Temporal and Spatial Distribution of Forest Fires and their Environmental and Socio-economic Implications in Nepal

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Abstract

Forest fire is a global phenomenon, resulting in devastation across regions. Nepal is not an exception where forest ecosystems and environment are vulnerable to forest fires, causing loss of properties and lives. While a range of studies have been conducted on the causes of forest fire and its impact, temporal and spatial dimensions along with ecological and socio-economic implications are largely overlooked. This paper aims to identify the temporal and spatial distribution of forest fire, and its implications on forest ecology, environmental, and socio-economic sectors of Nepal. Data on fire incidences and burnt areas were obtained from the Moderate Resolution Imaging Spectroradiometer (MODIS) and information pertaining to environmental and socio-economic implications were collected from various secondary sources. The 2001-2020 data revealed increasing forest fire incidences. Seasonally, pre-monsoon appeared to have higher frequencies of forest fires. By province, the Tarai and Siwalik regions of the Sudurpaschim Province, Madhesh Province, Lumbini Province, and Bagmati Province are susceptible to fire. In terms of fire risk, the Tarai-Siwalik region of Sudurpaschim and Madhesh Province are at very high forest fire risk. In terms of environmental loss and damage, every year on an average, 3,098 fire incidences occur resulting in damage to 172,040.65 hectares (ha) of forest and biomass loss of 7.07 million tons per year accounting to emission of 3.30 million tons of carbon per year. During 2020-2021 period, a total of Nepalese Rupees (NPR) 1890000 (USD 15240.70) was lost due to the damage incurred by forest fire. Likewise, from 2007 to 2021, 71 human casualties have been recorded. Both natural and anthropogenic factors are responsible for the occurrence of forest fire in Nepal. Thus, for the protection of forests, properties and lives, strict forest fire mitigation policies and practices ensuring sustainable forest fire management is crucial.

Keywords: Fire drivers, fire occurrence, fire risk, forest fuel, MODIS active fire

INTRODUCTION

Forest fire has remained as an important phenomena affecting the Earth's surface, atmosphere and human life. Around 4 per cent of the global forest burns every year due to climate change and human induced interventions (Marlon *et al*. 2008; Randerson *et al*. 2012; Morton *et al*. 2013). Globally, 3,753 people has been reported to be killed and around properties worth USD 54,828 million damaged from forest fire between 1901 and 2014 (Doerr and Santın 2016). The temporal and spatial distibution of forest fire vary according to the vegetation type, geograhic feature, climatic conditions and land use patterns. Wood and Ventimiglia (2021) have reported that the forest burnt area appears to have declined over the past decades, however, in 2017 - 2018, forest fire has increased in California, Canada in 2014, 2017 and 2018, in the Mediterranean during 2017-2018, in Siberia during 2003, 2012, 2019, and in Australia during 2009, 2013, 2019, affecting the environment, economies, ecosystems, and people. Similarly, forest burnt area seems to have increased by 3–4 per cent in Southeast Asia, the Middle East and Boreal North America during the period of 1996 to 2012 (Giglio *et al*. 2013; van Lierop *et al*. 2015; Andela *et al*. 2017). Globally, mean fire season length has increased by 18.7 per cent from 1979 to 2013 (Giglio *et al*. 2013).

In the recent years, forest fire is increasing due to natural and anthropogenic causes threatening forest ecosystems (Moreira *et al.* 2011). The natural causes of forest fire include rising atmospheric temperatures, low precipitation, accumulation of forest fuel (biomass) and topographic features (Flannigan *et al.* 2005; Holden *et al.* 2009). Among the natural drivers, climatic factors are prime drivers of regional fire occurrences (Bowman *et al.* 2009; IPCC 2014). Forest fuel that includes dead and live woody or non-woody biomass is one of the major contributing natural drivers of forest fire (Sandberg *et al.* 2001). The most common surface fuels like dead and fallen woody materials, litter, grasses, herbs and shrubs all contribute to increasing forest fire incidents (DeBano *et al*. 1998; Reinhardt *et al.* 2006). In forest, tall or small trees, shrubs and climbers that maintain vertical layer as ladder fuels are the most important parts of forest fuel (Nemani *et al.* 2003; Stephens *et al.* 2009). Similarly, topographic factors (aspect, elevation and slope) are also the key natural drivers causing forest fire (Romero *et al.* 2008; Bradstock *et al.* 2010; Wood *et al.* 2011; Estes *et al.* 2017). The data of the past twenty years show increasing intensity and spread of forest fires in Asia, which can be largely attributed to rise in temperature and decline in precipitation in combination with increasing intensity of land-use (IPCC 2007).

In addition to the natural causes, anthropogenic factors have been playing a dominant role in contributing to forest fire incidents, which are reported to be 10 times higher than the natural causes (Bowman *et al.* 2011; González *et al.* 2015; Lewis *et al*. 2015). Most of the human-induced fires are a result of behavioral issue including carelessness or lack of attention by the wood collectors, campers, hikers, travelers and garbage burners (Bowman *et al.* 2011; González *et al*. 2015). In boreal forests of China, distance between forests and human settlement or road have been reported to play a crucial role driving forest fire occurrence (Guo *et al.* 2015, 2016). Likewise, the distance of forest from the road has been found to be highly correlated with the severity of fire occurrence in Golestan, North-east Iran (Abdi *et al*. 2016). In the present context, forest fire has been emerging as a challenging issue at regional and global scales (Andela and van der Werf 2014; Juárez *et al.* 2017). Among others, high value forests have remained vulnerable to forest fires (Chen *et al.* 2014; Abdi *et al.* 2016; Ahmad *et al.* 2017).

In Nepal, for the last 20 years, the temporal and spatial distribution of forest fire occurrence has varied. Forest fires are increasing over the past few decades due to both natural and anthropogenic causes making the high-value forests vulnerable (Karkee, 1991; Bajracharya 2002; Goldammer 2003; Kunwar and Khaling 2006; Kanel 2007; DFRS 2015; Khanal 2015; Parajuli *et al.* 2015; Matin *et al.* 2017). Karkee (1991) has observed that around 40 per cent of forests fires are caused by the human activities like cattle-grazing, honey collection, poaching and non-timber forest product collection in the Mid-hills of Nepal. In similar line, Goldammer (2003) and Kanel (2007) have reported increase in forest fire incidents due to human activities. Similarly, Kunwar and Khaling (2006) have reported increase of forest fire in the Terai region due to increasing human-forest interface. Furthermore, Sharma (2006) reported that forest fire contributed to 14 per cent damage in community forests in 2003, which increased to 24 per cent in 2004. According to Khanal (2015), 375,000 hectare (ha) of forest was damaged due to forest fire during the period from 2001 to 2014.

With respect to risk and loss, the forest is becoming vulnerable to forest fire over the past few decades (Bajracharya 2002; DFRS 2015; Khanal 2015; Parajuli *et al.* 2015; Matin *et al.* 2017). According to Bajracharya (2002), 400,000 ha of forest is lost annually due to forest fire. Around 27.8 per cent of forest fires result into loss and damage of forest biomass (DFRS 2015). Khanal (2015) have reported that around 3,75,000 ha of forest fire was burnt during the period from 2000 to 2014. Furthermore, the Lumbini and Sudurpachhism provinces have reported higher forest fire vulnerable in Nepal (Parajuli *et al*. 2015) Similarly, in 2016, forest resource worth USD 1,07,798 was lost due to forest fire in Nepal (Bhujel *et al*. 2018). The previous studies have mostly focused on drivers of forest fire, forest fire situation, and temporal and spatial forest fire trends in a certain geography. Thus, this paper aims to identify the temporal and spatial distribution of forest fire, forest fire risk zones, and its implications on environment and socio-economy in Nepal.

METHODOLOGY

Forest Fire Incidences and Burnt Area

The temporal and spatial distribution of forest fire occurrences (incidences and burnt areas) were obtained from the MODIS active fire data of the National Aeronautics and Space Administration (NASA) during the period from 2001 to 2020. The MODIS image with resolution 1 km × 1 km records fire incidences four times a day by Terra and Aqua. MODIS provides two standard fire products, i.e. the active fire product that specifies the location of forest fire point and burnt area. The MODIS active fire product detects fires in 1 km pixels that are burning at the time of overpass under relatively cloud-free conditions using a contextual algorithm. The geographical coordinates of the forest fire points and the date of fire occurrences were downloaded from the active fire data of the National Aeronautics and Space Administration (NASA)[1]. The forest burnt area was estimated from the burnt-area product (MCD45A1 collection 5.1), a monthly 500 m spatial resolution gridded burnt-area product[2]. The product is based on bi-directional reflectance model-based change detection approach for mapping the burnt-areas. The algorithm used in MODIS detects the approximate date of burn based on the observed changes in the daily MODIS reflectance product. The shape-file of Nepal's boundary including physiography and province was obtained from the Department of Survey (2002), Government of Nepal.

The digital map of forest fire incidences (points) from 2001 to 2021was generated from MODIS active fire data by clipping physiographic and provincial level layers of Nepal using Arc-GIS (10.2 version). It was exported into shape file (year wise). The data-wise forest fire points were downloaded and counted in MS-EXCEL with reference to the latitude and longitude. The spatio-temporal distribution of forest fires was analysed using the point density module of Spatial Analyst tool which calculates the fire point's magnitude per unit area from point features that fall within each cell and/or neighborhood cells.

In connection to the burnt area, the shape-file burnt area was delineated using the Arc-GIS (10.2 version) by clipping the boundary of Nepal including the physiographic and provincial level. The fire point was converted into polygon by Arc-GIS (10.2 versions). The burnt area of each physiographical and provincial level was estimated by converting database file (dbf) in to excel. The accuracy of the burnt area was validated by direct field observation and comparing with the general accuracy statement of the MOD14 product performance. The monthly and seasonal fire days were estimated from the MODIS data.

Forest Fire Risk Zone Delineation

In order to analyse forest fire risk, Kernel Density Estimation (KDE) tool was used considering the intensity of fire historic points and hotspot through Arc-GIS (10.2 version). The KDE produces a smooth density surface of point events over space by computing event intensity as density estimation (Serra-Sogas *et al.* 2008).

[1] https://earthdata.nasa.gov/earth-observation-data/near-real-time/firms/active-fire-data
[2] https://modis-fire.umd.edu/links.html

Environmental and Socio-economic Implications

The data related to environment, especially carbon emission was calculated by using the equation providd by IPCC (2006).

$$Lfire = A*MB*Cf*Gef*10^{-3}$$

Where,

Lfire is the amount of greenhouse gas emissions from fire (t)

A is the area burnt (ha)

MB is the mass of fuel available for combustion (t/ha) of dry biomass 194.5 t/ha (adopted from DFRS 2015) and the available to burn biomass, 35 per cent adopted from Kasischke *et al*. (2005).

Cf is the combustion factor value (0.47) (IPCC 2006)

Gef is the emission factor (g/kg dry matter burnt), 0.6 per cent combustion efficiency for all types of Asian forest was adopted (IPCC 1997).

The equivalent carbon emission due to forest fire was estimated using the conversion factor from carbon mass to carbon compound mass, i.e., the equivalent carbon dioxide (CO_2), carbon monoxide (CO) and methane (CH_4). Carbon dioxide was estimated multiplying the carbon mass by 3.67, CO was estimated by multiplying the carbon mass by 2.33 and CH_4 was calculated by multiplying the carbon mass by 1.33 conversion factors (Trozzi *et al*. 2002).

Data pertaining to socio-economic implications of forest fire were collected through review of published journal articles, technical reports, media reports and National Disaster Risk Reduction and Management Authority (NDRRMA) portal[3].

Data Analysis

The forest fire incidences and burnt area were processed by using the Arc-GIS programme (10.2 version). The data on forest fire incidences and burnt area were tabulated, and bar and line diagrams were generated using the MS-Excel. Similarly, the forest fire risk zone map of Nepal was prepared using the Kernel Density tool, considering the forest fire incidences points through Arc-GIS.

RESULTS AND DISCUSSION

Temporal Distribution of Forest Fire

In Nepal, the temporal forest fire incidences and burnt areas were found to vary during the period of 2001 to 2020. On an average, 3,098 fire incidences, and burning of 172, 040.65 ha of forest area was found annually (Figure 1). Out of those, 65 per cent of fire incidences were recorded in April, 17 per cent in March and 13 per cent in May. Likewise, according to the year-wise distribution, the highest forest fire incidences (10,658) and burnt areas (5,95,875 ha/yr) were found in 2016 followed by 2014 (4,488 incidences with 2,38,777 ha/yr burnt area), 2009 (4,080 incidences with 2,07,799 ha/yr burnt area), 2010 (3,950 incidences with 2,19,448 ha/yr burnt area), 2012 (3,666 incidences with 2,17,567ha/yr bunt area) and lowest in 2015 (465 incidences with 21,689 ha/yr burnt area) (Figure 1).

[3] http://drrportal.gov.np/

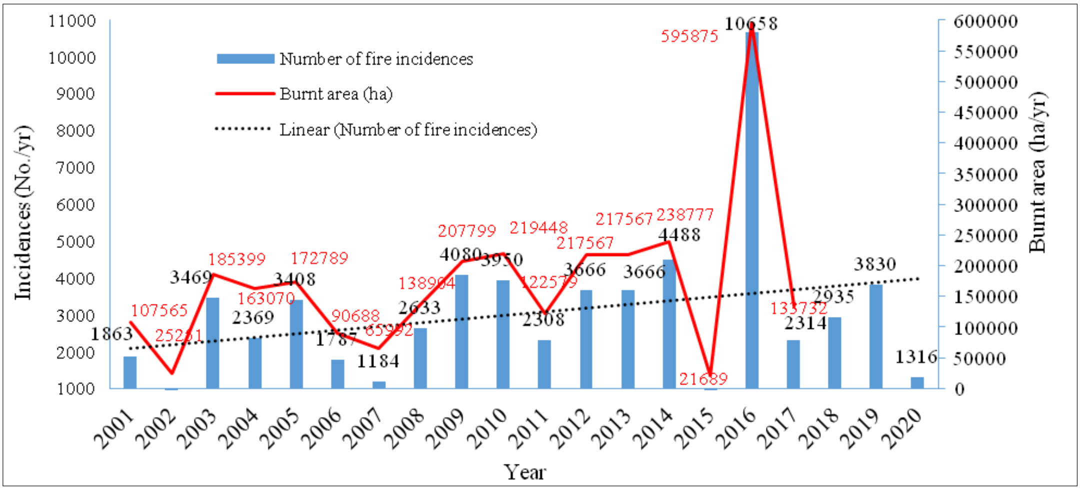

Figure 1: Temporal and Spatial Forest Fire Distribution Pattern in Nepal from 2001 to 2020

Previous studies have reported similar results during the same period from last two decades, and have attributed to higher temperature, lower precipitation and longer dry period (Parajuli *et al.* 2015; Matin *et al.* 2017). Parajuli *et al.* (2015) have revealed higher forest fire incidences in 2003, 2005, 2009 and 2012. In the same period, Matin *et al.* (2017) have observed higher forest fire incidences in 2009, 2010 and 2012.

In Nepal, on an average, 77 forest fire days were recorded per year during the period of 2001 to 2020. The highest number of fire days were found during April (16 days) followed by March (14 days) and May (10 days) (Figure 2). In contrast, lower number of forest fire days were observed in October, November, and December (Figure 2). A separate study by Bhujel *et al.* (2018) have reported 140 forest fire days in 2016 across the country, which was attributed to increase in air temperature, long drought period and accumulation of fuel in the forests. In the Tarai and Siwalik regions, 25-36 fire days have observed during the period of 2003 to 2013 (Matin *et al.* 2017).

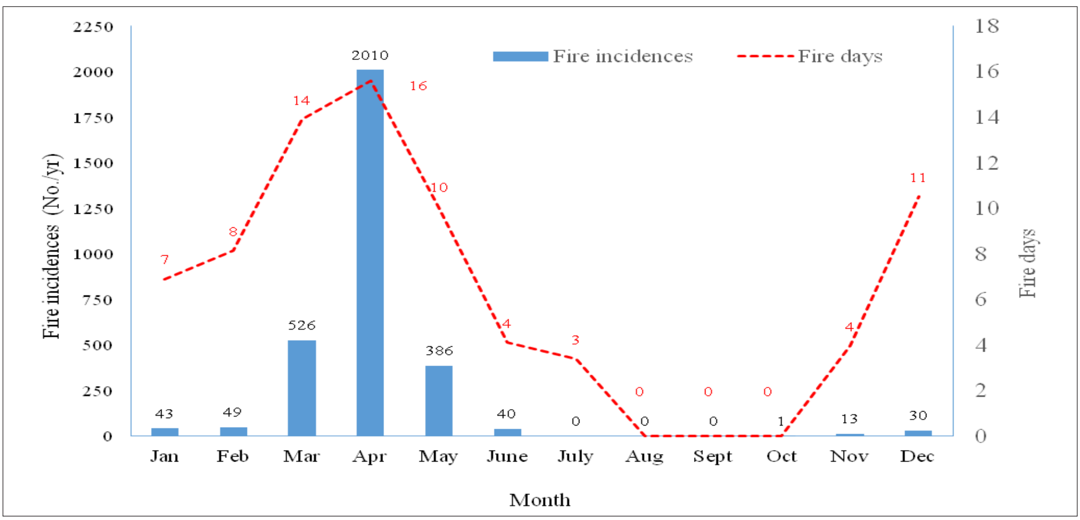

Figure 2: Month-wise Forest Fire Incidences and Fire Days

The forest fire incidences were found to vary across seasons throughout the year (Figure 3). Over the past two decades, the highest number of forest fire incidences have been recorded during pre-monsoon (2922), followed by winter (122), post-monsoon (14) and summer (40) seasons. This result was consistent with the research findings of Matin *et al.* (2017) and Parajuli *et al.* (2015). Matin *et al.* (2017) have observed 89 per cent of forest fire incidences in the pre-monsoon during the period of 2003 to 2013. For the same season, 92 per cent of forest fire incidences has been recorded by Parajuli *et al.* (2015) during the period of 2001 to 2013.

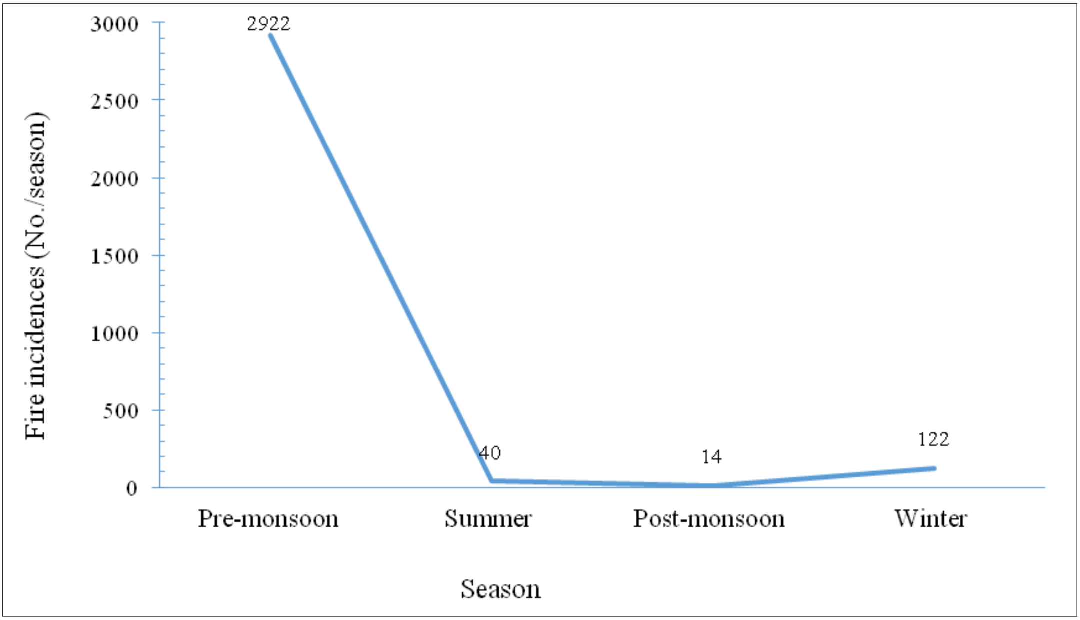

Figure 3: Average Forest Fire Incidences Across Seasons in Nepal

Spatial Distribution of Forest Fire

The forest fire distribution varies with vegetation types, geographical feature and climatic conditions. Nepal encompasses various physiographic regions and MODIS fire data revealed variation in forest fire occurrences according to those regions. Higher forest fire density (0.11 incidences/km^2 with 4.74 ha/km^2 burnt area) were found in the Tarai region as compared to the Siwalik (0.07 incidences/km^2 with 4.65 ha/km^2 burnt area), and the High Mountain and Himalaya (0.01 incidences/km^2 with 1.57 ha/km^2 burnt area) (Table 1). The result is consistent with preceding studies (Matin *et al.* 2017; Bhujel *et al.* 2018; Parajuli *et al.* 2020) conducted during the period of 2001 to 2017. Bhujel *et al.* (2018) have reported an average of 0.09 forest fire incidences with 3.4 ha burnt forest per km^2 in 2016. Likewise, in their analysis during the period of 2003 to 2013, Matin *et al.* (2017) have revealed that the Tarai and Siwalik regions are more susceptible to forest fire in comparison to other physiographic regions. Similarly, for the period between 2001 and 2018, Parajuli *et al.* (2020) have observed more than half of the total forest area (65%) of the Tarai Arc Landscape (TAL) as high in risk of forest fire.

Table 1: Forest Fire Densities by Physiographic Regions in Nepal

Physiographic regions	Forest area (km²)	Fire incidences (No./yr)	Burnt area (ha/yr)	Average fire incidences (No./km²/yr)	Average burnt area (ha/km²/yr)
High Mountain and Himalaya	24763	572	38854.19	0.02	1.57
Middle Hill	23161	747	48336.13	0.03	2.09
Siwalik	13964	1092	64898.92	0.07	4.65
Tarai	4211	485	19951.41	0.11	4.74
Total	**66099**	**2896**	**172040.65**		

In terms of provinces, highest number of forest fire occurrences (annually 545 incidences with 72,090 ha burnt area) were found in Lumbini Province and lowest (annually 204 incidences with 3,890 ha burnt area) in Gandaki Province. Among the provinces, Sudurpaschim Province stood second (annually 524 incidences with 26,366 ha burnt area) followed by Karnali Province (annually 396 incidences with 24,512 ha burnt area), Bagmati Province (Annually 312 incidences with 9,504 ha burnt area), Madhesh Province (Annually 287 incidences with 23,462 ha burnt area), and Province 1 (Annually 220 incidences with 8672 ha burnt area) (Figure 4).

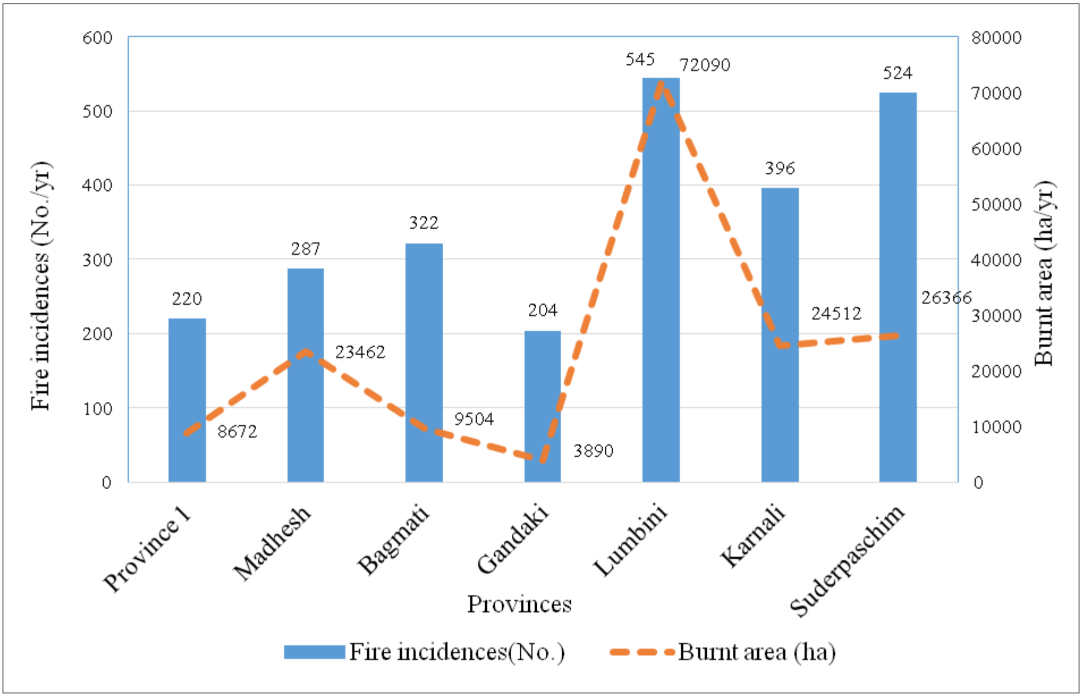

Figure 4: Annual Forest Fire Incidences and Burnt Area by Province

Forest Fire Risk Zones by Province

In terms of forest fire risk zone, among the seven provinces, the Tarai and Siwalik regions of the Sudurpaschim and Madhesh provinces were found to be at high risk in comparison to other provinces. This can be closely attributed to persistence of longer hottest days and large fuel accumulation in the forest. Similarly, the Tarai districts of Lumbini and Bagmati provinces showed high fire risk, while Karnali and Gandaki provinces stood in the medium risk category (Figure 5). The previous studies (Matin *et al.* 2017; Parajuli *et al.* 2020) have reported similar findings in regards to forest fire risk zones in Nepal. According to Parajuli *et al.* (2020), the forest of TAL area of Sudurpaschim, Lumbini, Bagmati provinces, and Madhesh provinces pose high fire risks, however, Province-1 stood in as a low-risk zone. Similarly, most of the districts of Tarai and Siwalik regions of Sudurpaschim, Lumbini, Bagmati and Madhesh Province have been reported to lie in very high and high forest fire risk zones (Matin *et al.* 2017). This is mainly linked to high surface temperature, low rainfall, and large amounts of accumulated fuels in the forests.

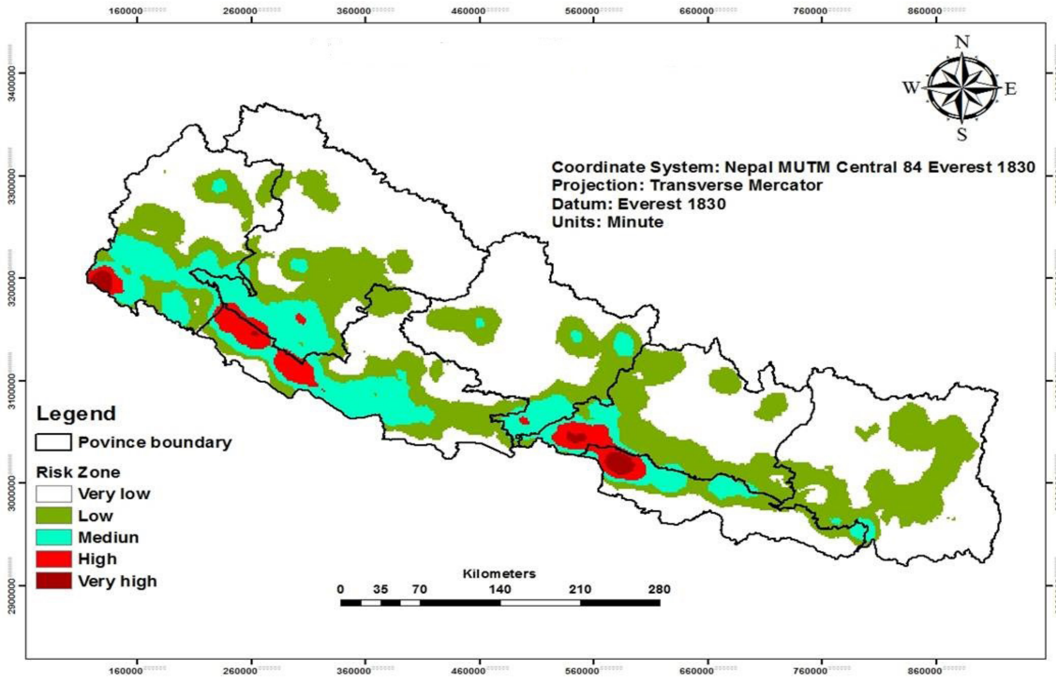

Figure 5: Forest Fire Risk Zones in Nepal

Environmental and Socio-economic Implications

Environmental Damage and Loss

In Nepal, during the period of 2001 to 2020, approximately 172, 040.65 ha of forest was damaged due to forest fire resulting around 7.07 million tonns (40.84 t/ha/yr) biomass loss (Table 1). Annually, large scale forest damage was found in the Tarai (4.74 ha/km^2) and Siwalik (4.65 ha/km^2) regions followed by the Mid-hills (2.09 ha/km$^{2)}$ and High Mountain and Himalaya (1.57 ha/km^2). Studies (Sibanda 2011; Bhujel *et al.* 2021) have reported loss of forest biomass and carbon due to forest fire in Nepal. According to Bhujel *et al.* (2021), leaf-litter, herbs and grasses have been severely damaged accounting to over 90 per cent biomass loss, around 0.01-0.4 per cent tree biomass, 2-5 per cent of pole size tree biomass and 5-10 per cent sapling biomass loss due to the surface fire.

With respect to carbon emission due to forest fire, annually about 3.30 million tons of carbon was found to be emitted during the period of 20 years (2001-2020). In terms of equivalent carbon emissions, the total annual CO_2 emission accounted to 12.12 million tonnes, 7.69 millions tonns CO, and 4.39 millions tonnes CH_4 (Table 2).

Table 2: Carbon Emission and Equivalent to CO_2, CO and CH_4 in 20 years

Total biomass loss (million tonnes/year)	Total carbon emission (million tons/ha/year)	Carbon convert equivalent to CO_2, CO and CH_4 (million tonns/year)		
		CO_2	CO	CH_4
7.07 (40.84 t/ha/yr)	3.30 (19.19 t/ha/yr)	12.12 (70.45 t/ha/yr)	7.69 (44.72 t/ha/yr)	4.39 (21.88 t/ha/yr)

Previous studies (Sibanda 2011; Bhujel *et al.* 2021) have reported carbon emission and its equivalent to CO_2, CO and CH_4 in different types of forests due to forest fire. Bhujel *et al.* (2021) have reported 2,360.56 tonnes per year biomass and 1,108.47 tons per year (0.4 t $ha^{-1}yr^{-1}$) carbon loss from 3,151.50 ha burnt forest due to the surface fire in the Lower Tropical Mixed-broadleaf Forest of Nawalparasi District during the period of 2000 to 2017. The carbon emission is equivalent to approximately 4066 t CO_2, 2581 t CO and 1474 t CH_4 emissions from 3158 ha burnt forests. Likewise, Sibanda (2011) has reported an average of 1669.0 tons/ha/yr carbon emissions from the forests of Ludikhola Watershed in Gorkha District.

Human Loss

In Nepal, forest fire occurrences are increasing in the recent years resulting in loss of human lives. According to the National Disaster Risk Reduction and Management Authority (2022)[4], loss of NPR 1890,000 (USD 15240.70[5]) was accounted during the period of 2020 and 2021 from forest fire. Over thousands of houses and cattle sheds in proximity to the forest was lost due to forest fire over the last 20 years period across the country. In total, 71 human lives have been reported to be lost during the 13 years period (from 2007 to 2020) in different areas of Nepal. Higher number human lives lost was reported during of the period of 2009 to 2016 (Table 3).

Table 3: Loss of Human Lives due to Forest Fire in Nepal

SN	Fiscal Year	No. of Lives Lost	Location	Remarks	Reference
1	2007	4	Bhairabthan Forest Palpa	General public	Nayapatrika, May 8, 2016
2	2009	49	Rammechhap Forest	Nepal Army, Others	Kathmandu Post, April 29, 2019
3	2016	15	Forests of Parbat and Gulmi	General public	Kathmandu Post, April 29, 2019
4	2021	3	Arghakhanchi, Salyan	General public	NDRRMA, Report 2021
	Total	71			

[4] http://drrportal.gov.np/

[5] USD exchange rate 124.01, 25-05-2022

In order to control forest fire and better manage the forest ecosystem, understanding the forest fire drivers is crucial. In Nepal, previous studies have reported an increase in forest fire caused by various natural and anthropogenic factors (Sharma 2006; Matin *et al.* 2017; Parajuli *et al.* 2020; Bhujel *et al.* 2021). Bhujel *et al.* (2021) reported the natural drivers of forest fire including temperature, precipitation, humidity, forest fuel (biomass), aspect, elevation, slope and lightening, and the anthropogenic drivers as forest distance from roads and settlements, wildlife poaching, non-timber forest product (NTFP) collection, smoking beehives, fuel-wood collection, camp-firing, cigarette butt, grass collection, throwing burning matches, trash fire and vehicular sparks. Bhujel *et al.* (2017) and Bhujel *et al. (*2018) have revealed that the climatic factors especially precipitation and humidity are significantly correlated with forest fire occurrence in Nepal.

CONCLUSION

This paper focused on the temporal and spatial distribution of forest fire and their enviornmental and socio-economic implication in Nepal. Over the past 20 years, the temporal and spatial forest fire incidences were found to vary with increase in fire incidences affecting enviornment and socio-economy. The active fire season and fire days are increasing in the recent years due to both natural and anthropogenic factors. The Tarai and Siwalik regions of Sudurpaschim Province, Madhesh Province and Lumbini Province are at very high forest fire risk. Annually, approximately 172,040.65 ha forest is damaged leading to 7.07 million tonnes biomass loss resulting 3.30 million tonnes carbon emission. Similarly, NPR 1890000 (USD 15240.70) was lost during 2020-2021. Likewise, 71 human casualties have occurred during 2007-2021 period. Relevant policies have provisioned to secure people's lives, public properties and forest ecosystem through awareness and enhanced capacity with necessary tools and techniques at the local level. However, there is a lack of implementation compounded by inadequate representative of the changing context of Nepal for sustainable forest fire management. Thus, for the protection of forests, properties and lives, strict forest fire mitigation policies and practices ensuring sustainable forest fire management are recommended.

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