Wildfire Dynamics and Occasional Precipitation during Active Fire Season in Tropical Lowland of Nepal

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ABSTRACT

Occasional precipitation plays a vital role in reducing the effect of wildfire. This precipitation is especially important for countries like Nepal, where wildfires are a common seasonal event. Approximately 0.1 million hectare of forest area is affected annually due to wildfires in active fire season. The study on the relation of these forms of occasional precipitation with wildfire incidence is still lacking. This research was objectively carried out to examine the correlation of occasional precipitation with wildfire incidence and burnt area. The Moderate Resolution Imaging Spector-Radiometer (MODIS) satellite images and precipitation records for 15 years gathered from Department of Hydrology and Metrology were used as input data for this study. The images were analyzed by using ArcGIS function while the precipitation records were analyzed by using Statistical Package for the Social Science (SPSS) program. The linear regression model was applied to find correlation of occasional precipitation with wildfire incidence and burnt area. Analysis revealed decreasing trend of precipitation in study area. We found significant correlation ($p<0.05$) of precipitation with wildfire incidence and burnt area. Findings will be useful for policy makers, implementers and researchers to manage wildfire in sustainable basis.

1. INTRODUCTION

The Intergovernmental Panel on Climate Change showed that global warming has been a challenge for living beings in the world. Biodiversity loss, desertification and food insecurity are major negative impacts of climate change (IPCC, 2015). However, there are more impacts like increasing incidence of fires inside and outside forests at the micro level. The increasing days of warming cause fewer rainy days in monsoon and other seasons. Warming helps to dry the fuel in the forest which leads to fire incidence. Occasional precipitation, which can be defined as precipitation occurring at irregular or infrequent intervals in active fire season, assists to reduce the fire incidence and its effects.

Wildfire frequency, seasonality, intensity and extent are variables that are more likely to control forest distribution (Foster et al., 1998). Fire behaviors are affected by various factors, such as weather conditions, human activities, fuel characteristics, and land use dynamics. Wildfires are considered as one of the major forces shaping Mediterranean landscape and controlling vegetation communities' succession and structure (Millington et al., 2009). Wildfires also contribute to the development of the pattern of vegetation succession, the rate of which largely depends on the prevailing plant traits (Mouillot et al., 2003). Among these factors, climate change is considered to be a key factor attributing to wildfires regime. Climate is of fundamental importance in defining the conditions that permit fire. Thus, climate helps to shape geographic patterns of fire (Krawchuk et al., 2009).

Temporal variation in precipitation at seasonal, inter-annual, and inter-decadal timescales is widely recognized as a major driver of variation in wildfire frequency and extent in fire-prone regions (Swetnam and Betancourt, 1990). Fire frequency is expected to increase with human-induced climate change, especially where precipitation remains the same or is reduced (Stocks et al., 1998). A general but moderate increase in precipitation, together with increased productivity favors generation of more flammable fine fuels. The investigation of the role of either fuel or climate on the occurrence of large wildfires has been mainly based on the assumption that these are either limited by (a) climate or (b) fuel accumulation (Meyn et al., 2007). Models relating fire activity to weather parameters contribute to improve the understanding of the underlying mechanisms behind fire regimes and provide valuable information for fire management.

Nepal has been experiencing irregular wildfire events in recent years including trans-boundary wildfire and haze pollution (Government of Nepal, 2010). Around 0.1 million ha of forests are annually affected due to wildfire. The active fire season in the country ranges from March to May. There is no systematic and complete record of wildfire occurrence and their effects in Nepal (Bajracharya, 2001). Extreme climatic conditions have led to increased incidence of wildfire in recent years (MoE/GoN Nepal, 2010). The wildfire problems are acute for three to four months during the dry period between March and June every year (Bajracharya, 2002). Repeated incidence of fire has resulted in changes in many Terai forest ecosystems (Kunwar and Khaling, 2006). Community based fire management could be the key to overcome the recurring problems of forest fires in Nepal (Sharma, 2006). The precipitation pattern of Nepal is dominated by the presence of the monsoon circulation and its interaction with the topography, and the Siwalik and the Terai belt which generally receive less total seasonal rainfall compared to the middle hills (Kansakar et al., 2004). Of the total 75, 30 districts that are mostly allocated in the Siwalik and Terai region fall in high forest fire risk classes (Matin et al., 2017).

Developing countries like Nepal are still lacking research on the relation of the occasional precipitation with wildfire incidence including others parameters. Moreover, there is poor database management and lack of a clear understanding about the relation of climatic variables especially with the occasional precipitation and its severity of forest resources in the lowland of country. The context is complex and, therefore, several questions are raised. Specifically, what are the characteristics of occasional precipitation, and is there a relationship between precipitations and wildfire incidence including burnt area? This research was carried out to examine the relationship between the occasional precipitation and wildfire incidence, and burnt area in active fire season in one of the wildfire-prone districts, during the years 2000 through 2014.

2. METHODOLOGY

2.1 Study area

The study was conducted in Nawalparasi district located in the western lowlands of Nepal within latitude 27^{o}21' to 27^{o}47' and longitude 83^{o}36' to 84^{o}25' (Figure 1). The altitude ranges from 91 to 1936 m above average mean sea level. Terai and foothills of Siwalik are considered as low land (DFRS Nepal, 2015). It covers an area of 2,162 km^2, which is 1.5% of the total area of Nepal. About 55% (122,365 ha.) of the district is under forest cover. This study area was divided into three physiographic regions namely Terai, Siwalik and Hill which cover 22.5%, 61.6% and 16% of the district areas respectively. The Siwalik is a narrow strip of fragile hills extending east-west in between the Terai and Hill. The Terai is a fertile, flat land to the south of Siwalik. The Terai and Siwalik regions have a gentle slope up to 15^{o}, while Hill range bears steep slope 15^{o} -50^{o}. There are four types of forest, namely lower tropical Sal (*Shorea robusta*) forest, Sal hill forest, and two Riverine forests (*Dalbergia sissoo* and *Acacia catechu*). Most of the forests are located in the Siwalik and Hill regions. The area is vulnerable to wildfire particularly during the summer season (March to April) when conditions are very dry, thereby causing loss of forest products and environmental degradation of forest.

2.2 Data sources and collection methods

Active fire data from the Moderate Resolution Imaging Spectroradiometer (MODIS) device on NASA’s Terra and Aqua satellites dating from 2000 to 2014 was used as the main data source for mapping and analyzing the wildfire incidences. The resolution of MODIS image is 1 km × 1 km which records four fire incidence observations per day, basically on 1030 and 2200 h from Terra and 0130 and 1330 h from Aqua. The coordinates of wildfire points and the date of wildfire incidence can be obtained free of cost from the MODIS active fire products (version 5.1). Those obtained point data from https://firms.modaps eosdis.nasa.gov/download/, in the form of shape files, were further analyzed in Arc Map 10.1.

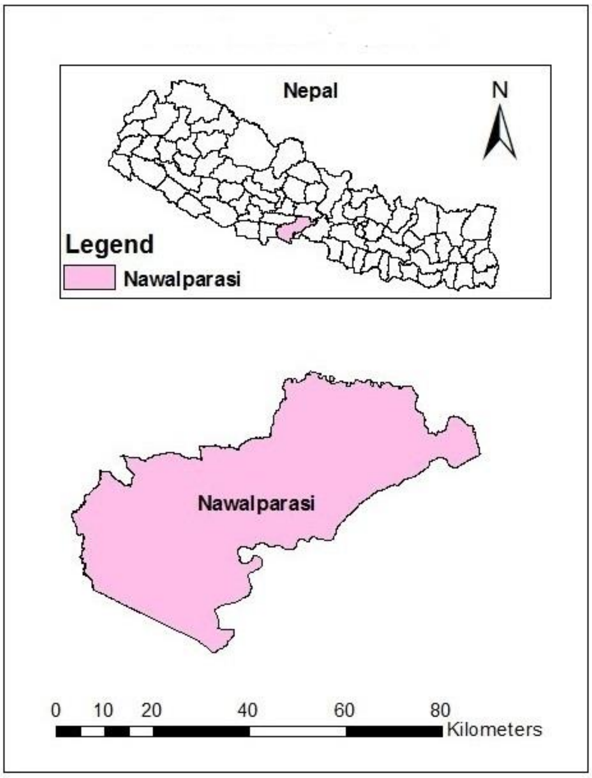

Figure 1. Location of study area

MODIS also provides the data related to burnt area in the form of GEOTIFF images with clearly distinguished burnt area pixels (including burnt-date information) from other adjacent pixels. The monthly level 3 gridded (500 m) burnt area product (MCD45A1) was downloaded from the ftp server (ftp://ba1.geog.umd.edu/Collection5/TIFF/Win18/). Burnt area pixels within the study area were then extracted from the TIFF images, processed in Arc Map 10.1 and the monthly burnt area data throughout the study period was calculated and analyzed. The accuracy of burnt area and number of wildfire incidence was checked by comparing with the general accuracy statement of MOD14 product performance and direct filed observation.

2.3 Data analysis

The collected data of wildfire incidence, burnt area and climatic variable over 15 years (2000-2014) was analyzed using Microsoft Excel and SPSS 20. The trend analysis and linear regression model were used to find the dynamics of occasional precipitation and its relation with wildfire incidence and burnt area. The wildfire point locations were further analyzed in Arc Map 10.1. Point count by polygon method was used to identify the number of wildfire incidence in the study area. Burnt area pixels within study area were then extracted from the TIFF images using clip function processed in Arc Map 10.1. Again clip function was applied to extract district boundary shape file of study area and then calculated the burnt area.

The daily data of the average annual occasional precipitation was compiled for three months of active fire season over the study period. The temporal data of average occasional precipitation was graphically plotted by using Microsoft Excel. The dynamics of occasional precipitation was demonstrated by trend lines especially in the month-wise and total average occasional precipitation of three months of active fire season. The records of numbers of wildfire incidence and burnt area of active fire season were presented in the bar graphs and lines for showing the historical patterns of wildfire incidence.

The relationship between wildfire incidence and burnt area against climatic variables, especially occasional precipitation, of active fire season was analyzed. The linear regression was used to find the relationship between precipitation and wildfire incidence including burnt area. The mean, standard error, standard deviation, maximum and minimum range of precipitation, number of wildfire incidence and burnt area were analyzed by descriptive statistical tool. The value of Pearson correlation (r) and r^2 were calculated and t-test was done at 5% level of significance to find out the correlation between occasional precipitation against the number of wildfire incidence and burnt area.

The validation was done to compare the research findings with other similar research works (Nickeson, 2016; Morisette et al., 2005; Csiszar et al., 2006). Moreover direct field observation and consultation with related key persons were carried out for validation purpose.

3. RESULTS AND DISCUSSION

3.1 Trends of precipitation in active fire season

The highest monthly total precipitation (562 mm) during the active fire season was found to occur in May and lowest (0 mm) in March and April over the 15 year period. On average, the active fire season precipitation was very low in year 2003, 2007, 2008, 2012 and 2014 (Figure 2(a)). The total precipitation during active fire season was only 11% of the total annual precipitation during the 15 years, which was comparatively lower than total pre-monsoon precipitation (12.5%) of Nepal (Government of Nepal, 2015). In fact, the trend of total average precipitation during active fire season showed decreasing order (Figure 2(b)), indicating long precipitation-free intervals with low moisture in the fuel of forest provides a favorable environment for burning.

Our research findings are consistent with the findings of Lafon and Quiring (2012), which indicated that the precipitation regime with long precipitation-free intervals would generate more days per year that favors burning. A study done on precipitation trend in Kerela, India showed that the record of precipitations vary according to month, season and days (Krishnakumar, 2009). The total average precipitation and precipitation days were found to have decreasing trends in China (Song et al., 2011). A similar study was done in India, showed that there was decreasing trend of precipitation in the long term (Kumar et al., 2010). The findings of these past studies are consistent with our findings.

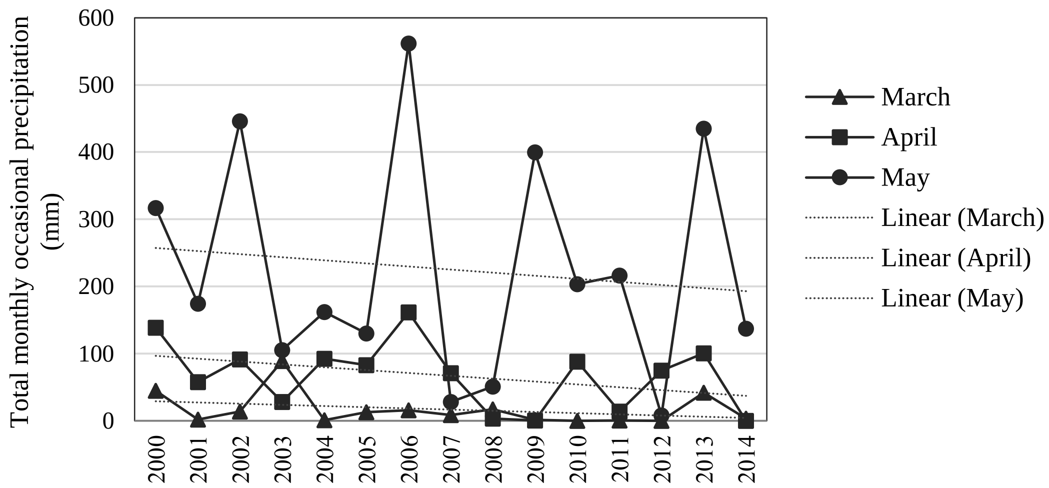

Figure 2(a). Status of precipitation in active fire season

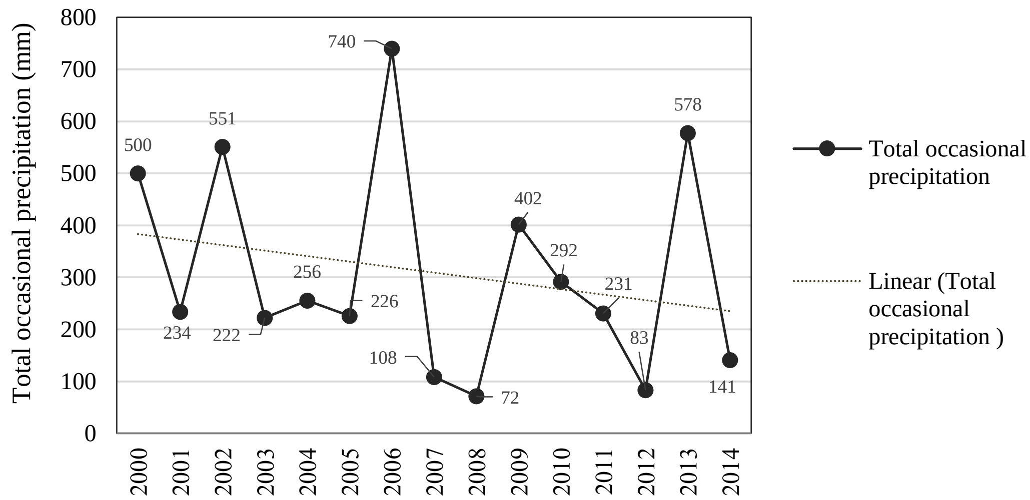

Figure 2(b). Trends of total precipitation in active fire season

3.2 Trends of forest fire incidence and burnt area

The incidence of wildfire varied widely during the active fire season (Figure 3). The highest numbers of wildfires were recorded in April of 2003, 2005, 2009, 2010 and 2012, while the lowest records were found in March and May. The highest coverage of burnt areas were found in years 2005, 2009, 2010, 2012 and 2014. The number of wildfires and burnt areas showed an increasing trend. In total, 1,472 wildfires and 4615.28 ha of forest area burnt were recorded in the active fire season in the 15 years, which constitutes 82.5% of total annual wildfires and burnt area. The number of wildfires and burnt areas increased annually. The highest number of wildfires and burnt areas were recorded in April. The finding was similar with the findings of Srivastava and Garg (2013), which also showed the higher incidences of wildfires in March and April in India due to the long spell of dryness and increased wildfire incidence caused by the reduction of precipitation. Moreover, extreme wildfire events are globally distributed across all flammable biomes and are strongly associated with extreme fire weather conditions (Bowman et al., 2017).

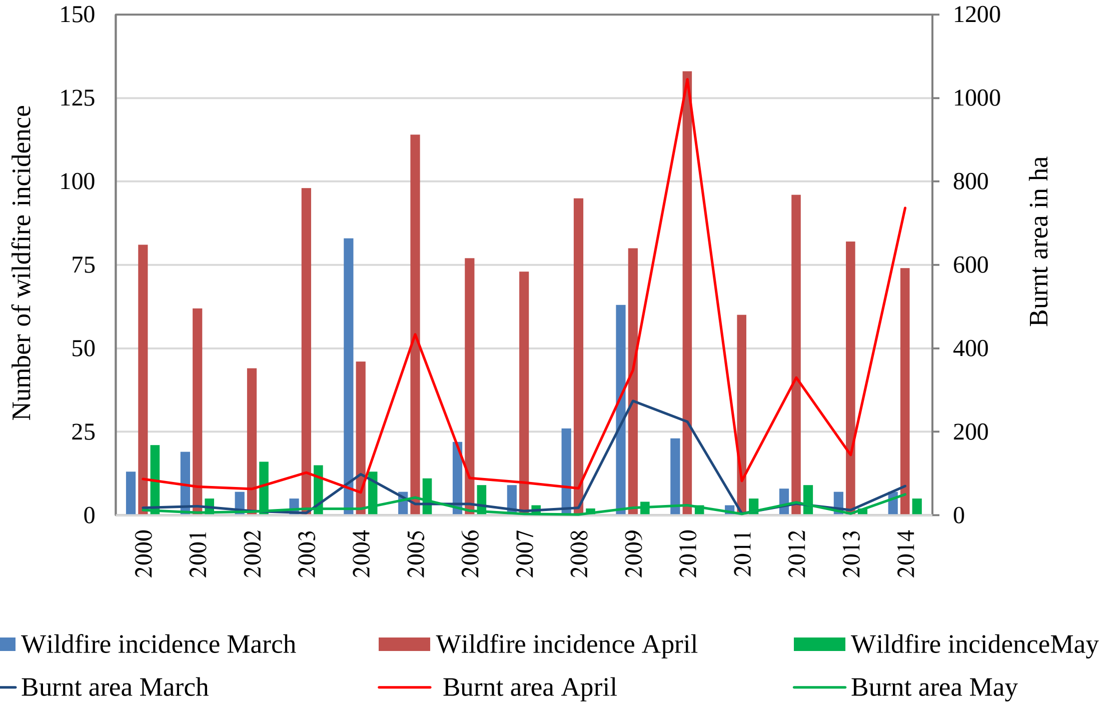

Figure 3. Trends of forest fire incidence and burnt area

3.3 Descriptive analysis of precipitation, wildfire incidence and burnt area

The highest mean occasional precipitation (about 225 mm) was recorded in May while the lowest (nearly 17 mm) observed in March. The highest mean values of wildfires and burnt areas were 81 fires and 248 ha respectively in April. The lowest mean values of wildfires and burnt area were 8 fires and 16.26 ha, respectively that occurred in May (Table 1). The variation of these parameters indicated the instability of occasional precipitation pattern and wildfire behavior.

Table 1. Description of precipitation, wildfire incidence and burnt area

Variables	Months	Mean	Std. Deviation	Std. Error	Minimum	Maximum
Precipitation	March	17.00	24.48	6.32	0	89
	April	67.00	49.73	12.84	0	162
	May	225.00	169.02	43.64	8	562
Number of wildfire incidence	March	20.13	5.92	22.94	83	3
	April	81.00	6.18	23.94	133	44
	May	8.20	1.51	5.87	21	2

Table 1. Description of precipitation, wildfire incidence and burnt area (cont.)

Variables	Months	Mean	Std. Deviation	Std. Error	Minimum	Maximum
Burnt area	March	56.46	21.36	82.74	274	4
	April	248.46	75.68	293.13	1045	55
	May	16.26	3.79	14.68	50	1

3.4 Relationship between precipitation with wildfire incidence and burnt area

The regression equation was $y = -0.0691x + 43.56$, which was derived between monthly occasional precipitation and wildfire incidence. In this equation, y indicates number of wildfires and x denotes monthly occasional precipitation of active fire season. Similar equation like $y_1 = -0.2859x_1 + 136.47$ was derived between annual average precipitation and burnt area, where y_1 is burnt area and x_1 stands for monthly occasional precipitation of active fire season. The r^2 values were 0.0617 and 0.0360 of wildfire incidence and burnt area (Figure 4(a) and 4(b)). These values showed the weak and negative relationship between occasional precipitation and wildfire incidence (Figure 4(a)). A similar relation was found between occasional precipitation and burnt area in active fire season (Figure 4(b)).

A t-test was conducted to examine the correlation between occasional precipitation and wildfire incidence and burnt area in active fire season. The p values for the estimated coefficients of occasional precipitation were 0.000 and 0.001 respectively (Table 2), indicating that precipitation was significantly correlated with the wildfire incidence and burnt area.

Table 2. Relationship equation values

Relations	t-test (P-value)	
	constant	Slope
Precipitation and fire occurrence	0.000	0.000
Precipitation and burnt area	0.001	0.001

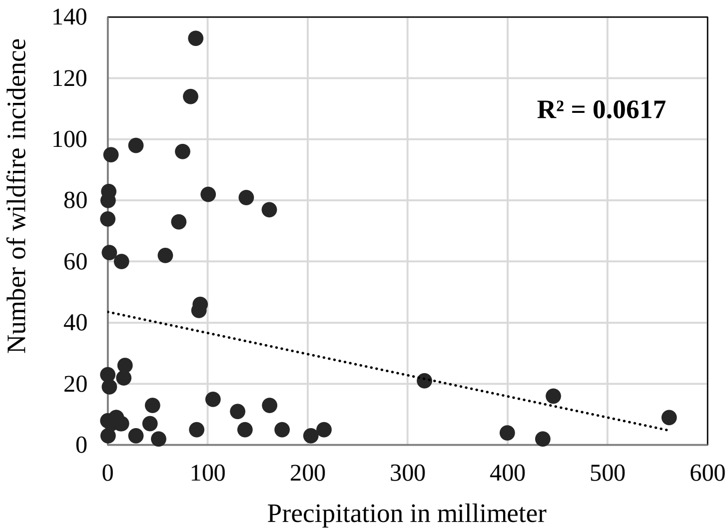

Figure 4(a). Relationship between precipitation and wildfire occurrence

The correlation between climatic factor (precipitation) and wildfire activities, like incidence and burnt area, indicated the significant effect of occasional precipitation on wildfire incidence and burnt area. This is consistent with the findings of Chen et al. (2014), which had indicated significant relationship between occasional precipitation and wildfire activities in the five eco-regions of Yunnan in China. Moreover, (Ponomarev et al., 2016) showed significant correlations were found between forest fires, burned areas and precipitation in the Siberian Larch Forest. Similar results were found by other authors like Khanal (2015), Good et al. (2008) and Littell et al. (2009) which indicated strong relationship between climatic variables and number of wildfires and area burned.

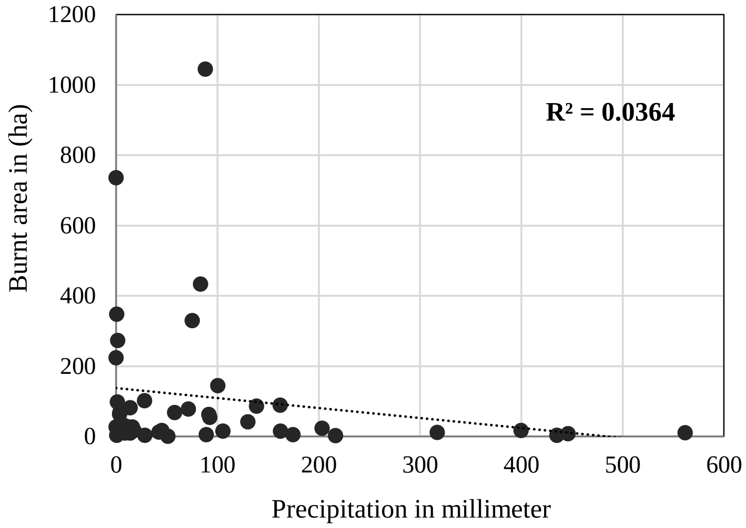

Figure 4(b). Relationship between precipitation and burnt area

4. CONCLUSIONS

The occasional precipitation was found to be the highest in March and lowest in April. The lowest occasional average precipitation showed decreasing trends in active fire season over 15 years period. The number of wildfires and burnt areas showed increasing trends over the same period. The highest numbers of wildfires were noticed in April of 2003, 2005, 2009, 2010 and 2012. There was a significant correlation between precipitation and wildfire activities (viz., number of wildfires and forest burnt area). The occasional precipitation variable affects the wildfire activities in the study area. The findings can be useful to both the policy makers and local forest managers for developing pre-fire alert system, preparedness for fire control and mitigation, and managing wildfires in the field.

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