Forest Fire in the Hindu Kush Himalayas: A Major Challenge for Climate Action

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Abstract

Forest fire has been one of the compelling issues in the Hindu Kush Himalayan (HKH) region. To promote regeneration, clearing fields for agriculture, hunting, and security reasons, local people deliberately set forests on fire. In this paper, active fire incidents, temperature, precipitation, and the changes of Aerosol Optical Depth (AOD) and Carbon monoxide (CO) value associated with forest fire were evaluated. The active forest fire incidents obtained from the Moderate Resolution Imaging Spectroradiometer (MODIS) satellite are supplemented by the ERA5-land dataset to see the relation between precipitation and temperature with forest fires. MODIS and Tropospheric Monitoring Instrument (TROPOMI) sensor datasets were used to see the changes in AOD and CO in the region. MODIS sensor detected more than 30,462 active fires incidents in March and April 2021 in the study areas. Shan State of Myanmar recorded the maximum number of active fire incidents which is due to the practice of shifting cultivation and minimum in Bhutan due to the awareness campaigns and technology improvement. The temperature recorded in the study sites shows an increasing trend as compared to the reference period (2010-2020). Apart from Shan and Bago of Myanmar, precipitation in the study sites is also less during the study period. AOD and CO values show prominent peaks in a fire season which coincide with days of the maximum number of fire counts inferring the influence of forest fire on air quality. Developing countries like Nepal, India, Myanmar, and Bhutan are willing to take part in climate finance and are bound to accept expensive insurance premium due to forest fire incidents. Unless forest fires are effectively managed and mitigated, achieving Nationally Determined Contributions (NDCs) and global agendas, including United Nations Decade of Ecosystem Restoration is onerous.

Key words: Active forest fire, climate action, HKH, precipitation, temperature

INTRODUCTION

Forest fire is the term used for unwanted wildfires, which is one of the environmental issues of the present world. Forest fire can shape the vegetation distribution, structure, and composition in many ecosystems. Although having this ability, these fires are also hazardous for human lives, their properties, and biodiversity. Globally, an area of more than 350 million hectares is estimated to be affected by forest fire each year (Amiro *et al.* 2001; Merino *et al.* 2004). Every year, montane forests are burnt; most of the fire incidence in the forests of the Himalayas is human-induced (Giriraj *et al.* 2010) and not stemming from natural phenomena as in Australia or California (Helvarg 2019; Tran *et al.* 2020). Each year 85 per cent of the global surface area burnt lies in the tropical savannahs (Willis 2017), which makes 19 per cent of the total land cover (Global Forest Watch 2021). In April 2020, the number of fire alerts across the globe was up by 13 per cent compared to April 2019, which was the record year for forest fire (WWF 2020). The top fifteen wildfires in the United States from 2000 to

2017 caused almost 1 billion United States Dollar (USD) worth of damage, which includes not only the loss of houses and infrastructures but also the procurement of equipment and logistics support for fire control/ fire fighting (NOAA 2021). The expenses increased from 2017 onwards, and the cost of 2017-2018 was more than 40 billion USD (NOAA 2021).

In 2019, wildfires caused an estimated loss of around 4.5 billion USD in California and Alaska (NOAA 2021). In 2020, out of the six largest fires in California and Oregon, five fires saw historic levels of wildfire spread and damage. Wildfires across the West led to weeks-long periods of unhealthy air quality levels for millions of people (C2ES 2021). Certainly, all these fire events increased the greenhouse gas (GHGs) emissions (Ribeiro-Kumara *et al.* 2020). The projection reveals that at least 50 per cent of GHGs emissions will be increased by 2080 in Western North America, Southeast Asia, Africa, and Australia (Touma *et al.* 2021) from wild fires alone.

Forest fire is one of main drivers of forest degradation contributing to depletion of productivity of forest ecosystem, forest biodiversity, forest carbon stocks, nutrient cycling and other ecosystem services (Amiro *et al.* 2000; Amiro *et al.* 2001; Pérez-Cabello *et al.* 2012). Forest fires are becoming a serious ecological concern in the Hindu Kush Himalayan (HKH) region due to changing climate and associated factors (Littell *et al.* 2016; Sannigrahi *et al.* 2020; Vachula *et al.* 2020; Zhang-Turpeinen *et al.* 2020), thus contributing to forest degradation in the region.

Frequent occurrence of forest fire in the summer season is a common phenomenon in the Western Himalaya due to high fuel load on the forest floor and low moisture content in the soil (Chandra and Bhardwaj 2015). However, in the north-eastern region of India, forest fires are mainly associated with shifting cultivation (Puri *et al.* 2011). A total of 520,861 active forest fires were detected in India during 2003–2017, which are mainly concentrated over the dense evergreen and deciduous forests in the eastern Himalayan states (Sannigrahi *et al.* 2020). The Chir Pine forests distributed in the hilly Himalayan states are also found to be highly vulnerable to forest fires (Joseph *et al.* 2009). This relationship underscores the necessity for monitoring forest fires and accurate data on the emission of trace gases.

Forests are basic component of the global carbon cycle. However, forest fires pose serious threat to the forest ecosystems that degrade net primary productivity, gross primary productivity and carbon sequestration services (Dixon *et al.* 1994). Forest is one of the major carbon pools in the terrestrial system. Upon burning, a vast amount of carbon is released into the atmosphere (Gibbs *et al.* 2007). Increasingly, forest fire is recognised as a prime concern of greenhouse gas (GHG) emissions and particulate matters in the HKH as well as other regions (Martinho 2019). A recent study of the amazon forest shows that there is a significant emission of carbon dioxide mainly due to intentional forest fires aimed at clearing the land for beef and soy production (Carrington 2021). This forest area which used to be a net carbon sink is, now experiencing acceleration in carbon emissions. Undeniably, forest fires develop a positive feedback loop as increase in forest fires triggers the emission of GHGs that escalates climate change. Contrastingly, in the absence of fire, the carbon pool in forest landscape increases, thereby contributing to climate change mitigation.

Trans-boundary fire and smoke pollution during the dry season are creating adverse effects on the wellbeing of humans and the ecosystems, which needs to be addressed regionally (Cheong *et al.* 2019) . Even though forest fire has emerged as one of the major environmental concerns in the HKH region, research in this domain is scarce. This paper aims to show the linkage between temperature, precipitation, AOD and CO with forest fire. A total of 187 forest fire-related articles across the globe and more specifically on the HKH region were reviewed. Those include scientific journals, technical reports, web sites, blogs, and news articles. Furthermore, active fire incidences and their linkage with temperature and precipitation and impacts on the environment was explored.

METHODOLOGY

Study Area

For this study, general scenario of forest fires in the HKH region was explored. The study area included Bhutan, India (Uttarakhand, Himachal Pradesh and Mizoram), Myanmar (Shan and Bago) and Nepal (figure 1).

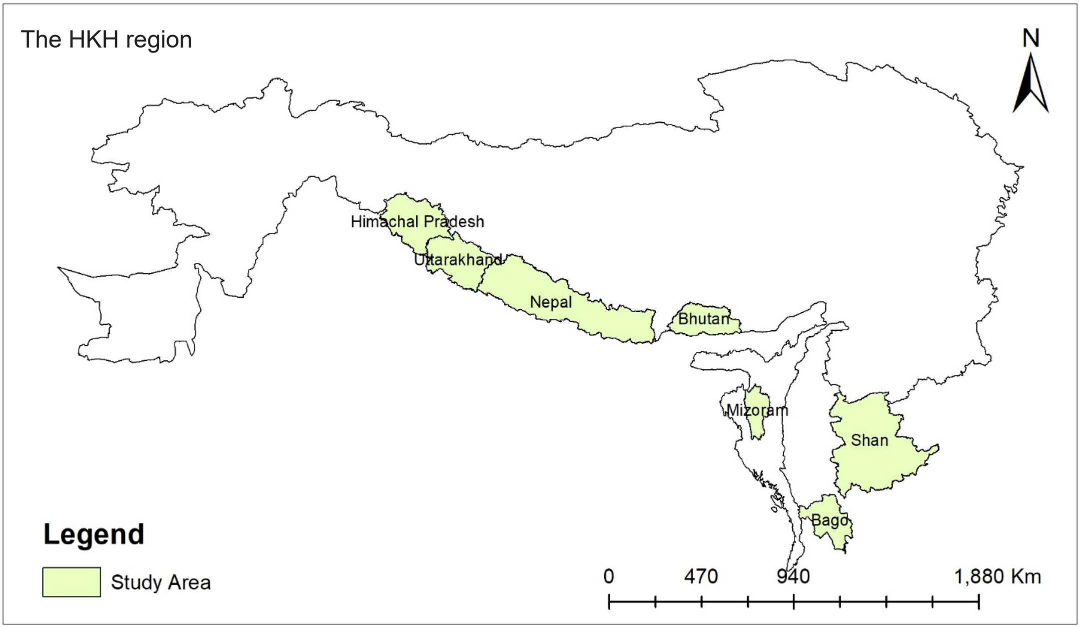

Figure 1: Countries and Regions in HKH Selected for the Study

Research framework

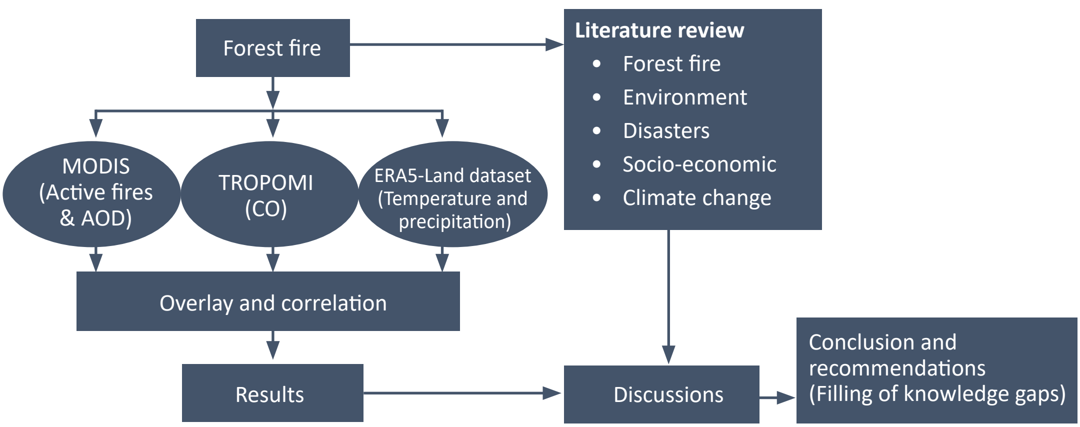

Figure 2: Research Framework

Forest Fires

The secondary data obtained from the literature review were used to analyse and evaluate the primary data extracted from Moderate Resolution Imaging Spectroradiometer (MODIS) instrument. MODIS active fire products are widely used and very much proven for its effectiveness on fire detection. Snapshot of events were captured by the satellites as it passes over the globe. Detection algorithms identify the fire pixels, and each active fire corresponds to the centre point of a 1x1 km pixel and reflects one or more fire incidents that took place within that 1 square kilometre area (Giglio *et al.* 2003). For each potential fire pixel, the algorithm uses its brightness temperature and examines each pixel and finally assigns it to the classes as missing data, cloud, water, non-fire, fire, or unknown. This study accessed the MODIS active fire data from the NASA web portal. MODIS active fire has a confidence level ranging from 0 per cent to 100 per cent. To avoid the false active fire, more than 50 per cent confidence level were chosen for this study.

Air Pollution Observed from Space

MODIS onboard Terra and Aqua satellites measure radiance in 36 spectral channels with the spatial resolution ranging between 250 m to 1 km and a swath width of 2300 km. MODIS sensor in Terra and Aqua crosses the equator at 10:30 and 13:30 local solar time (LST), respectively (Levy *et al.* 2007). The Dark Target (DT) 10 km and 3 km aerosol products and Deep Blue (DB) 10 km aerosol products have been validated and widely used over the years (Remer *et al.* 2005, 2013; Levy *et al.* 2007; Levy *et al.* 2013). The Multi-Angle Implementation of Atmospheric Correction (MAIAC) is a new algorithm that retrieves aerosol optical depth (AOD) at the higher spatial resolution of 1 km using MODIS measurements (Lyapustin *et al.* 2011). The algorithm uses the reflectance values in blue (470 nm), green (550 nm), and shortwave infrared (2130 nm) bands of MODIS (Jethva *et al.* 2019). The previous studies show the validation report of MAIAC AOD with the Aerosol Robotic Network (AERONET) observations from different parts of the world (Martins *et al.* 2017; Jethva *et al.* 2019; Mhawish *et al.* 2019).The higher correlation coefficient, higher percentage of retrievals falling within the expected error, and low root mean square error demonstrates that the MAIAC AOD has higher accuracy than the DB and DT AOD over South Asia (Mhawish *et al.* 2019). We used the combined Terra and Aqua MAIAC product (MCD19A2v006) available at the Google Earth Engine (GEE) data platform for this study.

Tropospheric Monitoring Instrument (TROPOMI) is a sensor onboard Sentinel-5 Precursor (S5P) satellite launched by the European Space Agency, which flies in a sun-synchronous orbit at 824 km altitude and crosses the equator at 13:30 LST (Landgraf *et al.* 2016). It provides daily global coverage at a spatial resolution of 5.5 km×7 km over a swath width of 2600 km. The retrieval algorithm derives the total column density of CO from the measurement of Earth's radiance spectra in the 2.3 μm spectral range of the shortwave infrared (SWIR) region (Landgraf *et al.* 2016). We used the offline (OFFL) version of CO data available in the data catalogue of the GEE data platform. GEE converts the original S5P Level 2 (L2) data into Level 3 (L3) by the 'harpconvert' tool using the 'bin_spatial' operation. The first validation of TROPOMI CO data showed good agreement with the Copernicus Atmosphere Monitoring Service (CAMS) dataset over the South Asian region (Borsdorff *et al.* 2018).

The Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) satellite carries the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) instrument, which acquires aerosol and cloud profile information. It flies in a sun synchronous orbit, crosses the equator at 14:00 LST, and has an orbit repeat cycle of 16 days (Winker *et al.* 2013). The standard browse image version 4.11 is used in this study to identify the aerosol sub-type.

Precipitation and Temperature

The seasonal precipitation and temperature for the selected regions for the reference period of 2010-2020 and for the year 2021 is derived from the ERA5-Land dataset. Many studies have previously used ERA datasets in the Himalaya region (Lutz *et al.* 2014; Wijngaard *et al.* 2017; Li *et al.* 2018). ERA5-Land is an improved version of the land component of the ERA5 climate reanalysis (Hersbach *et al.* 2020) with a resolution of 9 km (Muñoz-Sabater *et al.* 2021). Monthly datasets were downloaded and extracted for all the regions.

RESULTS AND DISCUSSION

Active Forest Fires in the HKH Region

In a decade (January 2010 to May 2021), more than six hundred thousand active fires with a confidence level of 50 per cent or more were recorded in the HKH region by MODIS sensors as shown in figure 3. During the summer season, March experienced the highest number of active fire records of 311,540 and April as the second highest with 170,317. Whereas in the winter, more than 11,000 active fires were recorded in the month of December.

The MODIS sensor detected more than 30,462 forest fire incidences in the study sites during the month of March and April 2021 as depicted in figure 4. Although area wise data was not possible, which needs ground mapping and validation, but frequency of incidence is quite alarming as this excludes fire in agriculture land. Year 2021 had become one of the worst periods for forest fire. Uncontrolled forest fire spanned from western Himalayan Indian states of Himachal and Uttarakhand to the entire range of hills in Nepal extending to Northeast India and up to Myanmar. The fire incidents in Myanmar and Mizoram were much more higher than other places because of the slash and burn agriculture practice in the dense forest to clear the floor (Springate-Baginski

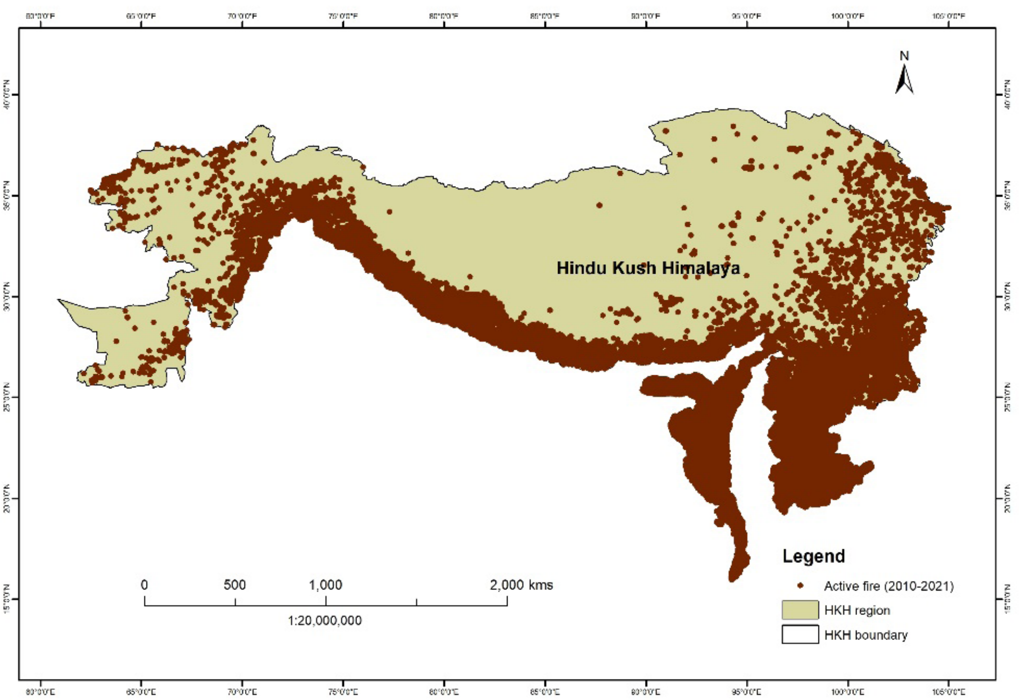

Figure 3: Spatial Distribution of Active Fire in the HKH Region from the Year 2010 to 2021

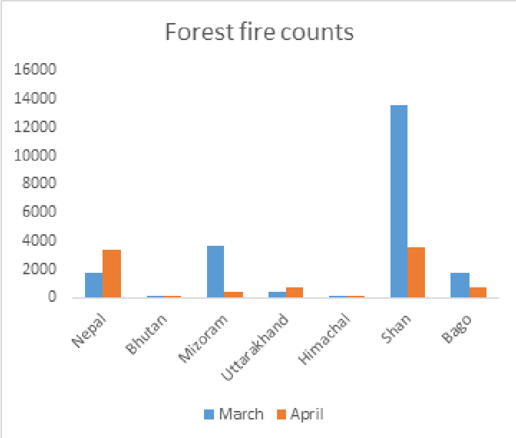

Figure 4: Monthly Status of Active Fire in the HKH Region for 2021

2018; Sati 2019). This indicates that most of the forest fire incidents are anthropogenic. Forest fires usually occur in the dry season, starting from December till the end of May before the monsoon sets in, with March and April as the peak. When winters are dry with prolonged drought periods, the fuel load in the forest increases causing more intense fire that transmits faster. In addition to this, forest fires spread in suitable conditions such as warm, dry, and windy conditions. If these conditions become extreme, it will trigger forest fire, increasing the severity of emissions.

Forest fires of 2021 in Nepal can be considered as the worst in a decade (Azarkan 2021) with more than 95 per cent of fire incidents occurring in March and April. Forest fires for the same year in some parts of northern India and Nepal have been most destructive in the past 15 years (Khadka 2021). In Nepal, the National Disaster Risk Reduction and Management Authority recorded 2,700 wildfires since November 2020- the highest over a decade, affecting around 200,000 ha of forest (GoN 2021). This might be due to increase in temperature and dry conditions, as temperature has increased by 0.2^{O}C as compared to the reference period (average of 2010-2020) (table 1).

In Uttarakhand, around 989 forest fire incidents were recorded from October 2020 to April 2021, which burnt approximately 12,973.43 ha of forest area (DownTo Earth 2021). In a slightly different finding, our study showed that 1,236 forest fire incidents occurred within two months, which might be due to different data sources and sensors and also the confidence level. In a period of two weeks in April 2021, 476 forest fire cases were recorded in Himachal Pradesh with the forest area loss of 4,555 ha, whereas in March 2021, over 8,400 ha of forest area was ravaged by the fire (Sharma 2021). In Mizoram, a total of 4071 forest fire incidents were decteted during the month of March and April 2021. In 2020, State of Mizoram reported more than 1,300 forest fires, most of which started from shifting cultivation practice (Agarwal 2021). In 2021, the Forest Survey of India (FSI) reported that there were as many as 2,671 forest fire points in Mizoram state between April 20 and 26, with over 400 points on April 26 alone (Nandi 2021). FSI sent 386,031 forest fire alerts in 2021 upto the month of May which is more than double from the previous year's figure of 154,032. The increased number of forest fire in 2021 has resulted in loss of livelihoods of forest dwellers (Mishra 2021). Analysis from FSI for 2019 showed that 36 per cent of India's forests are prone to fire, out of which, one third is highly susceptible (FSI 2019).

Our study identified a total of 19,683 forest fire incidents in Shan and Bago state of Myanmar. Among the total identified fire episodes, Shan witnessed 17,192 whereas Bago had 2,491 forest fire incidents. Although the media coverage, and published reports and scientific journal articles on wildfires in Myanmar were nominal, the actual number was high enough and remained unabated in 2021. According to the Global Disaster Alert and Coordination System, between 2 April to 21 April 2021, 11,000 ha were classified as forest fire burnt areas in Myanmar. As per MODIS sensors, Myanmar witnessed around 50,000 active fires from January to June 2021 whereas only 194 active fires was experienced in Bhutan in the same period. During the study period, Bhutan only had 110 forest fire incidents. This might be due to the introduction of modern facilities in the rural communities such as education, television, clearer radio services through which forest department can timely provide awareness programmes.

Temperature-Precipitation-Forest Fire Nexus

The annual precipitation and precipitation for the month of Feburary, March and April for all regions for the reference period (2010–2020) and 2021 has been shown in Table 1. Rainfall in the month of February, March, and April affect soil moisture condition and subsequently the number of forest fires because these are the driest months and most susceptible timing for forest fire. So any rainfall in these months causes the fire incidence to decrease drastically. Even though the annual precipitation has increased for most of the regions in 2021 compared to the reference period, the precipitation in the months from February through April has decreased in all regions, except for Bago and Shan of Myanmar. All regions showed increase in annual temperature of about 0.3 °C. However, the average temperature has increased by around 1°C for the FMA except for Myanmar. The decrease in precipitation, increase in temperature and increase in number of forest fires in year 2021 in comparison to the reference period is shown in red colour in Table 1.

In a similar scenario, most of the forest fires in the HKH region occur during the month of February through April. It constituted at least 90 per cent of all the forest fires in Nepal, Bago, Shan, Uttarakhand, and Mizoram. In Bhutan, it constituted 80 per cent whereas in Himachal it constituted 68 per cent of the total annual forest fire incidents. The highest increase in the number of forest fire in Nepal was by more than 100 per cent annually and around 250 per cent in February, March, and April in 2021 compared to the reference period. In Uttarakhand and Himanchal, the number of forest fires increased by around 200 per cent during February through April. Similarly, Uttarakhand recorded deficiency in rainfall at 18 per cent in 2019 and 20 per cent in 2020, even though India had near-normal monsoon rainfall (Guhathakurta *et al.* 2020). The increase in number of forest fire incidents coincided with the decrease in precipitation and increase in temperature for all regions during February through April. The decrease in rainfall in this area coupled with increase in temperature during the three months can be attributed to the increase in number of forest fires in this period (Table 1). Figure 5 shows the spatial variation in the change in precipitation for all the regions during the three-month period. The precipitation increased by 60 per cent in some parts of Myanmar and decreased by 60 per cent in Mizoram. The figure shows that the precipitation has decreased in most part of the study areas. This indicates that regions with higher decrease in precipitation would have most likely faced more forest fire incidents.

Table 1: Precipitation, Temperature, and Number of Forest Fires for February, March, April during the Reference Period (2010-2020) and 2021 for the Selected Regions.

Regions	Period	Annual			Feb-Mar-Apr		
		Precipitation (mm)	Temperature (°C)	No. of forest fires	Precipitation (mm)	Temperature (°C)	No. of forest fires
Nepal	2021	2563.9	12.4	5570*	136.5	10.0	5281
	Reference period	2120.5	12.2	**2156**	200.6	9.3	**1522**
Shan, Myanmar	2021	1541.7	21.3	21092*	117.5	21.8	19682
	Reference period	1736.5	21.3	**16421**	86.6	22.1	**15664**
Bago, Myanmar	2021	2137.9	26.0	3107*	107.7	27.3	2869
	Reference period	2245.7	26.0	**3451**	39.8	28.0	**3032**
Uttarakhand	2021	1961.5	11.1	1494*	155.3	8.3	1337
	Reference period	1734.8	11.0	**1120**	232.1	7.6	**404**
Mizoram	2021	1749.0	22.1	4563*	24.3	22.5	4528
	Reference period	1906.3	21.5	**3036**	142.5	21.5	**3011**
Himanchal	2021	1219.6	3.8	427*	251.0	-0.6	291
	Reference period	1353.5	3.9	**378**	332.4	-1.0	**91**
Bhutan	2021	3311.1	9.0	194*	433.6	5.6	155
	Reference period	3413.3	8.5	**217**	479.3	5.4	**156**

* indicates the data for forest fire only for the month of Jan-May

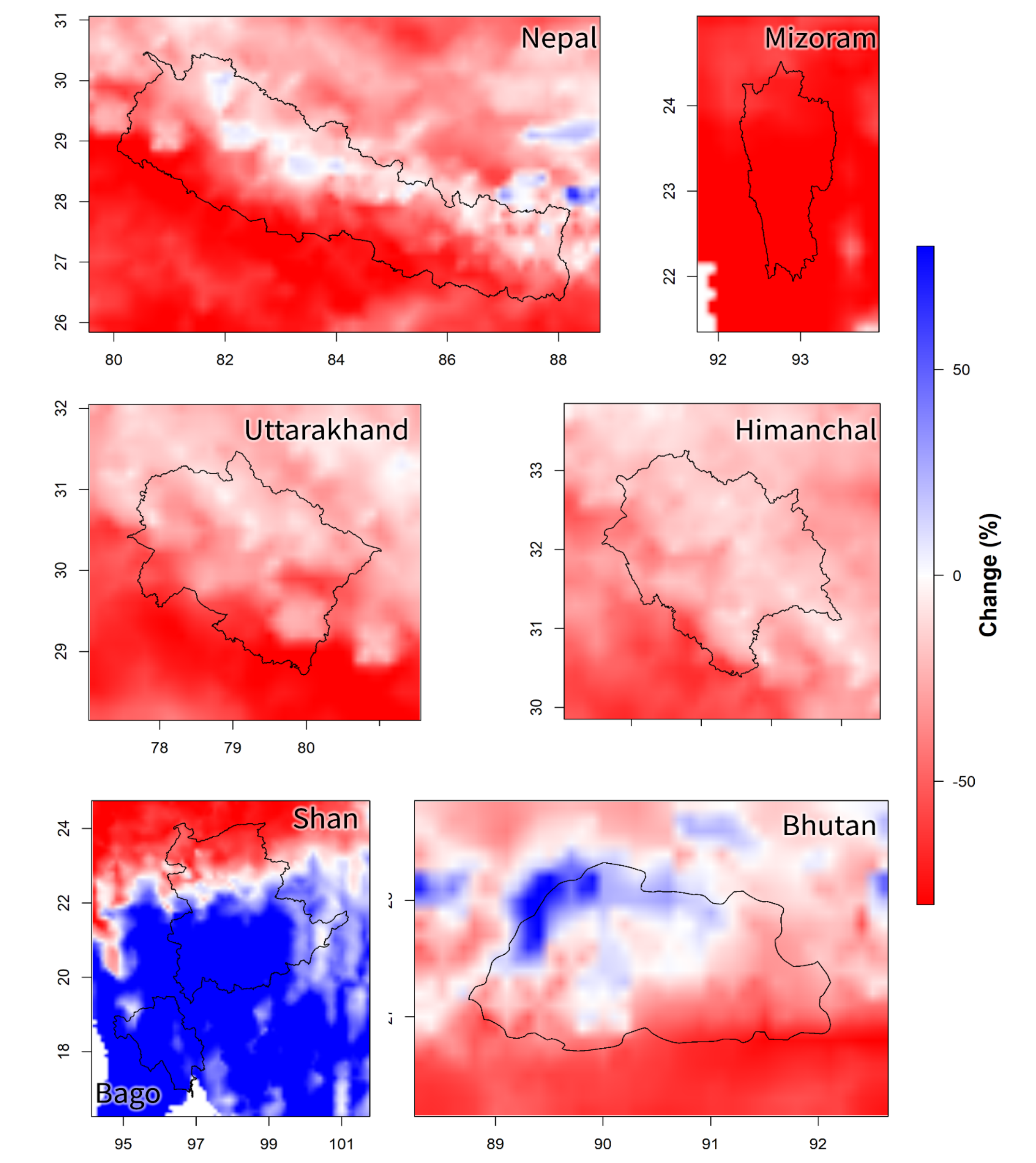

Figure 5: Spatial Distribution of Relative Change in Annual Precipitation for the Year 2021 with Respect to the Reference Period of 2010-2020.

Air Pollution Induced by Forest Fires

Forest fire releases a vast volume of smoke, aerosols, and trace gases which tend to influence the atmospheric chemistry and impacting air quality and human health (Sastry 2002) . The dimensionless AOD value incorporates the Mie scattering of solar radiation by aerosols and gives information on the columnar load (Dahal *et al.* 2022), which is considered as a proxy of Particulate

Matter 2.5 ($PM_{2.5}$). To see the changes in AOD and CO, we used multi-satellite observations. Figure 6 shows the columnar CO concentration during the intense haze episode of 2021 in the HKH region with the maximum number of fire counts. Kathmandu region and its surroundings have a higher concentration of CO, unlike the Indo-Gangetic Plain in the vicinity, which is one of the most polluted regions in the world. Moreover, the north-western Indian region had a lower concentration of CO during the study period, which in the post-monsoon season is influenced by agricultural biomass burning emissions (Liu *et al.* 2018; Sarkar *et al.* 2018). Some hotspots of CO over Myanmar were observed; however, the Shan and Bago region selected for this study have a significantly lower value.

Figure 7 shows the temporal variation of AOD and CO during the forest fire season. Unlike Nepal and Bhutan, India has no enhanced peak values for AOD and CO during the study duration; however, the site-specific values show a significant variation. In 2021, AOD values over Nepal show prominent peaks during the last week of March and the first week of April that coincide with the days with maximum number of fire counts inferring the influence of forest fire on air quality. However, the AOD value over Shan fluctuated throughout March and April during 2019 and 2020 along with the haze episode period in 2021. The CO values over Nepal, Bhutan, and Uttarakhand during the forest fire episode in 2021 surged (as high as 0.06 mol/m2) beyond the pre-episode values. The previous studies conducted in Uttarakhand (Thakur *et al.* 2019; Shuchita and Senthil 2020) reported increment in the surface level CO, tropospheric Nitrongen Dioxide (NO_2), and AOD during widespread forest fire in 2016. Although TROPOMI captures the peak values of CO in Bago and Shan during the fire episode in 2021, similar peaks in previous years (2019 and 2020) showed no specific impact of forest fire in 2021. Likewise, Figure 8 shows the aerosol subtype for March 29, 2021, along a transect crossing the region near Bhutan, based on CALIPSO observation. The elevated smoke was present near the altitude of 5 km that further corroborates the biomass burning emission.

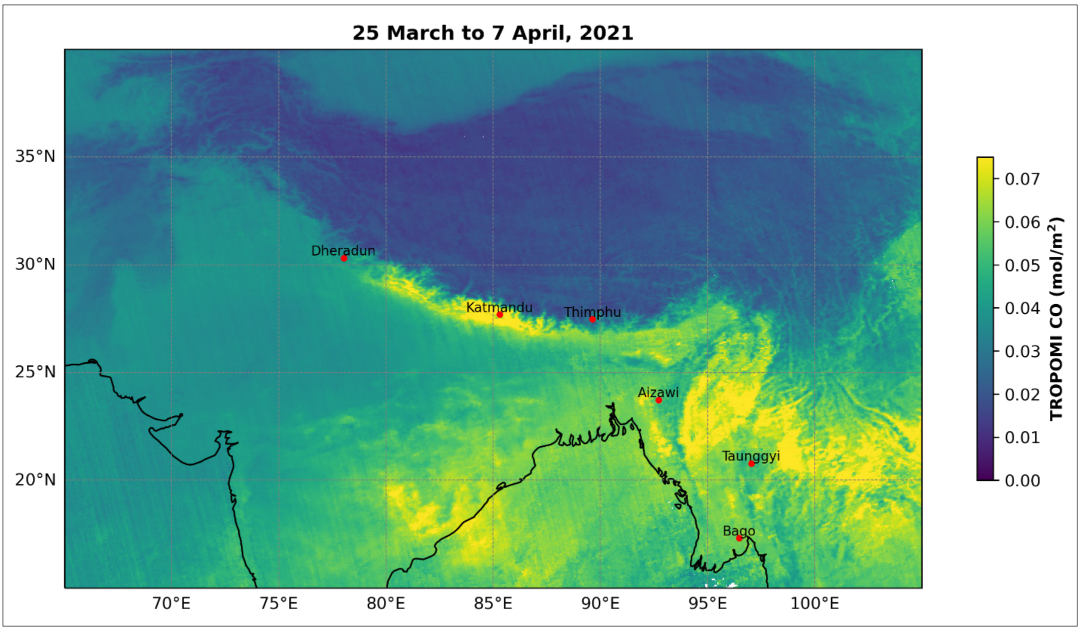

Figure 6: Spatial Variation of Columnar CO Concentration in the HKH Region

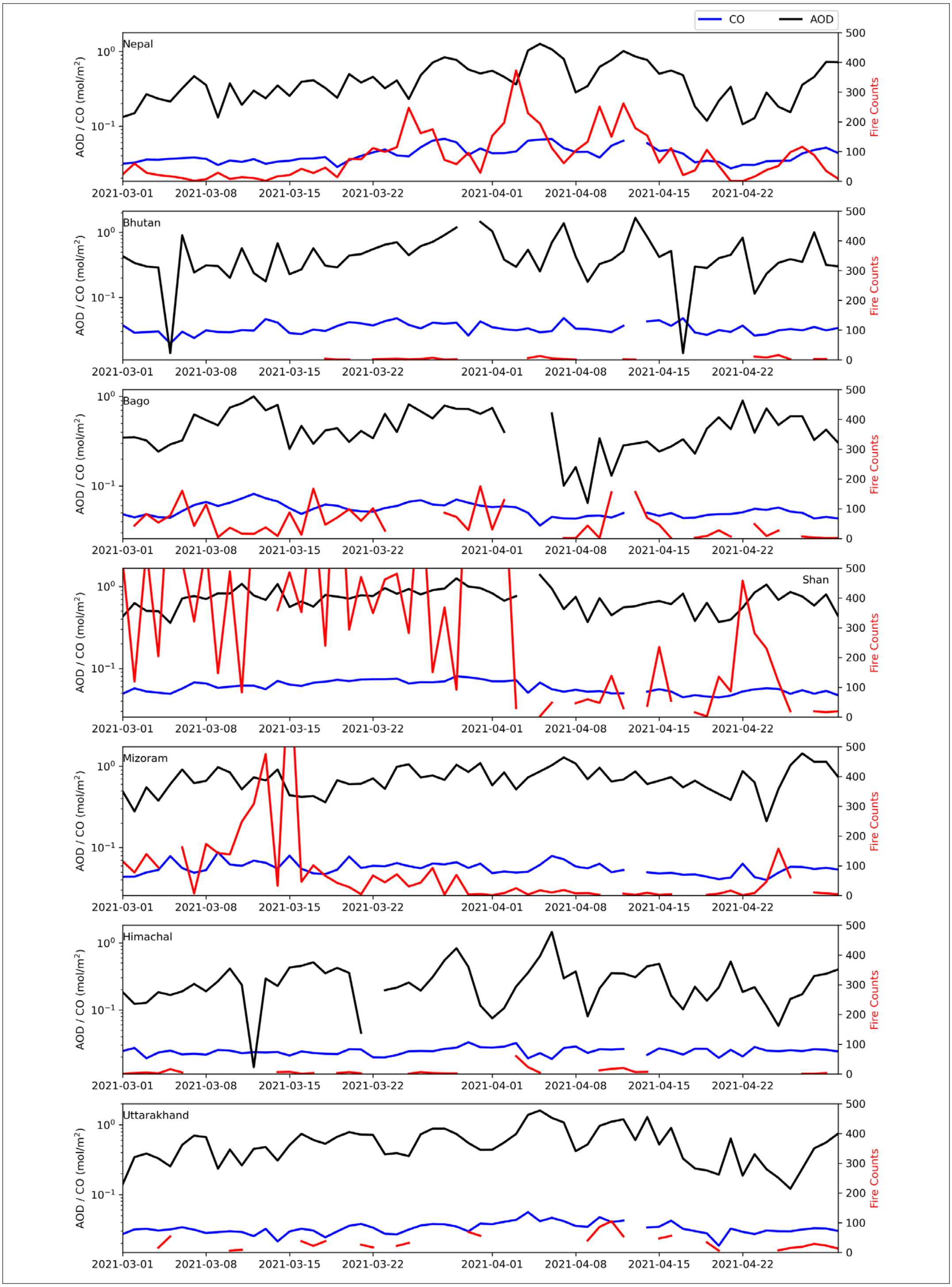

Figure 7: Temporal Variation of MODIS AOD and Fire Counts, and TROPOMI CO

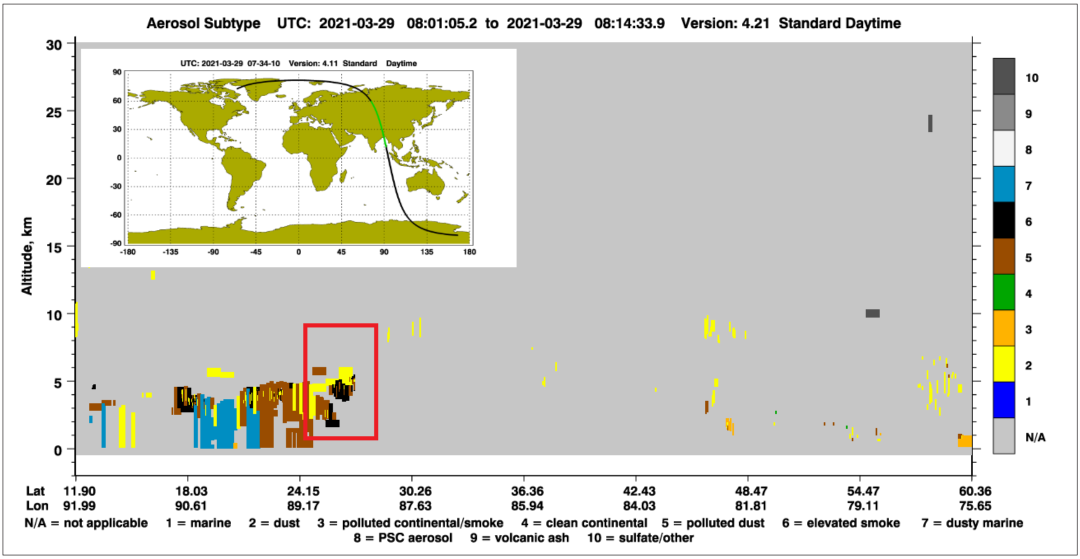

Figure 8: CALIPSO Aerosol Subtype on the Himalayan Foothills

Forest Fire Risk Mitigation and Climate Finance

Forest fire in a controlled manner is an important forest management tool in minimising the spread of wildfires. These take place by consuming natural fuels from forest floor, controlling weeds, and therefore providing prospects for reducing emissions and increasing carbon sequestration. Controlled fire has positive aspects as it helps in destroying the diseases and provides nutrients for the new growths. The Paris Agreement has recognised the contribution of forests in sequestering carbon under the Reducing Emissions from Deforestation and Forest Degradation (REDD+) framework which Bhutan, India and Nepal have already endorsed (Rawat *et al.* 2020). This instrument is linked with the financial instrument based on carbon sequestered by the countries through afforestation, reforestation, conservation, and managing forests. The agreement offers an attractive incentive for the HKH region to draw climate finance for investment for mitigating CO_2 emission, sequestrating atmospheric carbon into landscape through a biological process. However, forest fire incidents as witnessed in 2021 can disqualify countries from the eligibility of climate financing, since the sequestered carbon is released back into the atmosphere, as opposed to the conditions of the financing mechanism Additionally, CH_4, and NO sequestered by forest over many decades can be released back into the atmosphere within hours of forest fire event.

Methane is estimated to have a global warming potential of 28 to 36 over 100 years, while nitrous oxide is 298 over 116 years (US EPA 2020) . Therefore, any carbon credit traded from the forestry sector makes it a risky business proposition with the threat from forest fire. This is translated in the expensive insurance premium for forest carbon projects due to this risk factor from fire. Therefore, in this region, the buffer against forest fire accounts for up to 15 to 20 per cent of carbon credit revenue.

However, after forest fire, carefully designed rehabilitation actions can be an opportunity to restore the lost natural values. This will also help in addressing the global agenda like the UN Decade of Ecosystem Restoration. Around 2 billion ha of land is available in the world for restoration activities (IUCN 2014). But these open areas might have some unpalatable, unwanted, invasive plant species. In this case, fire can be a medium to eradicate those unwanted plant species and apply a suitable ecological restoration model. This not only helps in ecological restoration but also in the sustainable livelihood of the forest dependent communities if selection of plant species is done keeping possible future climatic conditions in mind and aimed at improving the ecosystem services from forest.

Forest Fire and SDGs

Although, forest fires are not explicitly mentioned in the Sustainable Development Goals (SDGs), eight out of 17 goals are directly, or indirectly, linked to forest fires (figure 9). Uncontrolled forest fires are one of the main concerns for desertification and land degradation, which heats the soil affecting the fertility and its stability. Furthermore, the air that we breathe in also gets polluted which also affect the water quality and livelihood of the local communities and breaks the chain of sustainable harvesting of fuelwood. These fires are also threat to the life on land (SDG 15) which not only damages the biodiversity but also have serious impact on the nearby settlements. With expanding population, houses/communities are getting closer to the forest, and pose risk to spread of fire towards the settlement. In addition, the deadwood used by the communities as main source of cooking also gets ignited, thus triggering the spread of fire. In Dang of Nepal, more than 460 households were in danger due to forest fire, fortunately there weren't any human losses but villager lost their agriculture crops and hay that were piled up to feed their livestock (THT 2021).

1. Desertification and land degradation

2. Heating effects on soils, mainly effects on fertility, soil stability and water infiltration characteristics

3. Air quality, Combustion of vegetation and conversion to another, vegetation type, Damage to cultural artefacts

6. Post-water water quality, availability and treatability

7. Effects on sustainable firewood harvesting

13. Release of greenhouse gases and particulates, Changes in albedo, Changes in soil moisture retention capacity

14. Water quality, post fire runoff into water bodies

15. Combustion of vegetation and conversion to another, vegetation type and land use, Heating effects on soils, mainly effects on fertility, soil stability, water infiltration characteristics and soil moisture retention capacity

Figure 9: Forest Fire Impacts on SDGs

CONCLUSION

In the HKH region, most forest fires are human-induced (intentional, negligence and accidental). Except in the monsoon and winter seasons, the forests are susceptible to fires. Farmers use fire to clear undergrowth in the forest so that new forage can grow for livestock to graze. They also burn the agricultural field to remove crop stubble as it is the least labour-intensive method. Most of the protected areas in the Terai undertake controlled burning to manage grasslands once a year, necessary for wildlife and for clearing the undergrowth in forests. Managed forest fires are beneficial and are part of the forest and grassland management practices, but wildfires are not. It may start as a small, controlled fire for agriculture land management. However, with prolonged drought conditions, increased temperature and increased fuel load, the fire transmits to forests developing into an uncontrolled wildfire that may last for days to months. This has resulted in health implications due to increased concentrations of AOD and CO in the atmosphere.

The main drivers behind the increase in forest fire are persistent hotter and drier weather, as well as other human influences such as land conversion for agriculture and inadequate forest management (WWF 2020). Forest fires can release millions of extra tonnes of carbon, decimate biodiversity, destroy vital ecosystems, impact economies and people, threaten property and livelihoods, and cause severe long-term health problems for millions of people in the HKH region and across the globe.

The haze episode of 2021 has highlighted as to how critical forest fire can be to the urban population and has underscored the necessity to promulgate local-level fire management plans. The plan need integration in all forestry-related programmes such as restoration, sub-national REDD+ action plans, adaptation plans, or nature-based solutions. A forest fire can only be managed and avoided with local community support. Although numerous initiatives on controlling forest fires are identified, their execution is weak. There is a huge untapped potential to mobilise climate finance for fighting forest fires. The forest fire events that have occurred in the region in past, indicates the type of management needed. Learning from these events is helpful to know what kind of support is necessary for protecting our forests and homes. Though forest fires may occur due to natural or anthropogenic causes, however, once the impacts of the events are minimal, it is of utmost importance for scientists, managers, policy makers, foresters, forest user groups, and all other associated stakeholders to grasp the opportunity to rethink forest management and foster more resilient landscapes. Regular patrolling of fire-prone areas is a bit of a challenge in the HKH region due to harsh terrain and insufficient allocation of human resources. Thus, suitable vegetation/silvicultural measures of employing rehabilitation of burnt site with broad-leaved evergreen trees is a suitable alternative, grazing and browsing by livestock and using mechanical mowers can also contribute to forest fire risk reduction. Despite of knowing the effectiveness of these interventions, there is limited field implementation.

RECOMMENDATIONS

Controlling Wildfires

To control wild forest fire, laws banning fire in agricultural fields and forest are now in place in most countries, and they get more emphasis every fire season. But enforcing the law, policing and punishment is weak. There is lack of strong political commitment to act against local communities that ignite wildfires. The existing policies are rarely implemented, indicating the failure of those policies. Thus, a shift to incentive-based policies needs to be in place. In India, the government devised subsidies for farmers for using mechanical machines that replaces stubble burning practice. In 2019, the Supreme Court ordered northern states to give Indian Rupees (IRs) 2,400 per acre to every farmer owning the land who didn't burn stubble (BBC 2020). The innovative incentive-based instruments are also being tested for farmlands. But controlling forest fire is more challenging as much of the forests lie on state owned land.

In the HKH terrain, reducing forest fire occurrence and intensity is a difficult task. It can only work if the local people come together in a collective way. Besides, forest fire education and awareness initiatives are essential. For people using forests for adventurous activities, there is a fire detection system, watchtowers, and a communication network, as well as strict approvals and warnings. Forest fires can have both short- and long-term consequences on invaluable resources. So, landowners and associated communities can work to mitigate their effects. Forest fires can be controlled using a variety of ways, including using fires to put out fires, creating fire lines, enhancing communication. If the forest fire spreads to settlements or urban areas, protecting life and property, should be of primary concern. Planting low-flammable tree species that can act as green firebreaks by slowing or preventing the spread of fire is one of the solutions. The appropriate species can be strategically selected to achieve biodiversity advantages.

Using mechanical flail mowers and grazing livestock such as goats and pigs can substantially reduce the fuel load in the forest floor and mitigate risk of wildfire. But livestock grazing and browsing is banned in most forests while mechanical mowers have limited use in mountain landscapes. Flail mowers also replace fire management practice in grasslands in more accessible parts of protected areas.

In the future, pre-fire and post-fire management and plans should be implemented effectively to minimise the impacts of forest fires. In addition to these, countries also need to integrate and prioritise forest fire mitigation in national and provincial level adaptation plans. The governments also need to focus on generating and leveraging the funds for forest fire management and mitigation. Unless the forest fires are well managed and mitigated, achieving nationally determined contributions on the forestry sector and the global agendas like SDGs, UNCCD, and UN Decade of Ecosystem Restoration is arduous. Governments allocate budgets for plantation, but rarely for fire management in HKH.

Community Forest Fire Management Strategy

To deal with forest fires, communities must adopt a Forest Fire Management Strategy at the local level. Each community plan must include a strategy and activities based on their resources and needs for fire management, depending on the vulnerability, topography, gradient, and proximity to settlements. Pre-fire preparedness is the most successful technique for dealing with forest fires, and requires adequate annual financial allocation. Community leaders and local fire-fighting crews carry out all pre-fire and fire-fighting actions at the community level. The effectiveness of this activity is mostly determined by the mobilization of the local populace, accessibility of the area and availability of tools. Communities can develop rainwater harvesting ponds in the forest which can serve as a reservoir for extinguishing wildfires. As a result, developing a forest fire management strategy at the local level and integrating it with other strategies is critical and can be integrated with local plans and/ or community-based forestry plans.

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