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Effect of Climatic variables on fire incidence and burnt area in tropical forests in Nepal

KRISHNA BAHADUR BHUJEL[1*], REJINA MASKEY [2], AMBIKA P. GAUTAM [3] AND RAM ASHESHWAR MANDAL [4]

[1,2] Central Department of Environmental Science (CDES), Tribhuwan University (T.U), Nepal
[3] Kathmandu Forestry College, (T.U), Nepal
[4] Central Department of Botany, TU

**bhujelkb@gmail.com*

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ABSTRACT

This research was objectively done to correlate the climatic variables with the number of wildfire incidence and burnt area in Nawalparasi, Nepal. MODIS satellite data was used to detect the fire incidence and burnt areas. Climatic (temperature and humidity) data for 2000-2014 periods were obtained from Government of Nepal. The burnt areas of each year were clipped using Arc GIS to calculate the fire affected areas and number of incidences. Meanwhile, the correlation was evaluated to determine the relationship of climatic variables with the fire incidence and burnt area. The analysis showed that temperature and humidity of the study area varied throughout the active fire season (March to May). R^2 values were 0.0123 and 0.0260 of temperature with number of fire occurrence and brunt area respectively. R^2 was same nearly 0.0288 of the correlation of humidity with fire incidence and burnt area. The regression models were tested applying t-test ($p \leq 0.05$) for humidity with fire incidence and burnt area. The results showed that there was a clear relationship between wildfire and climatic factors, especially the humidity. The findings can be useful to establish baseline information for forest fire management in Nepal and other developing countries with similar ecological contexts.

Key words: Burnt area, climatic variables, fire occurrence, MODIS

INTRODUCTION

Wildfires are integral component of the earth system, which play key role in regulating vegetation structure and ecosystem functions (Balling, Meyer and Wells 1992). An increase in the number of wildfires and burnt area has been reported during the last decades in many parts of the world (Stocks et al., 1998) and (Flannigan, Stocks and Weber 2003; Brown JT 2004) . Fuel load inside forest governs the occurrence of fire along with the dryness of the fuel which indirectly determines the availability of fuel moisture (Chuvieco et al., 2004). Fire regimes are controlled by a very wide array of factors (Krebs et al., 2010). There is relation between patterns of fire and the climatic variables (Debnath et al., 2012)

Climate variables like temperature and humidity are two crucial drivers of fire activities. High temperatures and low humidity can cause fuel drying and hence an increase in fire occurrence. Climatic conditions affect the fuel accumulation and moisture, thus having an effect on the probability of a fire to occur as well as on its spread over the landscape (Syphard et al., 2008 and Vilar et al., 2010). The climatic factors have been emerged as evidence for wildfires, especially large wildfires (Piñol, Terradas and Lloret, 1998; Gillett, 2004 and Swetnam, 2006).

Global temperature has increased by ~0.2^{0}C per decade over the last three decades (IPCC, 2007). Nepal also experiences increase in mean annual temperature by 0.04^{o}C and 0.01^{o}C in maximum and minimum respectively during 1971-2012. The highest temperature was recorded in the Terai and Siwalik regions and the lowest in the High Himalaya region (Government of Nepal 2015). Nepal has experienced anomalous wildfire events in recent years including some transboundary fires (Government of Nepal 2010). Despite the fact that wildfire has been a major environmental problem, there is no systematic and complete record of the wildfire occurrence and their effects in Nepal (Bajracharya, 2001). In this context, the paper attempts to answer a key question: does the fire incidence and burnt area respond to climatic factors? Hence the study was carried out to identify correlation of climatic variables with the number of wildfire incidences and burnt area in Nawalparasi district of Nepal during period of 2000-2014.

MATERIALS AND METHODS

Study area

The study district is located in the Lumbini Zone in the Western Development Region of Nepal and lies within latitude 27^{o}21' to 27^{o}47' and longitude 83^{o}36' to 84^{o}25' covering an area of 2162 sq.km, The elevation ranges from 91m to 1936m above the mean sea level. About 55 % (122,365 ha.) of district land is under forest. *Shorea robusta* and Terai hard wood, Terai Hardwood forest, Riverine forest *Dalbergia sissoo* and *Acacia catechu* are the main forest types found in the district. *Shorea robusta* is the dominant species in 94% of the forest areas. Approximately 16% of the total area comprises mountain region and the remaining land include Siwalik (fragile small hills), Terai (flat lands) and Inner Terai (valleys in the Siwalik- foothills of the mountain) regions. The latter two regions have a gentle slope up to 15^{0}, while the Mahabharata (lower elevation hill) and Siwalik range bear steep slope 15-50^{0}. Most (61.7%) of the forests are located in the Siwalik. The Terai and hill regions have 22.45% and 15.98% forest covers, respectively. About, 6% of the forests have been handed over to local communities as community forest. The east-west national high way passes through the central part of the district. The study area has divided into three physiographical region such as Terai, Siwalik and hill where covers.

The study area is vulnerable to forest fire particularly during the summer months from March to April due to high temperature and very dry condition. According to District Forest Office (DFO), the occurrence of forest fire and its adverse effects on the forest services have increased in recent years; resulting in loss of forest products and adverse effect on the local economy.

Data sources and collection methods

Two types of data were collected and used in the research, including the Moderate Resolution Imaging Specto-radiometer (MODIS) of Terra and Aqua satellites observation data and the climatic data. The satellite data was downloaded free of cost from MODIS satellite image while climatic data for the period of 2000-2014 were acquired from the Department of Hydrology and Meteorology (DHM) Nepal. The active fire points are the past actual fire occurrences that have occurred in the area as recorded by MODIS of Terra and Aqua satellites. The past fire occurrences data, which provides the location and date of fire ignitions, were obtained from MODIS active fire products (version 5.1). Those point data in the form of shape files were then further analyzed in Arc Map 10.1. Point count by polygon method was used to identify the number of fire occurrences within the study area.

The burnt area related data was obtained from MODIS in the form of TIFF format containing burnt area pixels along with the burnt date information. The monthly level 3 gridded burnt area product (MCD45A1) of Terra and Aqua satellites were downloaded from the ftp server (ftp: //bal.geog.umd.edu/Collections5/TIFF/Win18/) for 15 years (2000 – 2014). Burnt area pixels within study district of Nepal were then extracted from the TIFF format using clip function processed in Arc Map 10.1. Again clip function was applied to extract district boundary shape file of study area. Meanwhile, the climate data (temperature and relative humidity) of the study area were collected as daily basis annual data from the Department of Hydrology and Meteorology for the period of 2000-2014. It was used to identify the climatic characteristics of study area in the spring season (March, April and May).

Data analysis

The data on fire incidences, burnt area and climatic variables over the 15 years (2000-2014) was analyzed using Microsoft Excel and SPSS 20 to find out trends, condition and its correlation between the wildfire occurrence, burnt area and climatic factors (temperature and humidity).The method adopted in data analysis is described in detail in the following sections.

Analysis of historical pattern of wildfire and climatic condition

The collected daily basis data of temperature and relative humidity was converted in to annual form by using the Microsoft Excel program. The mean, standard error, standard deviation, maximum and minimum of months of May, April and March over the 15 years period were analyzed by using the SPSS (version 20). The temporal data of climatic factors was graphically plotted by using Microsoft Excel tool. It helped explore the information of behavior of the climatic factors within the given period. The clip function was applied to extract district boundary shape file of study district. The number of wildfire occurrence and burnt area were extracted from the attribute tables of shape files. The extracted data was graphically analyzed by using the Microsoft Excel and SPSS (version 20).

Analysis of correlation between fire occurrence, burnt area and climatic variable

The relationship between the number of fires, burnt area against the climatic variable (temperature and relative humidity) of spring season (March, April and May months) was analyzed in SPSS 20 version. The linear regression was carried out to find the relationship between wildfire occurrence, burnt area and climatic variables. The mean, standard error, standard deviation, maximum and minimum range of temperature, humidity, number of fire occurrence and burnt area were analyzed by using the descriptive statistical tool. The value of Pearson correlation (r) and R^2 values were calculated by using liner regression and t-test at 5% level of significance to find out the relationship between mean temperature and relative humidity against the no. of fire incidence, burnt area of the study area.

RESULTS AND DISCUSSION

Climatic condition (Mean temperature and Humidity)

The March, April and May months comprise an active season in the study area. The mean temperature of March, April and May were 23.13°C, 28.80°C and 30.73°C, respectively. The (Fig.1a) showed the highest mean temperature in May, while it was lowest in

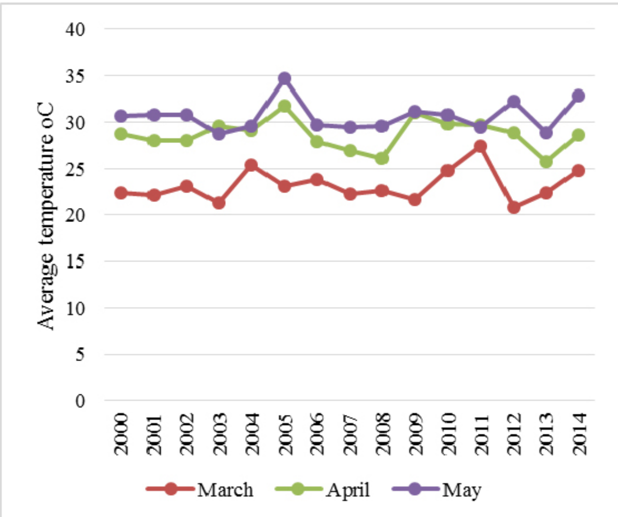

Fig.1a. Mean Temperature condition

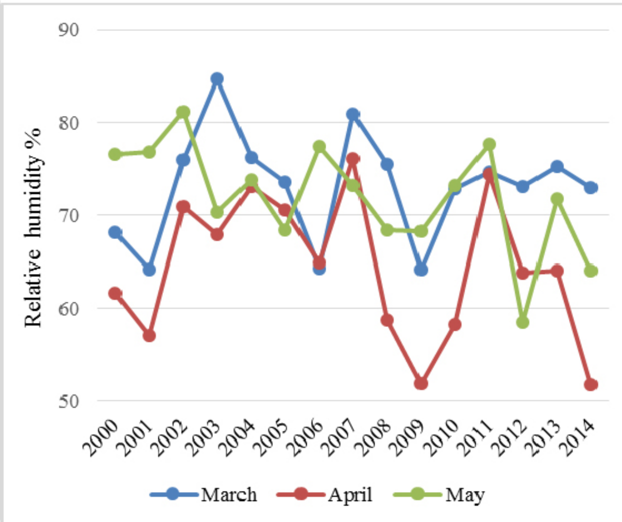

Fig. 1b. Average relative humidity in %

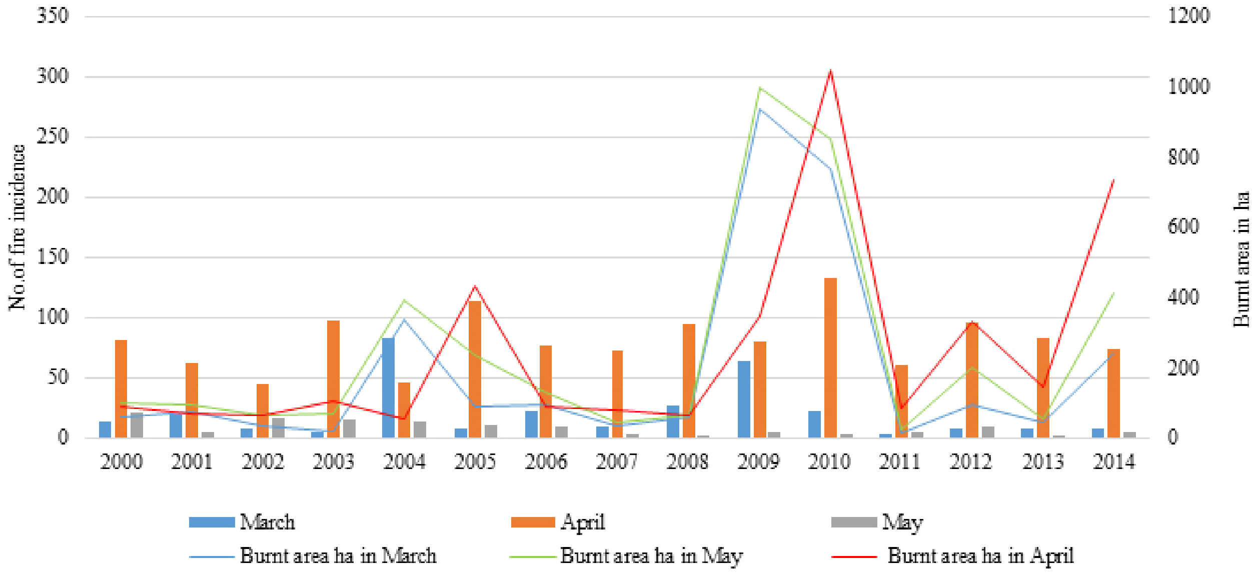

Fig. 2. Spatial and temporal no. fire incidence, burnt area

March. Meanwhile, relative humidity were recorded 73.13, 64.40 and 71.93% in of March, April and May respectively (Fig.1b). The lowest relative humidity was recorded 52 % in 2009 and 2014 years, which was followed by 2001 in April with 57%. The relative humidity was the highest in March and lowest in April. The overall condition of both climatic variables was found varying over the 15 years period in the study area.

Spatial and temporal status of fire incidence and burnt area

Trends of spatial and temporal fire incidence and burnt area of March, April and May months of 15 years showed that the number of fire incidence was the highest in April in comparison to March and May and same result was recorded for burnt area as well (Fig. 2).

The highest numbers of wildfire incidence noticed in April of 2003, 2005, 2009, 2010 and 2012 where other March and May months indicated lowest. The highest records of burnt areas were found in year 2005, 2009, 2010, 2012 and 2014. The 1,472 wildfire incidences and 4615.28 hectares forest burnt were recorded in the active fire season over the 15 years which constitutes 82.5% of total annual wildfire incidence and burnt area. The anomalous wildfire incidences were found during the active fire season (Fig. 2).

Statistics of temperature, humidity, number of fire occurrence and burnt area

The statistical result showed variation on the temperature, humidity, wildfire occurrence and burnt area of forest, resulting in instability of these variables. The maximum temperature (30.7°C) and humidity (73.1%) were recorded in May and March months while the highest mean number of fire occurrence (i.e. 81) and largest burnt area (248.5 hectares) occurred in April. It was indicated that April was higher affected month than other during the active fire season (Table 1).

Relationship of climatic variables with wildfire events

The regression fit line between temperature and forest fire incidence is presented in the (Fig.3a). This showed that the model y = 1.1684x + 4.134 whereas y denotes number of fire occurrence as dependent variable and x stands as independent variable for temperature. The R^2 = 0.0123 value showed positive relation between temperature and numbers of wildfire

9	*Celastrus paniculata* Willd. 1051	Celastraceae Balimi	Pengu	Shrub	Stem	Diaphoretic in rheumatism
10	*Centella asiatica* L. 1273	Apiaceae Sapajhara	Thalkuri	Herb	Leaf	Antidote to cholera
11	*Chloroxylon swietiana* Dc. 1038	Rutaceae Arjunjhari	Bheru	Tree	Leaf	Paste used to cure wound
12	*Cissampelos pareira* L. 1012	Menispermaceae Raipal	Akanbindhi	Shrub	Stem	Used as antiperiodic, diuretic, puragative and urinary troubles like cystitis
13	*Cissus quadrangula* L. 1044	Vitaceae Samala	Hadabhanga	Herb	Stem	Juice used in irregular menstruation,internode used in bone fracture.
14	*Colophyllum inophyllum* L. 1005	Clusiaceae Rohila	Polanga	Shrub	Seed	Oil mixed with hydnocarpus oil to treat rheumatic joints.
15	*Crateva magna* (Lour)Dc. 1010	Capparaceae Choraghati	Varuna	Tree	Leaf	Treatment of bronchitis,cough and abdominal tumours
16	*Desmodium gangetium* (L.)Dc. 1098	Fabaceae Raipal	Shalaparni	Shrub	Root	Diarrhoea,chronic fever, asthma and vomiting.
17	*Dillenia indica* L. 1610	Dilleniaceae Jambua	Oau	Shrub	Fruit	Juice used to treat weakness.
18	*Eclipta prostrata (L.)*L. 1284	Asteraceae Andhari	Bhrungaraj	Shrub	Leaf	Plant decoction with Stem paste of black pepper to treat fever.
19	*Grewia Tilliaceae subinaequalis* Dc. 1074	Pharisokoli Naunposi	Shrub	Root	Bark is	sed in rheumatism
20	*Gymnema sylvestre* (Retz.)R.Br. 1362	Asclepediaceae Jharbeda	Gudamari	Herb	Leaf	Powder used to treat diabetes
21	*Hydnocarpus laurifolia* (Denst.)Sleumer 1019	Flaucortiaceae Raipal	Chalmugra	Herb	Seed	Oil is applied in scabies .
22	*Ipomea mauritiana* Jacq. 1417	Convolvulaceae Tambur	Bhuin kakharu	Herb	Leaf Root	Treat tuberculosis
23	*Linum usitatissimum* L. 1032	Linaceae Chandposi	Alasi	Herb	Leaf	Powder used to treat gastritis.
24	*Mesua ferrea* L. 1027	Clusiaceae Phulabadi	Nageswara	Tree	Flower	Used to treat gistritis and stomach disorder
25	*Michelia champaca* L.1023	Magnoliaceae Raipal	Champa	Tree	Fruit Seed	Used for healing of cracks
26	*Mimusops elengi* L. 1329	Sapotaceae Shikheswari	Baula	Tree	Fruit	Used in curing dysentry
27	*Mitragyna parviflora* (Roxb.)Korth. 1279	Rubiaceae Jharalo	Kelikadamba	Tree	Flower	Used in fever and colic pain
28	*Melia azedarach* L. 1044	Meliaceae Gudapada	Mahanimbo	Tree	Flower Leaf	Applied to relieve nervous headaches
29	*Nyctanthes arbor-tristis* L. 1323	Oleaceae Mahurapani	Gangasiuli	Shrub	Bark,Leaf Flower	Cure malaria and stomach fever
30	*Nymphaea nouchali* Burm. 1003	Nymphaeaceae Jambua	Nilakain	Herb	Root	Powder used for piles, dysentry
31	*Olax scandens* Roxb. 1052	Olacaceae Chandposi	Bhadbhadalia	Shrub	Bark	Preparation used to restore blood during fever

Table 1. Statistical result showing variation

Variables	Months	Mean	Standard Error	Standard Deviation	Maximum	Minimum
Temperature (Degree Celsius)	March	23.1	0.44	1.72	27.00	21.00
	April	28.8	0.43	1.69	32.00	26.00
	May	30.7	0.43	1.66	35.00	29.00
Humidity (%)	March	73.1	1.56	6.04	85.00	64.00
	April	64.4	1.99	7.74	76.00	52.00
	May	71.9	1.51	5.87	81.00	59.00
No. of fire	March	20	5.92	22.94	83.00	3.00
	April	81	6.18	23.94	133.00	44.00
	May	8	1.51	5.87	21.00	2.00
Burnt area ha	March	56.5	21.36	82.74	274.00	4.00
	April	248.5	75.68	293.13	1045.00	55.00
	May	16.3	3.79	14.68	50.00	1.00

occurrence. The p values ($p \geq 0.05$) showed the temperature was insignificantly correlated with the incidences of wildfires.

The result of relationship between temperature and burnt area is presented in the (Fig. 3b). It showed the equation y = 8.5231 x - 122.81 whereas y denotes burnt area as dependent variable and x stands as independent variable for temperature.

The R^2 value of regression fit line between temperature and burnt area was 0.022 which showed positive relationship between temperature and numbers of fire occurrence. The value ($p > 0.05$) showed insignificant relationship between temperature and forest burnt area.

The Fig. 4a showed equation y= -2.5423x + 214.03 whereas y denotes number of fire occurrence as dependent variable and x stands as independent variable for humidity. The regression fit line with humidity and number of fire occurrence indicated negative relationship with R^2= 0.2621.The value ($P<0.05$) showed the correlation exists significantly between humidity and fire incidences.

The Fig. 4b showed equation y= -14.84x + 1149.3 whereas y denotes burnt area as dependent

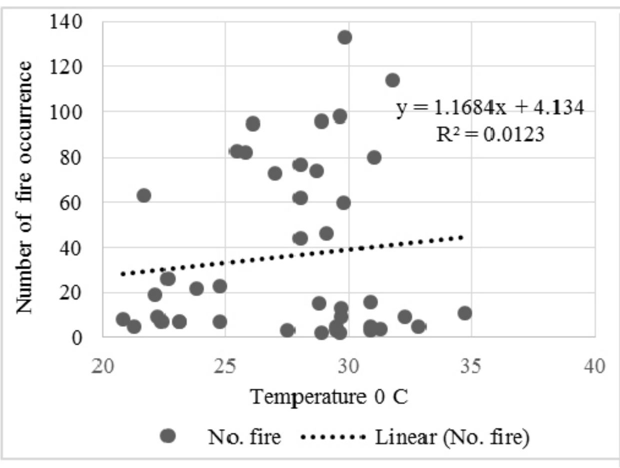

Fig. 3a. Relationship between temperature and number of fire occurrence

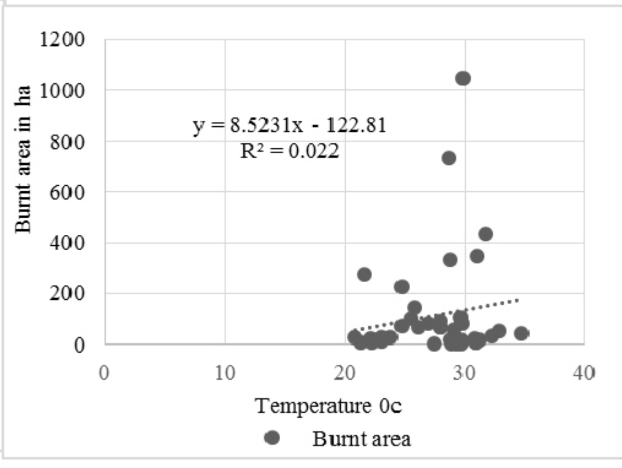

Fig.3b. Relationship between temperature and forest burnt area

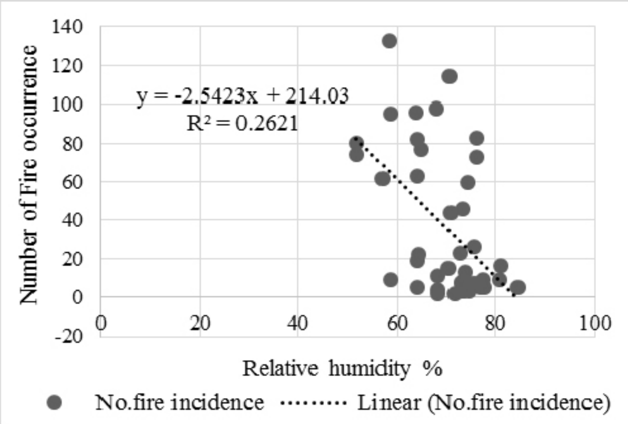

Fig. 4a. Relationship between humidity and numbers of wildfire occurrence

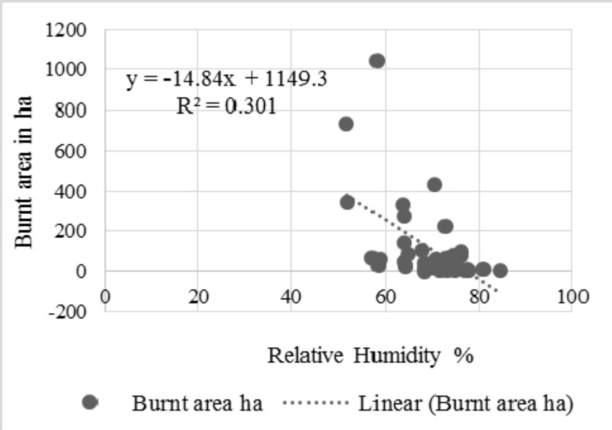

Fig. 4b. Relationship between humidity and burnt area

variable and x stands as independent variable for humidity. The regression fit line between humidity and burnt area was negative relationship having R^2 (0.301). Likewise, the value $p<0.05$ indicated the significant relationship.

DISCUSSION

This results showed the variation in the mean temperature which indicate a slight but definite warming trend in the mean temperature in the active fire season (pre-monsoon season). The study report of climate and climatic variation over Nepal (Government of Nepal, 2015) also showed the increasing trends of mean temperature between the periods of 1971-2012 in the entire country which was similar to this research findings. The (IPCC 2007) report also showed that future global temperatures will be warmer than current levels, resulting an increase in the drought areas creating favorable environment to wildfire activity which statement supported to this research. Similarly temperature change is also found in most parts of the China (Tang et al., 2010). Spatial and temporal analysis of rainfall and temperature trend of India study report showed the temperature fluctuations and increase significantly (Mondal, Khare and Kundu, 2015). Both results corroborate with our research findings.

The relative humidity also found to vary during March, April and May months. The lowest humidity (64.40%) was found in April month. The research finding was consistent with Alexandrose Dimitrakopoulos 2011, whose result showed the large fire incidents occurred during the heat waves (higher air temperature and lowest humidity). It was supported by Urbieta et al., 2015 result which indicated low humidity in April was the indication of favorable fuel as well as the hot temperature being suitable for ignition and expansion of the fire.

The number of fire incidence and burnt areas increased annually. The April month was found with highest number of fire incidence and burnt area during the fire active season. The finding was consistent with study of Kiran Chand et al., 2006 which showed higher numbers of forest fires incidence occurred in the mixed deciduous forests in central Indian range during the March– April. Bowman et al., 2017, study result indicated that the extreme wildfire events were globally distributed across all flammable biomes which supported this result.

The present research showed the positive relationship between number of fire occurrence and burnt area with the mean temperature. Meanwhile, it depicted negative relationship between humidity and number of fire occurrence as well as burnt area. The relationship coexists between wildfire and climatic factors, especially with the humidity. A research done by Khanal, S., 2015, showed that there was strong relationship of climatic variables with fire activity in Nepal. Another research by Srivastava, 2013, showed that the positive correlation exist between incidences of fire with temperature in tropical dry deciduous forest of India. Similarly, other research done by authors Swetnam, 2006 and Kodandapani, 2004, emphasized that the number of wildfires and burnt areas were increased in different terrestrial ecosystems across the globe. It can be said that three months like March, April and May are active fire season.

CONCLUSION

The climatic variables particularly temperature and humidity are the key factors affecting forest fire incidence and burnt area. The higher mean temperature and the lowest humidity cause increased long spell of dryness leading to low moisture in the combustible material which favor increase in fire incidents. The month of April showed the highest numbers of fire incidence and burnt area, which was followed by March. The relationship coexists between wildfire and climatic factors, especially with the humidity. The findings are expected to be useful for managing forest fires, with similar ecological contexts. Further research in this context is necessary to establish baseline information for wildfire management planners, early fire warning system and sustainable forest management.

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