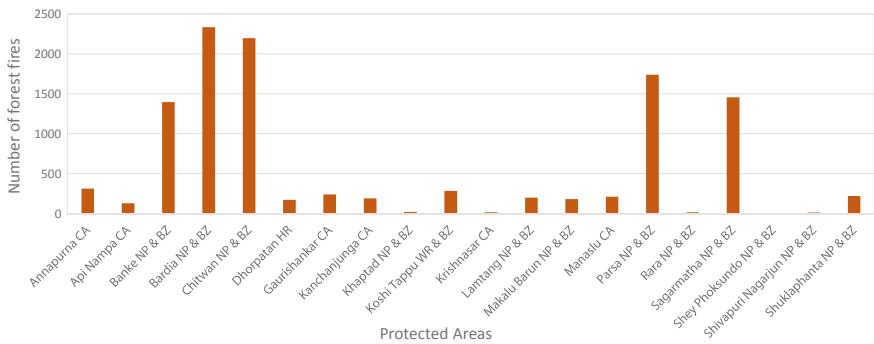
Fig. 8.8 Total number of forest fires in different protected areas (2001–2019)

the Terai region which has a higher temperature and lower humidity compared to other regions in Nepal. Moreover, the forests in these parks are mainly composed of tropical and subtropical species that shed large quantity of dry leaves, which results in a larger accumulation of fuel (Kunwar and Khaling 2006). Further, the analysis of fire incidences inside and outside the PAs revealed that the number of such incidents was two to three times higher outside the PAs. The fact that PAs practice conservation and management strategies and there is less anthropogenic activities inside them might be the reason that they don't record more incidents of fire.

Out of the five physiographic zones of Nepal, Siwalik zone recorded the highest number of fire incidents, approximately 35%, followed by the middle mountains (26%), Terai (21%), and the high mountains (13%), and the least in the high Himalaya. More than 80% of the broadleaved forests in the country lie in the middle mountains and Siwalik, the reason these areas record the highest number of fire events. The tropical broadleaved forests experience substantial leaf fall in the summer season, which results in the piling up of dry leaf litter, fueling successive
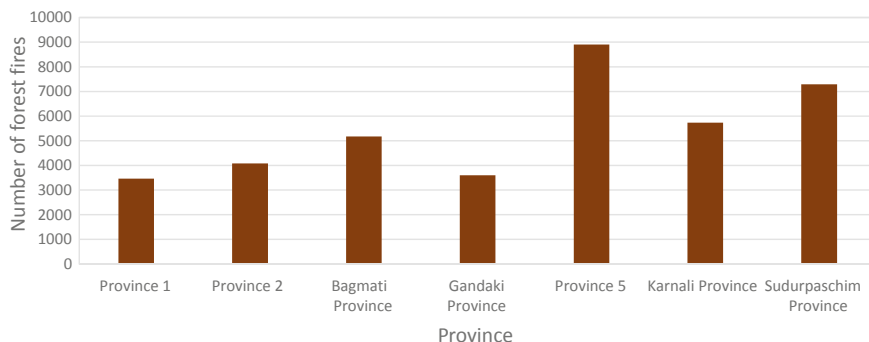
Fig. 8.9 Province-wise forest fire from 2001 to 2019

and extended incidents of fire during summers (Matin et al. 2017). In the forest-fire trend analysis, out of the seven provinces, Province 5 showed the highest number of fire incidents of about 23%, followed by Sudur Paschim (Province 7) of 19%, Karnali (Province 6) of 15%, Province 3 of 14%, Province 2 of 11%, and Gandaki and Province 1 of 9% (Fig. 8.9).

8.2.4 Characteristics of the Location of Fire Occurrence

The majority of the forest fires were reported from low-elevation areas (up to 1,000 masl). More than 85% of the fires were recorded below the elevation of 2,000 masl, of which 65 occurred below 1,000 masl. Only a negligible per cent (about 1%) of fire incidents were recorded above 4,000 masl. Besides elevation, slopes also have an effect on the distribution of forest fire. A significant number of fires were recorded in plain lands with less than 5% sloping and in moderate lands with 15–35% sloping. A negligible number of fire events were noted in the steep-land areas (>50% slope).

8.2.5 Forest-Fire Risk Zone and Vulnerability

Six major driving factors, namely, land cover, average summer land-surface temperature, distance from settlement, distance from road, elevation, and slope were taken into account while analyzing the forest-fire risk zone. The study demonstrates that out of 77 districts, 12 districts fall into very high forest-fire risk zones and 11 districts in the high-risk class (Fig. 8.7). Most of the districts located in Terai and Siwalik zones are in the very high and high-risk classes.
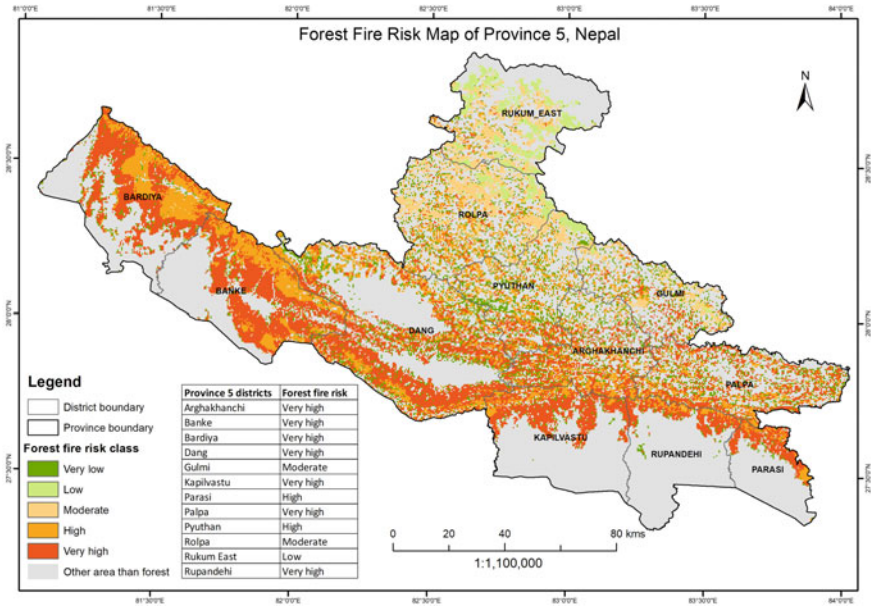
Fig. 8.10 Forest-fire risk map of Province 5

The province-wise forest-fire risk analysis reflects that the forest area (about 4,000 km^2) in Province 5 is more vulnerable and falls under the very high-risk category (Fig. 8.10), followed by Bagmati Province ($\approx$3,400 km^2) and Sudurpashchim Province (>2,600 km^2); whereas Province 1 is in very low fire-risk class (Fig. 8.11).
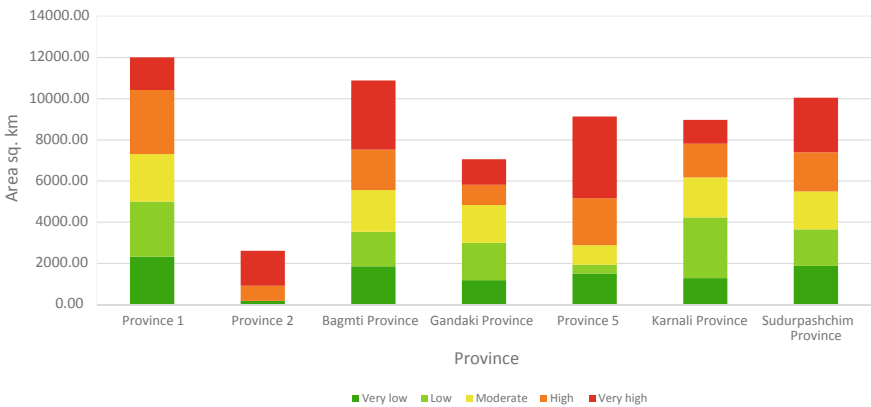

Fig. 8.11 Province-level forest-fire risk classification

8.2.6   Forest-Fire Monitoring System in Nepal

Nepal's forests exhibit a high level of threat from fires, which occur predominantly during February to May, with its peak being mid-April. In this regard, it is imperative to understand the temporal pattern of the fires in order to be better prepared and disseminate timely fire-alert messages. In a bid to record the forest-fire risk areas in Nepal, a SERVIR-HKH team and the DoFSC co-developed a map showing the fire-risk areas zones in Nepal. This map depicts the risk levels in all the 77 districts of Nepal—from very low to very high risk—which can help decision makers in prioritizing forest management activities, especially with regard to reducing the risk of forest fires. The map is placed in the forest-fire control room in DoFSC, which is the main monitoring station in Nepal that reports the occurrence of forest fires to the relevant agencies. Following hands-on training by the SERVIR-HKH team, the DoFSC has prepared province- and division-level maps to help the relevant stakeholders in reducing forest-fire risks at various spatial scales. Besides, based on a request from DoFSC, a forest-fire alert and monitoring web tool (http://geoapps.icimod.org/NepalForestFire) has been customized which contains a form that mentions, apart from other details, the extent of damage caused by such fires. The web tool is available both in Nepali and English languages (Figs. 8.11 and 8.12). This tool not only provides real-time information on the occurrence of forest fires but also sends SMSs and emails to officials from all forest divisions, subdivisions, and to the members of community forest user's groups across the country. In the year 2019, more than 300 fire-alert SMSs were sent to district officials in the months of April, May, and June; more than 200 SMSs were sent in the month of May alone, with Salyan district receiving the highest number (68) of fire-alert SMSs in that month (Fig. 8.13).
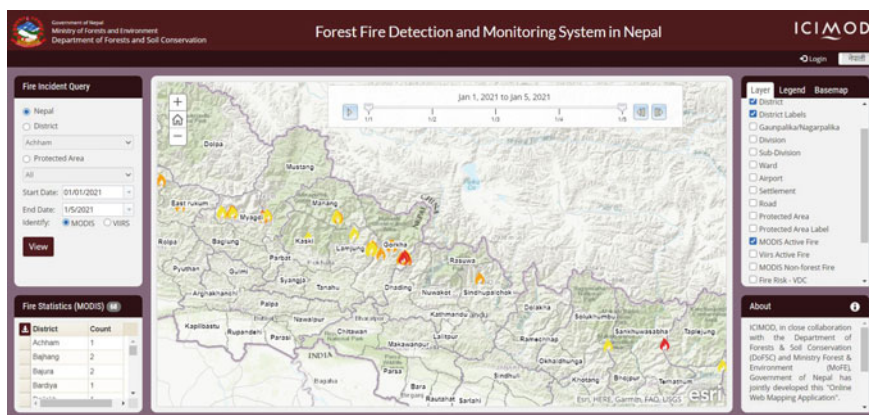

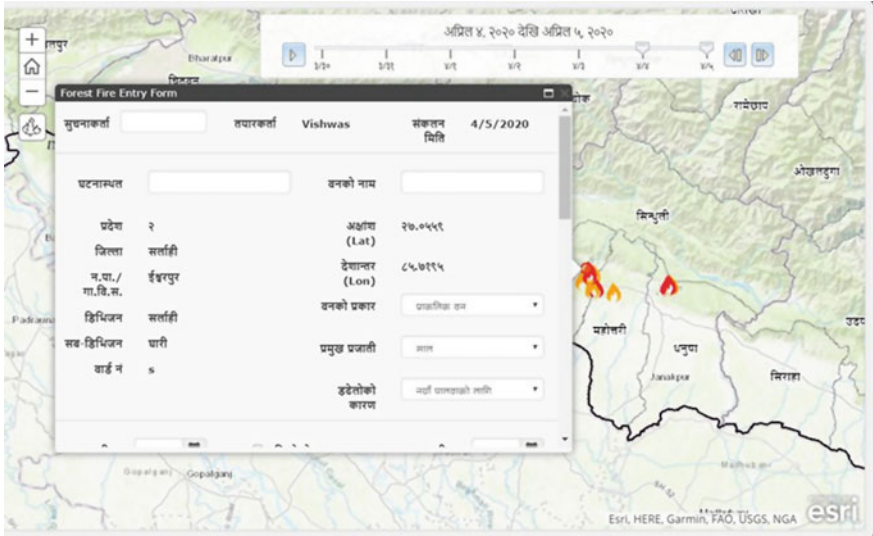**Fig. 8.12** Forest-fire detection and monitoring web tool

Fig. 8.13 Forest-fire damage-assessment form

8.3   Deployment of Forest-Fire Detection and Monitoring System

The system has been upgraded since it was operationalized in 2012, and recently, it has also incorporated data from the Visible Infrared Imaging Radiometer Suite (VIIRS). Besides, a mobile application, "Nepal Forest Fire Detection and Alert", has also been deployed to provide wider access to citizens to report on forest-fire incidents in Nepal. Earlier, the lack of mobile networks in remote parts of Nepal had hindered communication, but the situation has improved since 2016–17. It is also essential that the database of mobile numbers gets continuously updated as sometimes the relevant staff gets transferred to other places. Also, the validation and confirmation of forest-fire alerts are important. The brighter side in the whole context of fighting forest fires has been that there now exists a strong collaboration with DoFSC and there's increased awareness about forest fires and the role of RS and GIS in tackling the problem.

8.4   Limitations and Challenges

The following points ought to be considered regarding information on active fire:

a. The active-fire data provide only the location information, i.e., center of the fire pixel of 1×1 km area and it shall be used as alert over 1 km^2 area, not the exact point.
b. There are some problems with fire alerts:

   - Sometimes, due to the coarse resolution of the fire pixel, a fire occurring in one district may be falsely reported as one occurring in a neighboring district.
   - Certain small-duration fires may have been extinguished by the time the subscribers get the fire alert since currently, the alerts are sent after about two to four hours of the satellite's passing.

c. Certain fires may be missed out because they are of a smaller size or smoldering, and they were not occurring during the satellite's passing.
d. SMS alerts may not reach the subscribers on time because of some technical issues faced by Nepal Telecom.

8.5 Capacity Enhancement of Partners

Several training programs on forest-fire detection and monitoring systems have been provided to the DoFSC staff with the aim to enhance and strengthen the DoFSC's institutional capacity in generating information on important attributes such as forest-fire risk, fire occurrence, and damage to the forests. Training materials, hands-on exercises, and flyers have been developed on how to use the forest-fire monitoring system and web application. The DoFSC staff are now well acquainted with fire-monitoring system and web application. They have also become skilled in identifying the vulnerable zones, which has helped them in minimizing the impacts of forest fire.

8.6 Way Forward

With the help of fire-risk zonal maps and other forest-fire monitoring tools, the forest managers can now easily track the fire-risk areas and develop strategies in fire management. This has also enabled efficient and effective decision-making in minimizing the impacts of fires as well as in allocating resources to the province, district, or area that face high fire risk.

More users should be brought into the firefighting system—from the forest directorates in the seven provinces and the 84 divisional forest offices in the country. The MoFE, DoFSC, and the province-level forest directorates should work in unison and reach out to all levels of administration and community to tackle the menace of forest fires. This can be facilitated through appropriate policy and

program support, dissemination of information, and the monitoring of activities on the field. There's also a strong case for regional cooperation in the firefighting arena whereby all the relevant agencies are not only made aware of the seriousness of the problem but also of the fact that fires know no boundaries.

References

Adab H, Kanniah KD, Solaimani K (2013) Modeling forest fire risk in the northeast of Iran using remote sensing and GIS techniques. Nat Hazards 65:1723–1743. https://doi.org/10.1007/S11069-012-0450-8

Ajin RS, Loghin AM, Jacob MK, Vinod PG, Krishnamurthy RR (2016) The risk assessment study of potential forest fire in Idukki Wildlife Sanctuary using RS and GIS techniques. Int J Adv Earth Sci Eng 5(1):308–318

BBC (2012) Nepal forest fires 'cause big wildlife loss'. https://www.bbc.com/news/science-environment-17937620. Accessed Aug 2019

BBC (2019) The Amazon in Brazil is on fire-how bad is it? https://www.bbc.com/news/world-latin-america-49433767. Accessed Feb 2020

Bhujel KB, Maskey-Byanju R, Gautam AP (2017) Wildfire dynamics in Nepal from 2000–2016. Nepal J Environ Sci 5:1–8

Carmel Y, Paz S, Jahashan F, Shoshany M (2009) Assessing fire risk using Monte Carlo simulations of fire spread. For Ecol Manage 257(1):370–377

Chuvieco E, Aguado I, Yebra M, Nieto H, Salas J, Martín MP, De La Riva J (2010) Development of a framework for fire risk assessment using remote sensing and geographic information system technologies. Ecol Model 221(1):46–58

CIFOR (2017) Nepal's forest fires. https://forestsnews.cifor.org/48187/nepals-forest-fires?fnl. Accessed Aug 2019

CNN (2020) California wildfires have burned an area almost the size of Connecticut. https://edition.cnn.com/2020/09/14/us/california-wildfires-monday/index.html Accessed Sept 2020

FAO (2007) Fire management-global assessment 2006. A thematic study prepared in the framework of the global forest resources assessment 2005. FAO, Rome

Filipponi F (2018) BAIS2: burned area index for Sentinel-2. In: Multidisciplinary digital publishing institute proceedings, vol 2, no 7, p 364

Fuller DO (2000) Satellite remote sensing of biomass burning with optical and thermal sensors. Prog Phys Geogr 24(4):543–561

Giglio L, Descloitres J, Justice CO, Kaufman YJ (2003) An enhanced contextual fire detection algorithm for MODIS. Remote Sens Environ 87(2–3):273–282

Hirschberger P (2016) Forests ablaze: causes and effects of global forest fires [Winter S, von Laer Y, Köberich T (eds)]

Hua L, Shao G (2017) The progress of operational forest fire monitoring with infrared remote sensing. J Forest Res 28(2):215–229

IGES, ICIMOD (2013) Technical report: climate change adaptation needs of people of the Hindu Kush Himalayas. IGES, Hayama, Japan

Joseph S, Anitha K, Murthy MSR (2009) Forest fire in India: a review of the knowledge base. J For Res 14(3):127–134

Kathmandu Post (2016) Blazes raging across country. https://kathmandupost.com/national/2016/04/12/blazes-raging-across-country. Accessed Feb 2020

Kaufman YJ, Justice CO, Flynn LP, Kendall JD, Prins EM, Giglio L, Setzer AW (1998) Potential global fire monitoring from EOS-MODIS. J Geophys Res Atmos 103(D24):32215–32238

Kayet N, Chakrabarty A, Pathak K, Sahoo S, Dutta T, Hatai BK (2020) Comparative analysis of multi-criteria probabilistic FR and AHP models for forest fire risk (FFR) mapping in Melghat Tiger Reserve (MTR) forest. J For Res 31(2):565–579

Khanal S (2015) Wildfire trends in Nepal based on MODIS burnt-area data. Banko Janakari 25 (1):76–79

Kunwar RM, Khaling S (2006) Forest fire in the Terai, Nepal: causes and community management interventions. Int For Fire News 34:46–54

Leckie DG (1990) Advances in remote sensing technologies for forest surveys and management. Can J For Res 20(4):464–483

Mannan A, Feng Z, Ahmad A, Beckline M, Saeed S, Liu J, Shah S, Amir M, Ammara U, Ullah T (2017) CO_2 emission trends and risk zone mapping of forest fires in subtropical and moist temperate forests of Pakistan. Appl Ecol Environ Res 17(2):2983–3002

Matin MA, Chitale VS, Murthy MS, Uddin K, Bajracharya B, Pradhan S (2017) Understanding forest fire patterns and risk in Nepal using remote sensing, geographic information system and historical fire data. Int J Wildland Fire 26(4):276–286

Naderpour M, Rizeei HM, Khakzad N, Pradhan B (2019) Forest fire induced Natech risk assessment: a survey of geospatial technologies. Reliab Eng Syst Saf 191:106558

Nolan RH, Boer MM, Collins L, Resco de Dios V, Clarke H, Jenkins M, Bradstock RA (2020) Causes and consequences of eastern Australia's 2019–20 season of mega-fires. Glob Change Biol 26(3):1039–1041

Pádua L, Guimarães N, Adão T, Sousa A, Peres E, Sousa JJ (2020) Effectiveness of Sentinel-2 in multi-temporal post-fire monitoring when compared with UAV imagery. ISPRS Int J Geo-Inform 9(4):225

Parajuli A, Chand DB, Rayamajhi B, Khanal R, Baral S, Malla Y, Poudel S (2015) Spatial and temporal distribution of forest fires in Nepal, pp 7–11. XIV World Forestry Congress, Durban, South Africa

Rahman S, Chang HC (2017) Assessment of fire severity and vegetation response using moderate-resolution imaging spectroradiometer: moderate resolution (MODIS) satellite images to assess vegetation response after a big fire event at the selected national parks around Sydney, Australia. In: 2017 eleventh international conference on sensing technology (ICST), pp 1–6. IEEE

Roy PS (2003) Forest fire and degradation assessment using satellite remote sensing and geographic information system. Satellite remote sensing and GIS applications in agricultural meteorology, p 361

Salvoldi M, Siaki G, Sprintsin M, Karnieli A (2020) Burned area mapping using multi-temporal sentinel-2 data by applying the relative differenced aerosol-free vegetation index (RdAFRI). Remote Sens 12(17):2753

San-Miguel-Ayanz J, Schulte E, Schmuck G, Camia A, Strobl P, Liberta G, McInerney D (2012) Comprehensive monitoring of wildfires in Europe: the European forest fire information system (EFFIS). In: Approaches to managing disaster-Assessing hazards, emergencies and disaster impacts. IntechOpen

Schroeder W, Oliva P, Giglio L, Quayle B, Lorenz E, Morelli F (2016) Active fire detection using Landsat-8/OLI data. Remote Sens Environ 185:210–220

SERVIR Global (2018) Satellite data aids forest fire detect in and monitoring in Nepal. https://servirglobal.net/Global/Articles/Article/2642/satellite-data-aids-forest-fire-detection-and-monitoring-in-nepal. Accessed Feb 2020

Sharma SP (1996) Forest fire in Nepal. Int For Fire News 15:36–39

Sivrikaya F, Sağlam B, Akay AE, Bozali N (2014) Evaluation of forest fire risk with GIS. Pol J Environ Stud 23(1)

Smith A, Schismenos S, Stevens G, Hutton L, Chalaris M, Emmanouloudis D (2019) Understanding large-scale fire events: megafires in Attica, Greece and California, USA. In: Youth science policy interface publication-2nd special edition: disaster risk reduction: moving forward, thinking ahead, pp 29–34

Sombai IG, Karakatsoulis J, Gardner W, Gautam AP, Sharma SP, Adhikari B (2018) Forest governance in Nepal: rationale for centralised forest and wildfire management. J Manage Dev Stud 28:16–35

Stevens JT, Boisramé GF, Rakhmatulina E, Thompson SE, Collins BM, Stephens SL (2020) Forest vegetation change and its impacts on soil water following 47 years of managed wildfire. Ecosystems 1–19

Volkova L, Roxburgh SH, Surawski NC, Meyer CM, Weston CJ (2019) Improving reporting of national greenhouse gas emissions from forest fires for emission reduction benefits: an example from Australia. Environ Sci Policy 94:49–62

Wester A, Mishra A, Mukherji AB, Shrestha (eds) (2019) The Hindu Kush Himalaya assessment—mountains, climate change, sustainability and people. Springer Nature Switzerland AG, Cham

Zhang H, Qi P, Guo G (2014) Improvement of fire danger modelling with geographically weighted logistic model. Int J Wildland Fire 23(8):1130–1146

Zomer RJ, Trabucco A, Metzger MJ, Wang M, Oli KP, Xu J (2014) Projected climate change impacts on spatial distribution of bioclimatic zones and ecoregions within the Kailash Sacred Landscape of China, India, Nepal. Clim Change 125(3–4):445