


Role of Climatic Variables on Forest Fire in the State of Mizoram



Dhruval Bhavsar , Kasturi Chakraborty, Jakesh Mohapatra, K. K. Sarma, and S. P. Aggarwal

Abstract In a view of increasing fire incidences and risk of climate change on the ecosystem, current study has been carried out in Mizoram state of north east India which is one of the fire-prone states in the country. The study is carried out to analyse the effect of climatic variables (precipitation, temperature and humidity) on forest fire occurrence using trend analysis (MK test) and spatial relation between the two. Active fire points (MODIS) from 2003 to 2020 and gridded climate data (ERA 5 & FLDAS) were used for spatial analysis. Significant (at 95% confidence level) trend analysis showed an increase in temperature (1.97–3.03) and humidity (1.98–3.18) in monsoon and post-monsoon seasons. Precipitation was observed to decrease in September for Lawngtlai (−2.05) and Mamit (−1.97). Overall forest fire occurrence in the state was found to be decreasing while spatial analysis over the state showed an increasing trend in parts of Mamit, Lunglei and Lawngtlai districts. The same region was found to have negative relation for temperature in winter season while rest of the state had positive relation with fire occurrence. Precipitation and humidity both were having negative relation to forest fire occurrence with exception of areas mentioned earlier, with positive relation in winter, premonsoon (precipitation) and monsoon seasons (humidity). Despite the major role of anthropogenic activities in forest fire in the state, the variability in results suggests that forest fire occurrence may be due to the response of climatic conditions, but it is restricted to certain areas.

Keywords Forest fire · Temperature · Precipitation · Humidity · Climate trend

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1 Introduction

Forest fire is a natural component of forest ecosystems but becomes dangerous when uncontrolled. Recently, the frequency and intensity of forest fires have increased throughout the world and hence, have become a threat to the biodiversity and lives of people living in the vicinity of forests. While fire can be important for maintaining ecosystems processes and vegetation in some ecosystems, e.g. savannahs and grasslands [45], it is now occurring more frequently in ecosystems that rarely experience large fires (e.g. tropical forests). An increase in the frequency and intensity of wildfires [48] especially in ecosystems that are not adapted to fire, could lead to lasting changes in vegetation structure and composition [10, 35], wildlife populations [5, 31], soil erosion [39] soil nutrient status [7], atmospheric chemistry and biogeochemical cycles [27] and the benefits humans derive from these landscapes [47]. Precious forest resources including carbon locked in the biomass are lost due to forest fires every year, which adversely impact the flow of goods and services from forests.

Globally, only around 4% of all forest fires have natural causes such as lightning. In the remaining cases, human activities are responsible for the fires directly or indirectly [19]. However, the changes in patterns and increasing intensity of fires are attributed to two factors: climate change-driven changes in extremes [13, 26] and widespread land use change [3, 4, 12], including and especially increasing anthropogenic ignitions [6, 9]. The interaction between climate change and forest fire is like a feedback system. As climate change has an impact on forest fire, the forest fire may also have an impact on climate change. There is mounting evidence that forest fires will increase in number and size due to different impacts of climate change such as increased frequency and intensity of El Niño due to an increase in temperature [29, 43] and climate stress [49]. Effect of trace gas emissions in forest fire have also been well documented on long-term climatic response [42]. High summer temperature, high wind velocity, steep terrain and availability of inflammable material in the forest account for major damage and extensive spread of forest fire [17]. The combination of these factors can cause rapid and intense fire. Such wildfires have become increasingly common in some parts of the world in recent past—California (2017 and 2018), Canada (2014, 2017 and 2018), the Mediterranean (2017 and 2018), Siberia (2003, 2012 and 2019), Australia (2009, 2013 and 2019) and India (2016, 2018 and 2020). The observations from 1987 to 2007 show that the increasing intensity and spread of forest fires in Asia were largely related to rise in temperature and decline in precipitation in combination with increasing intensity of land uses [21].

In India, forest fire is a major cause of forest degradation and particularly in tropical forests as it is a recurrent phenomenon [2]. Based on the forest inventory records by Forest Survey of India (FSI), 54.40% of forests in India are exposed to occasional fires, 7.49% to moderately frequent fires and 2.40% to high incidence levels, while 35.71% of India's forests have not yet been exposed to fires of any real significance [14]. Overall, 22.27% of the total forest cover of India is prone to forest fire from high to extreme level [22]. The Himalayan region has also reported increased fire frequency due to long dry spells of winter and increased temperature

as a result of climate change [1]. An analysis on loss from forest fire in India was estimated to be Rs. 440 crore annually [8]. Incidents of fires in Indian forests are increasingly threatening the valuable biodiversity and genetic resources [37].

North East India, one of the biodiversity hotspots of the world, contributes significantly (about 16%) to the total fire occurrence of the country [22]. The tribes of northeast India practicing jhum (shifting cultivation) have unique and varied community traditions. In practice forest is cut and then burned for agriculture which is also called as slash and burn agriculture. Jhum is the major factor for forest fire in the region. Within the north eastern states of India, Mizoram is highly prone to forest fire. Around 76% of the forest cover of Mizoram is under very high to extreme fire-prone category which is highest in the country [22]. Climate change study on Mizoram observed an annual rise in temperature by 0.01 °C since 1951 to 2010. Rainfall in Mizoram during May–August was found to be increasing while during the other months in a year showed a decreasing rainfall departure trend [20]. Earlier studies on climate change and forest fire are either based on non-spatial data or limited to only trend analysis. This gap in the information guided to carry out the present study in the state of Mizoram.

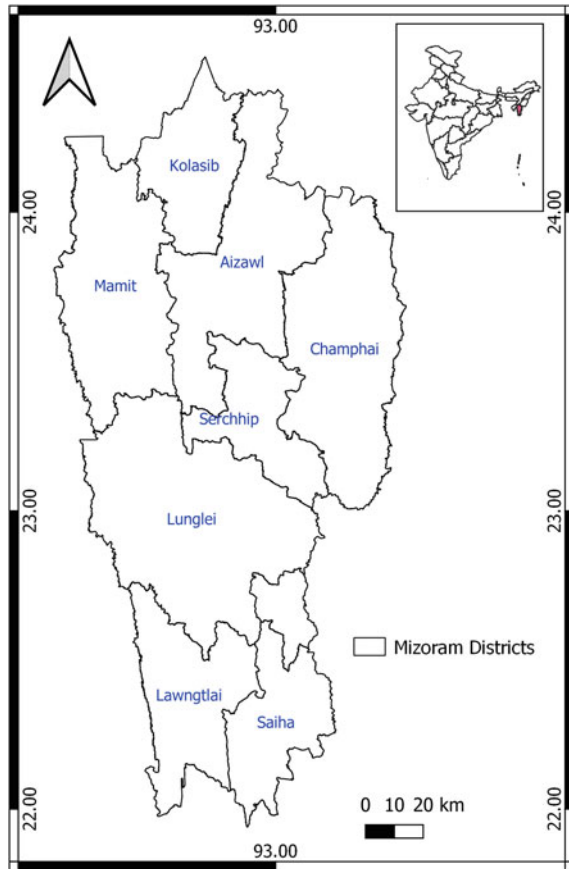
The present study is aimed to analyse the effect of climatic factors (precipitation, temperature and humidity) variation on forest fire occurrence. Spatial trend of climate variable was carried out to understand the distribution pattern. The relation between forest fire occurrence and climate variable was also estimated to understand role of climate in forest fire.

The chapter encompasses different sections where location and description of the study is presented in study area. Material and methodology section describes the source of data and procedure followed to develop relation between forest fire and climate data. In the next section results of trend analysis, spatial relation was presented. The inference of the result is explained in discussion and conclusion section.

2 Study Area

Mizoram has been considered as a study area which is a part of north eastern states of India. It is southernmost landlocked state of north east, sharing borders with Tripura, Assam and Manipur. The state also has 722 km border with neighbouring countries of Bangladesh and Myanmar. The geographical location of Mizoram lies between East Longitude 92°15' and 93°29' and North Latitude 21°58' to 24°35' and its total geographical area is 21,087 km² (Fig. 1). Geography of Mizoram consists hills, valleys, rivers and lakes. Mizoram has a mild climate, comfortable in summer 20 °C to 29 °C and never freezing during winter, with temperature from 7 °C to 21 °C. The region is influenced by monsoons, raining heavily from May to September with little rain in the dry or cold season. The average annual rainfall is 2540 mm.

Fig. 1 Geographic location of study area



Forest is one of the most important landuse in Mizoram occupying over 86.27% geographical area of the state. Major forest type in the state include: Tropical semi-evergreen, Tropical moist deciduous, Subtropical broadleaved hill, and subtropical pine forest. The Mizos, living in Mizoram, are highly dependent on the forest resources. The main pattern of agriculture followed is Jhum in the state. Jhum is an integral part of socio-cultural life of Mizos. Mizoram is the 2nd least populous state in the country. However, the state is highly literate agrarian economy, where about 80% of the people of Mizoram are engaged in agricultural pursuits. With increase in population, considerable pressure has increased on forest due to agricultural need. This has created a major challenge for the Mizo society to manage fire activities [11]. Mizoram recorded highest number of fire occurrence (12,846) within the north eastern states from the November, 2020 to June, 2021 [22]. The state is also having 76% of its geographical area under high to very high risk of getting forest fire [22] which is highest in the country. Majority of forest area in Mizoram is being converted to the bamboo due to jhum which has become more susceptible

of getting fire due to hot temperature and low humidity. With recent climate change and global warming scenario the risk of forest fire has increased. Hence, study on fire and climate relation becomes very important in Mizoram.

3 Material and Methodology

Climate variables and fire occurrence data are the requirement for the present study. Acquisition and processing of these dataset to fulfil the objective of the study is given in subsequent section.

3.1 Material

The study is focused on to identify the role of climate on the forest fire occurrence in the study area at spatial level. Three important parameters important for forest fire occurrence and intensity are temperature, precipitation and humidity. Spatial gridded data of ERA 5 (ECMWF reanalysis v5) data was used for the temperature and precipitation. Specific humidity of FLDAS (FEWS NET Land Data Assimilation System) data was used in the study. Both the datasets have spatial resolution of 0.1° which is the highest available for the study area. Since Mizoram has undulating terrain and geography which impact the changes in the climatic condition, use of such dataset was helpful to analyse the significant spatial variation among the climate variables.

The present study utilizes climate data in addition to the forest fire occurrence. The forest fire occurrence was acquired from Forest Survey of India which is an organization under MoEFCC, GoI, which distributes forest fire alerts all over the India. The historical data for forest fire is available from year 2003 generated from MODIS satellite imagery. This caused to limit the present study for 18 years (2003–2020). The information about the forest fire points and its availability is also presented in Sect. 3.1 Material.

Fire occurrence is one of the most essential data for the present study. Forest Survey of India (FSI) generates daily fire alerts, which was downloaded from its website [15]. Fire alerts are generated based on two satellite data viz. Moderate Resolution Imaging Spectroradiometer (MODIS) and Suomi National Polar-orbiting Partnership (SNPP) Visible Infrared Imaging Radiometer Suite (VIIRS). SNPP-VIIRS has higher spatial resolution (750 m) and provides more number of fire alerts compared to MODIS (1000 m). However, VIIRS data is available from year 2018 which cannot be utilised in the study which is dependent on the information of preceding years for better understanding of the trend and relation. MODIS data is available from year 2003 and was used in the present study. The climate data and forest fire occurrence data was used from year 2003 to 2020 to understand forest fire relation with climate.

3.2 Methodology

Methodology involves the processing of climatic data and fire points which is to make the data homogeneous with space and time. Various steps involved in the study are shown in Fig. 2. The details of each step are as follows:

Climate Data Preparation. The source of data is mentioned in the material Sect 3.1 “Spatial gridded data of ERA 5 (ECMWF reanalysis v5) data was used for the temperature and precipitation. Specific humidity of FLDAS (FEWS NET Land Data Assimilation System) data was used in the study.” “Fire occurrence is one of the most essential data for the present study. Forest Survey of India (FSI) generates daily fire alerts, which was downloaded from its website (<http://117.239.115.41/smsalerts/index.php>).” The data acquired for different climatic variable was in the netCDF (Network Common Data Form) format and to process the data, open source Python platform (Anaconda) was used. Climate data was acquired in monthly accumulated product. For temperature and humidity monthly average product and for precipitation, total rainfall during the month was used. These entire dataset was arranged and grouped for each year in different categories viz. district wise and state as a whole in spatial domain. For temporal domain, monthly and seasonal category of each year was used. The season used in the study was followed as per Indian Meteorological Department (IMD) nomenclature i.e. winter (January and February), premonsoon (March, April and May), monsoon (June, July, August and September) and post-monsoon (October, November and December). Trend analysis was carried out in each group for all the climate variables.

Fire Occurrence Data Preparation. Fire occurrence data was available in the tabular format with information of time, day and location of fire occurrence. This information was converted into the point data (shapefile) using QGIS software. Further to analyse

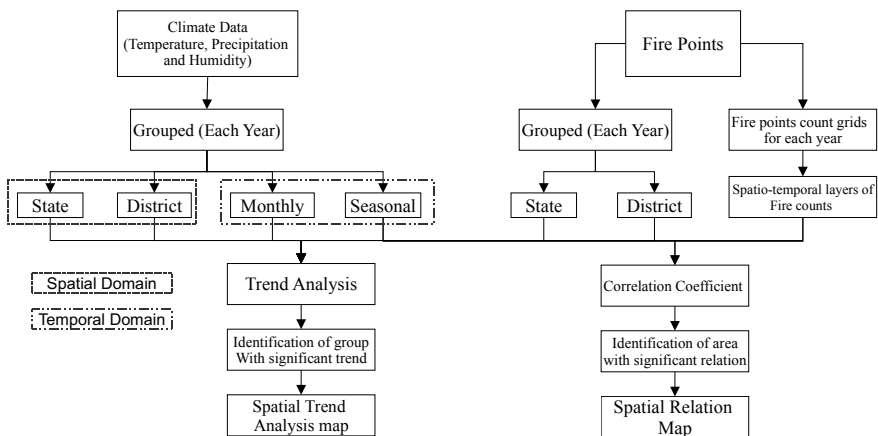


Fig. 2 Flow chart of methodology to analyse the trend and relationship between fire occurrence and climate variables

and make it compatible with climate data, point data was converted to gridded data. The grid size was chosen to be 0.1° which is same as of the climate data spatial resolution. The grids were created using the extent of Mizoram. The value of each grid was computed as total number of fire occurrence in each year. The process was done using spatial analysis tool in QGIS. The outcome of the process generates spatio-temporal data of fire occurrence in Mizoram from year 2003 to 2020.

Trend Analysis. Trends in the data can be identified using parametric and non-parametric methods. Temperature, rainfall and humidity are the non-parametric climatic variables. The non-parametric method does not require normality of time series and less sensitive to outliers [25]. In the present study, Mann–Kendall (MK) test [30, 36] was used for identifying trends in the climatic variable which is one of the most commonly used methods [18], is based on the test statistics, S, is defined as follows:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^n \text{sgn}(X_j - X_k) \tag{1}$$

where, n is the number of observations and X_j is the j th observation and $\text{sgn}(\cdot)$ is the sign function which can be defined as

$$\text{sgn}(\theta) = \begin{cases} 1 & \text{if } \theta > 0 \\ 0 & \text{if } \theta = 0 \\ -1 & \text{if } \theta < 0 \end{cases} \tag{2}$$

The variance of S can be computed as follows:

$$\text{VAR}(S) = \frac{1}{18} \left[n(-1)(2n + 5) - \sum_{p=1}^g t_p(t_p - 1)(2t_p + 5) \right] \tag{3}$$

where, g is the number of tied groups and t_p is the number of observations in the p th group. MK test statistic, Z can be computed as

$$Z = \begin{cases} \frac{S-1}{\sqrt{\text{VAR}(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sqrt{\text{VAR}(S)}} & \text{if } S < 0 \end{cases} \tag{4}$$

A positive or negative value of Z indicates the data tends to increase or decrease with time. At 5% level of significance, if the value of MK test statistics lies within the limits of -1.96 to $+1.96$, then the null hypothesis is accepted and there is no trend in the data. If the value lies beyond the above-mentioned range, the null hypothesis is rejected. If $Z > 1.96$, there is an increasing trend and if $Z < -1.96$, there is decreasing trend. To analyse the magnitude of the increasing and decreasing trend, Sen’s slope

was also calculated as follows

$$Q = \frac{Y_{i'} - Y_i}{i' - i} \quad (5)$$

where, Q is the slope estimate. $Y_{i'}$ and Y_i are the values at times i' and i , where i' is greater than i . Sen's slope is then calculated as the median from all slopes.

The trend analysis was also carried out using linear regression test for non-spatial data. For the non-spatial data, mean of the values of climatic variable as well as active fire points were extracted at state as well as district level. In the spatial data, trend analysis was performed on each pixel of the data. For the fire occurrence, spatial trend analysis was performed on the spatio-temporal gridded data.

Relation between Climate and Fire data. The relation between forest fire and climate data is important to relate with frequency and intensity. Correlation analysis was carried out between fire occurrence and each climatic variable. Linear correlation coefficient was used to determine the magnitude of relationship. Spatial products of both fire occurrence and climate variables were correlated with each other. All the layers were matched for the spatial extent and after that the correlation was performed. Fire occurrence data of entire year was correlated with different season's climatic data. Winter and premonsoon seasons are the period of forest fire in the state hence the relation between fire occurrence and climate data in these two seasons was carried for the same year. While climate condition of monsoon and post-monsoon period can affect the forest fire in upcoming year. Hence the correlation analysis in monsoon and post-monsoon season of fire occurrence in current year was related with climatic variable of previous year. For e.g. monsoon season precipitation of year 2004 was correlated with fire occurrence data of year 2005. As precipitation in monsoon season of year 2005 cannot impact the forest fire occurrence of year 2005 which has already been passed. To analyse the cumulative effect of climate pattern, all the datasets were compared in the interval of two year as well. The comparison of analysis of one year and two year interval can provide more information on their relationship.

4 Result

The result of trend analysis and relation between climatic variable and fire occurrence is presented in the following subsection.

4.1 Trend Analysis

Trend analysis of all the parameters (temperature, precipitation, humidity and fire occurrence) in the study analysed in non-spatially as well as spatially. Non-spatial

trend analysis at the district level in each month and season is given in Fig. 3. It has been found that there is no significant trend from February to June for all the three climate variables i.e. temperature, precipitation and humidity. The annual trend analysis also did not show any significant trend result. Detailed result with trend value is given in Appendix 1.

Temperature. Non spatial MK test (Fig. 3) shows that there is positive trend for temperature only in the month of September (1.97–3.03) for all the districts. The remaining months showed no trend in the outcome. However, non-significant trend results were positive as well as negative. The annual temperature variability over the years also showed no significant trend. In the seasonal pattern, premonsoon season showed positive trend for the Mizoram, which indicates temperature is increasing premonsoon season over a period of time. However, for individual districts significant trend results were not obtained. Winter and postmonsoon seasons showed no significant trend for any district or state. There is positive significant trend was found in the monsoon season for the districts Lawngtlai, Lunglei, Mamit, Saiha and Serchhip. Overall, significant temperature trend showed positive value in the outcome which describes that in Mizoram there is increase in the temperature over the period from 2003 to 2020, limited to certain time period and area. Linear trend of mean annual temperature presented in Fig. 4 also shows increase in temperature in Mizoram from 2003 to 2020.

To identify the area with significant trends spatial trend analysis was carried out. The results obtained from the spatial analysis showed significant outcome only in monsoon season. Similar findings were observed in the non-spatial trend analysis, where monsoon season had maximum significant outcomes. Figure 5 describes the magnitude of trend distributed over Mizoram with significant values. In the results only significant results of trend analysis were mapped. The outcome of trend analysis in winter, premonsoon and postmonsoon seasons did not show any significant values. It can be seen from the spatial map of trend (Fig. 5) that most of the part of Aizawl, Champhai, Mamit and complete Kolasib district has no trend. Zero value of Sen's slope in Fig. 5 shows no trend in the data. Temperature in the monsoon season was found to be increasing where magnitude of increment is higher in parts of Mamit, Serchhip and Champhai districts. These are the northern districts of the state. While southern districts of the state (Lunglei, Lawngtlai and Saiha) had lower increment rate compared to others.

Precipitation. Rainfall is discrete in nature its accumulation varies over a period of time and space. The non-spatial trend analysis results showed almost no trend in the entire state except for the two districts i.e. Lawngtlai and Mamit. Negative trend was found in the month of September for both the districts, i.e. -2.05 for Lawngtlai and -1.97 for Mamit (Fig 3). This negative trend indicates the decrease in the rainfall in the given period of time. Linear trend over a period of given time in Mizoram has been presented in Fig. 6 where trend line is almost flat. Precipitation after year 2017 has been decreased in the state. Minimum precipitation was observed in year 2014. Spatial trend analysis using MK test also showed no significant outcome. Therefore, spatial map of the MK test result was not generated. The non-significant results are

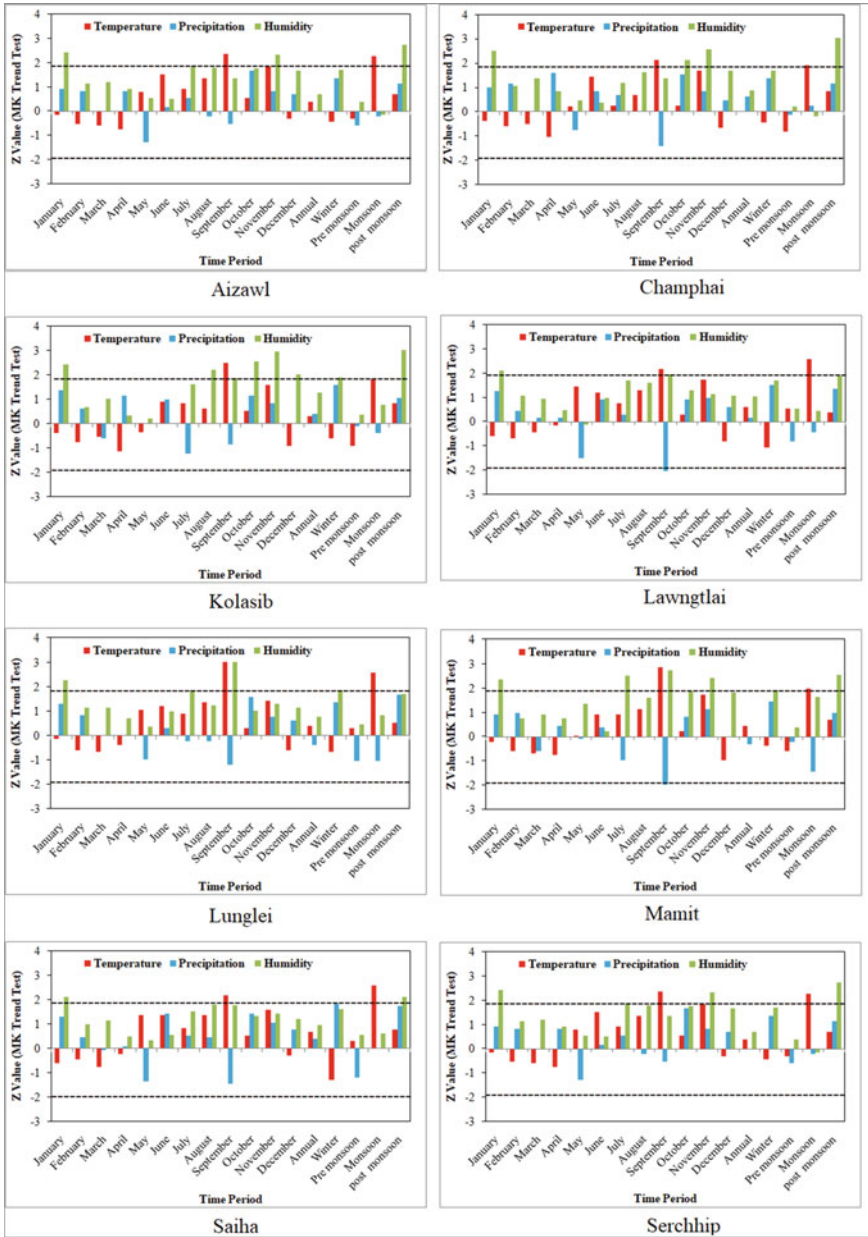


Fig. 3 Plot showing MK trend test (Z) with of various climatic variables over different districts of Mizoram at different time period. The dotted line is the threshold beyond which results are significant

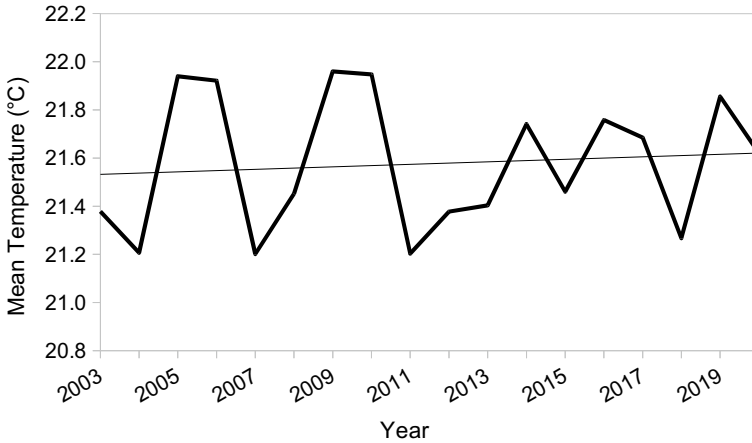


Fig. 4 Linear trend of temperature in Mizoram from 2003 to 2020

mixed of positive and negative trend but most of the districts showed decreasing precipitation in Mizoram.

Humidity. Overall trend for humidity in the study has been found to be positive (1.98 to 3.18) for all the districts and in all the months and seasons. In January month all the district and state has shown positive trend (>1.96 Z score) which is significant at 5% level of significance. Significant positive trend was also observed in July, August, September, October, November and December months (Fig. 3). It has been observed that pre-monsoon period which is very crucial for the forest fire has not shown any significant trend. Aizawl district has shown increase in humidity in winter as well as in post-monsoon seasons. The increase in the humidity in the monsoon season is also observed for entire state only. Linear trend for average annual humidity in Mizoram also shown to be having positive trend. However, humidity was low after 2017 (Fig. 6).

Humidity is the only climatic variable, that showed significant results in all the four climatological seasons using MK test (Fig. 7). However, few of the grids showed no trend at 5% level of significance which is marked as 0 in the map. The result of spatial trend analysis also showed humidity is increasing over a period of time in Mizoram; however the magnitude of the trend is varying which can be seen in Fig. 7.

Fire Points. Trend analysis for fire points was performed only on an annual basis because fire occurs mainly during winter and premonsoon period. During other season or months there is more or less no fire in the state. Fire occurrence in different district of Mizoram is shown in Table 1. Lunglei, Lawngtlai and Mamit are the districts having the maximum fire occurrence in the state from 2003 to 2020. Active fire points did not show any significant trend for the MK test. However, linear regression analysis performed using annual fire count over Mizoram showed decreasing trend as shown in Fig. 9. It can be seen from the data that the total fire occurrence

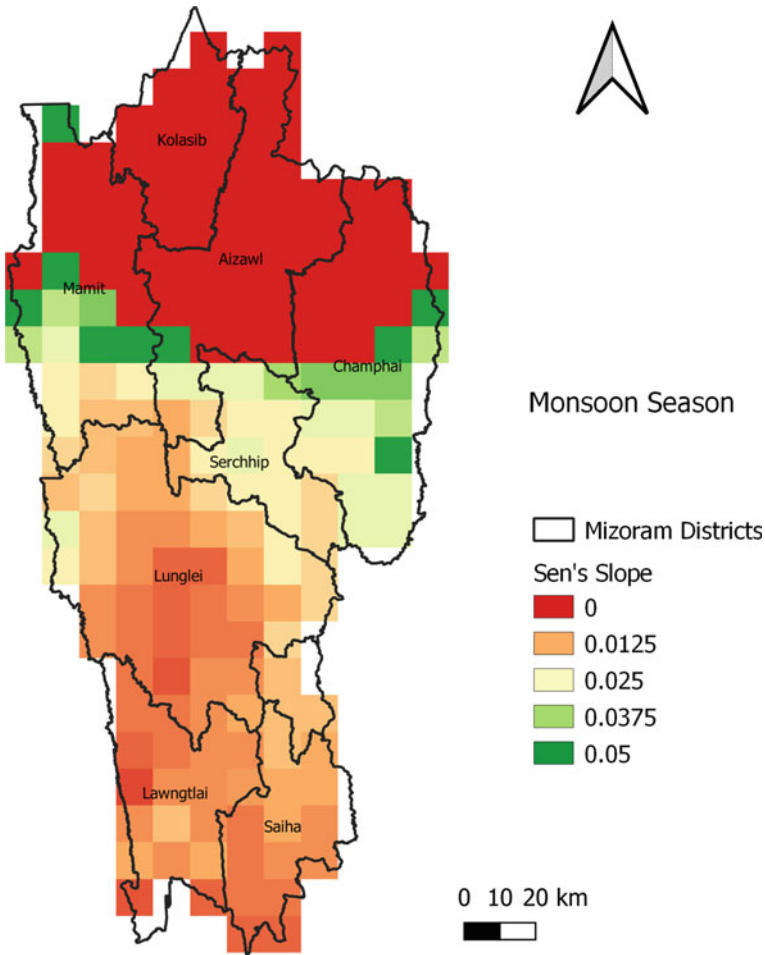


Fig. 5 Magnitude of trend of temperature in monsoon season in Mizoram at 5% level of significance

in the state has been reduced over a period of time. Maximum fire occurrence was found in year 2009 and fire occurrences have been reduced afterwards.

Spatial trend map of fire occurrence prepared using linear regression method is shown in Fig. 10. It can be observed that most of the parts of the state are showing negative trend. However, parts of Lawngtlai, Mamit and Lunglei districts showed increasing trend of fire occurrence. These districts area also having the highest number of fire occurrence, making it highly vulnerable to forest fire.

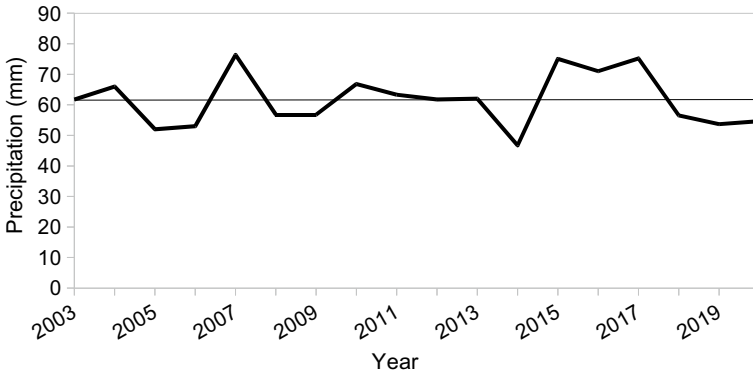


Fig. 6 Linear trend of total precipitation in Mizoram from 2003 to 2020

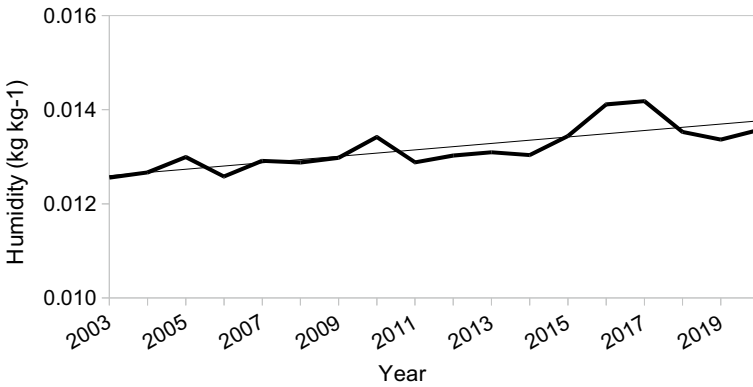


Fig. 7 Linear trend of humidity in Mizoram from 2003 to 2020

4.2 Relation Between Climate Variable and Fire Occurrence

Based on the result of trend analysis it can be inferred that climate variable and fire occurrence had opposite trend result. As temperature and humidity are increasing with decrease in precipitation which is suitable condition for fire occurrence. However, fire occurrence trend in decreasing over a period of given time. Hence, relation analysis between these two parameters will help for further understanding. Correlation analysis was carried out to understand the relation between fire occurrence and climate variable and correlation coefficient value obtained from the analysis is shown in Table 2. The analysis was carried for different seasons as already mentioned in the methodology section.

Temperature. Temperature and fire occurrence relation has been found to be positive for most of the categories except for the monsoon season. During the monsoon season

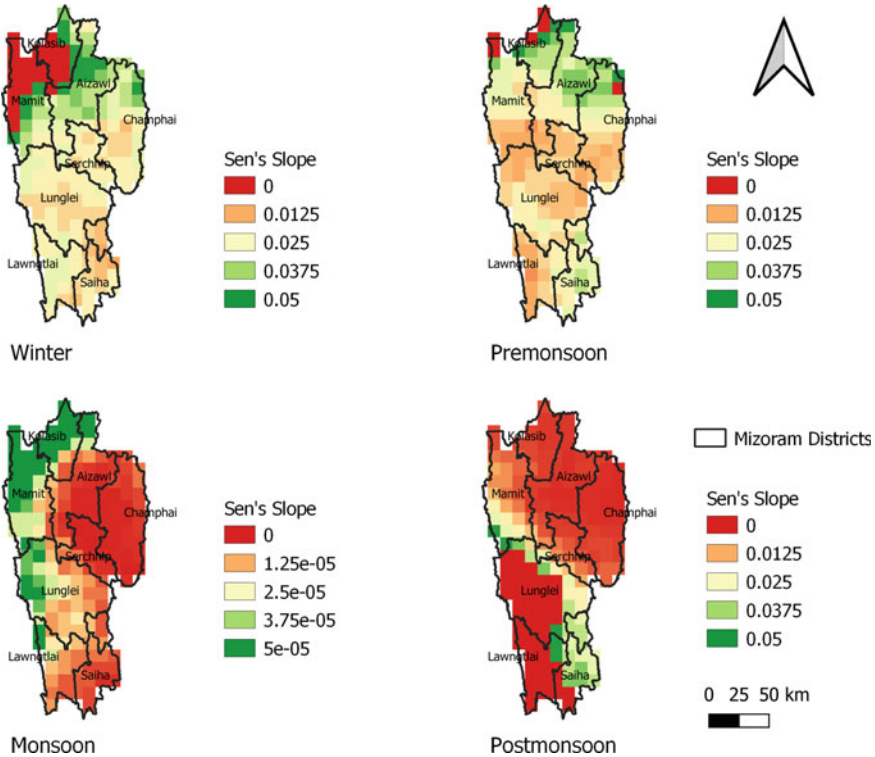


Fig. 8 Magnitude of trend of Humidity in difference season in Mizoram at 5% level of significance

almost all the districts and state have shown negative correlation coefficient value (Table 2). However, these values are not significant. Significant results were obtained in premonsoon (0.50–0.82) and cumulative winter and premonsoon seasons (0.51–0.75). It has also been observed that use of time interval with one year and two year has also shown some differences in the correlation coefficient values. The correlation coefficient value for two year time interval is mostly higher than the one year time interval. The positive relation in winter and premonsoon season shows that increase in temperature in the particular period may increase the chance of forest fire. The significant results were not found to be significant in Lunglei and Lawngtlai districts which are having maximum fire occurrences.

Spatial analysis map was also prepared for each grid in the state based on the correlation coefficient value which is presented in Fig. 11. There mixed kind of result was obtained in the spatial analysis which means that within each season there is positive as well as negative relation was found. During the winter and premonsoon seasons, south-western and eastern part of the state has shown negative relation coming under the Lunglei, Lawngtlai and Champhai districts as can be seen in Fig. 11. Some positive relation has been found in the northern and central districts i.e. Kolasib, Aizawl and part of Mamit. During the monsoon season the result is opposite to what

Table 1 Active fire points in Mizoram and its districts from year 2003 to 2020

Year	District								Mizoram
	Aizawl	Champhai	Kolasib	Lawngtlai	Lunglei	Mamit	Saiha	Serchhip	
2003	649	640	535	768	1112	817	216	294	5031
2004	572	798	460	1109	1418	834	379	363	5933
2005	722	461	403	731	1317	951	273	335	5193
2006	1046	1044	733	1039	1866	1367	416	456	7967
2007	765	566	635	960	1917	1360	503	228	6934
2008	487	464	212	525	885	610	142	179	3504
2009	930	701	573	1421	1992	1623	788	377	8405
2010	972	796	611	746	1395	1265	530	422	6737
2011	307	334	179	589	619	392	112	183	2715
2012	427	573	180	844	904	485	440	202	4055
2013	482	589	210	822	962	616	294	233	4208
2014	424	460	241	675	823	552	192	132	3499
2015	467	616	258	748	852	618	145	240	3944
2016	302	267	215	592	683	493	122	64	2738
2017	294	387	128	394	432	290	91	127	2143
2018	362	401	165	578	690	482	176	192	3046
2019	205	303	113	591	607	415	130	95	2459
2020	251	297	193	611	647	569	124	103	2795
Total	9664	9697	6044	13,743	19,121	13,739	5073	4225	81,306

is found during the winter and premonsoon seasons. Postmonsoon season has also shown negative relation for the entire state except few pockets.

Precipitation. The relation between precipitation (water) and fire is opposite in nature. In the present study also the significant relation between the two has been found negative, however the significant results are very few (Table 2). Annual precipitation relation with fire occurrence was found to be negative (-0.49) for entire Mizoram. The monsoon season which records the maximum precipitation during the year has shown significant negative relation with fire occurrence in only Champhai district (-0.58). The seasonal data showed inconsistent results for e.g. in winter season significant negative relation was found in Serchhip district (-0.55) for monsoon it is in Champhai (-0.58) and for post-monsoon, it is Lunglei (-0.49). In premonsoon season no significant results were found.

The result of spatial analysis in different seasons is shown in Fig. 11. It can be seen from the map that most of the parts of the state is falling under the negative relation. However, the value of the correlation coefficient is towards the lower side. In the winter season, it can be found that the western border of Lunglei and Lawngtlai has positive correlation. However, precipitation is very low during this season. During the monsoon season all parts of the state showed negative correlation where Champhai

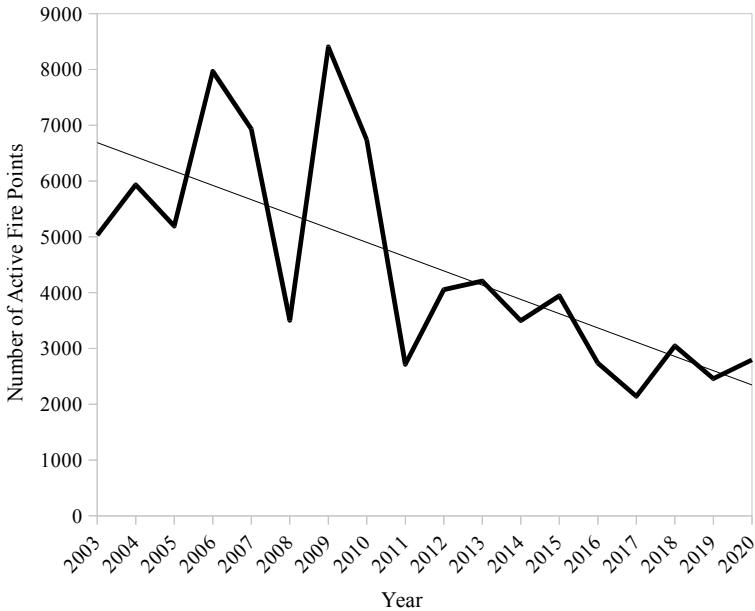


Fig. 9 Linear trend of fire occurrence in Mizoram from year 2003 to 2020

district showed highest negative relationship. While in post-monsoon season, parts of Lunglei showed highest negative correlation coefficient value. Overall it can be inferred from the analysis that the precipitation in monsoon and post-monsoon season might have a role in fire occurrence, however, its role is not that much significant.

Humidity. The relation of humidity with fire occurrence was found to be more consistent than other two climatic variables. The correlation coefficient value for all the season was found to negative and the in most of cases, the value is towards the higher side (Table 2). The monsoon season correlation coefficient values were almost significant except for few districts. It can be inferred that the humidity in monsoon season can have role in fire occurrence in the upcoming year as it can determine the moisture in the environment. Maximum correlation coefficient for the humidity relation was found to be for Kolasib district, i.e. -0.84 with time interval of two years followed by Champhai district which is -0.81 . Premonsoon and postmonsoon season found to have almost no role in relation to fire occurrence as the result were almost non-significant.

Spatial analysis results showed that almost all the area is under the negative relation except the few regions in Lunglei and Lawngtlai districts a monsoon season (Fig. 11). The relation is near zero in the winter season for the same region. Premonsoon and postmonsoon seasons maps showed most of the area with negative relationship. During the post-monsoon season, south-eastern part of the state in Lawngtlai and Saiha districts showed a high negative correlation coefficient which describes its role in upcoming fire events.

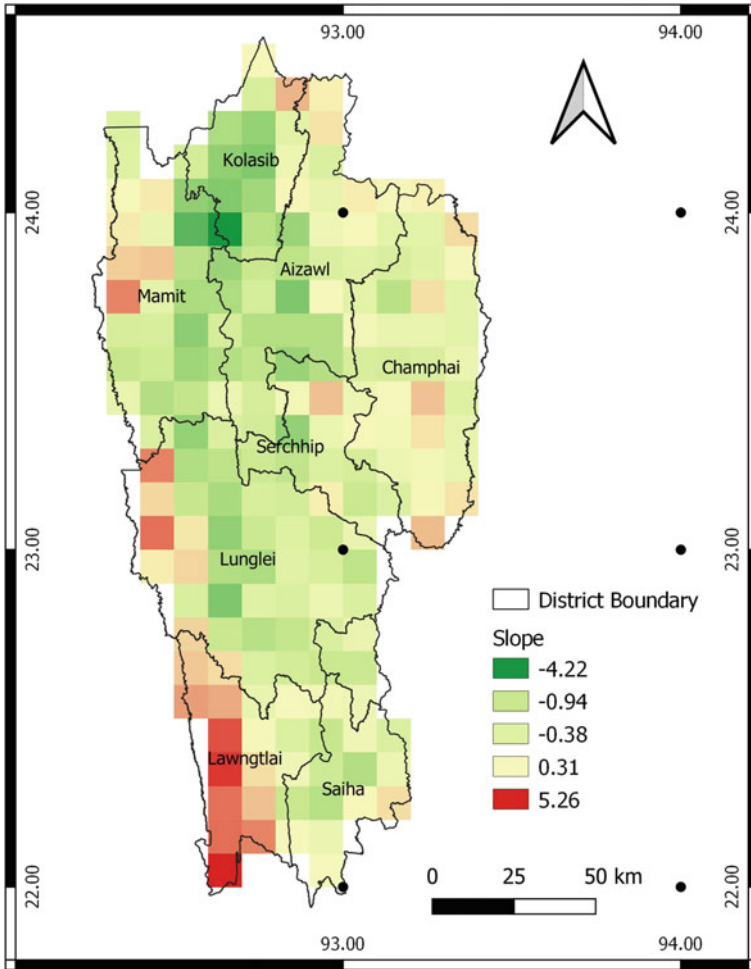


Fig. 10 Annual spatial trend of fire occurrence in Mizoram state

5 Discussion and Conclusion

Climate change being one of the most burning issues in recent times has link with other calamities. Change in the climate condition cause and effect, directly or indirectly to society and its functions. The changes in precipitation patterns causing alternations in timing of runoff into streams can lead to water stress for plants increasing risk of wildfire [44]. Natural phenomenon can also be affected, depending on the climatic conditions. Forest fire is one of such phenomenon associated with the climate or weather. Forest fire throughout the world has demonstrated ecological, social and economic effect in recent times and it has also been affecting the earth’s surface and atmosphere for over 350 million years [12]. Temperature rise is one of

Table 2 Correlation coefficient value obviated by the analysis between fire occurrence and climate variables in different season over Mizoram and its districts at time interval of 1 year and 2 year for the period of 2003–2020

District/State	Time interval	Winter			Premonsoon			Monsoon		
		Temperature	Precipitation	Humidity	Temperature	Precipitation	Humidity	Temperature	Precipitation	Humidity
Mizoram	1	0.40	-0.37	-0.54	0.45	0.12	-0.48	-0.17	-0.32	-0.74
	2	0.48	-0.33	-0.59	0.71	0.10	-0.51	-0.16	-0.20	-0.75
Mamit	1	0.39	-0.24	-0.39	0.54	-0.06	-0.45	-0.12	-0.06	-0.61
	2	0.47	-0.30	-0.45	0.82	-0.19	-0.48	-0.02	0.07	-0.62
Aizawl	1	0.47	-0.27	-0.50	0.62	-0.05	-0.43	-0.04	-0.41	-0.77
	2	0.53	-0.29	-0.52	0.79	-0.19	-0.46	-0.02	-0.31	-0.73
Lunglei	1	0.28	-0.17	-0.50	0.30	0.21	-0.52	-0.29	-0.20	-0.66
	2	0.34	-0.04	-0.57	0.56	0.36	-0.60	-0.26	-0.08	-0.73
Lawngtlai	1	0.27	-0.38	-0.50	0.06	0.26	-0.43	-0.38	-0.23	-0.61
	2	0.49	-0.30	-0.73	0.45	0.40	-0.50	-0.29	-0.16	-0.72
Champhai	1	0.48	-0.47	-0.64	0.47	0.08	-0.39	0.14	-0.58	-0.67
	2	0.53	-0.56	-0.65	0.62	0.05	-0.45	-0.20	-0.28	-0.81
Saitta	1	0.36	-0.38	-0.52	0.19	0.30	-0.29	-0.45	-0.23	-0.56
	2	0.50	-0.24	-0.56	0.47	0.28	-0.35	-0.21	-0.36	-0.48
Kolasib	1	0.38	-0.26	-0.43	0.50	-0.11	-0.42	0.08	-0.30	-0.67
	2	0.46	-0.42	-0.50	0.70	-0.28	-0.49	-0.15	-0.09	-0.84
Serchhip	1	0.52	-0.55	-0.56	0.40	0.17	-0.38	-0.16	-0.26	-0.76

(continued)

Table 2 (continued)

District/State	Time interval	Winter				Premonsoon				Monsoon							
		Temperature		Precipitation		Humidity		Temperature		Humidity		Precipitation		Humidity			
		0.63	-0.58	-0.58	-0.45	-0.47	-0.58	0.57	0.30	-0.41	-0.13	-0.17	-0.74	0.19	0.50	-0.59	
Mizoram	Time interval	Postmonsoon		Precipitation		Humidity		Winter + Pre Monsoon		Precipitation		Humidity		Total precipitation		Temperature	
	1	0.12	-0.45	-0.47	0.51	0.03	-0.59	0.66	-0.05	-0.57	0.25	-0.49	0.25	-0.57	0.50	-0.59	0.50
Mamit	2	0.19	-0.07	-0.29	0.53	-0.12	-0.50	0.66	-0.42	-0.47	0.42	-0.47	0.60	-0.47	0.47	0.11	0.11
	1	0.15	-0.37	-0.42	0.71	-0.30	-0.48	0.35	0.18	-0.59	0.17	-0.52	0.35	-0.57	0.04	0.04	0.04
Aizawl	2	0.43	0.00	-0.14	0.64	-0.12	-0.53	0.50	0.37	-0.61	0.01	-0.57	0.23	-0.37	0.04	0.04	0.04
	1	0.13	-0.26	0.04	0.75	-0.32	-0.50	0.23	0.19	-0.54	-0.37	-0.50	0.08	-0.05	0.37	-0.61	0.37
Lunglei	2	0.16	-0.02	0.11	0.57	-0.07	-0.58	0.58	0.28	-0.65	-0.05	-0.61	0.16	-0.29	0.27	-0.61	0.27
	1	0.10	-0.49	-0.41	0.66	-0.26	-0.56	0.66	-0.26	-0.56	-0.15	-0.67	0.23	-0.34	0.45	-0.67	0.45
Lawngtlai	2	0.23	-0.06	-0.03	0.36	0.24	-0.47	0.36	0.24	-0.47	-0.34	-0.34	0.01	-0.34	0.18	-0.34	0.18
	1	-0.01	-0.41	-0.47	0.59	0.20	-0.48	0.23	0.20	-0.48	-0.02	-0.38	0.08	-0.18	0.37	-0.38	0.38
Champhai	2	0.08	-0.18	-0.11	0.53	-0.16	-0.50	0.58	-0.16	-0.50	-0.58	-0.58	0.16	-0.42	0.40	-0.58	0.40
	1	0.16	-0.29	-0.40	0.66	-0.42	-0.51	0.66	-0.42	-0.51	-0.24	-0.64	0.16	-0.08	0.53	-0.64	0.53
Saiha	2	-0.02	-0.28	-0.58	0.57	0.04	-0.53	0.66	0.04	-0.53	-0.33	-0.61	0.02	-0.26	0.29	-0.61	0.29
	1	-0.04	-0.39	-0.31	0.69	0.07	-0.48	0.36	0.07	-0.51	0.19	-0.60	-0.04	-0.18	0.48	-0.60	0.48
Kolasib	2	0.01	0.23	0.07	0.59	0.20	-0.48	0.59	0.20	-0.48	-0.02	-0.38	0.01	0.23	0.38	-0.38	0.38
	1	0.19	-0.34	-0.53	0.53	-0.16	-0.50	0.53	-0.16	-0.50	-0.58	-0.58	0.19	-0.34	0.40	-0.58	0.40
Serchhip	2	0.29	-0.08	-0.55	0.66	-0.42	-0.51	0.66	-0.42	-0.51	-0.24	-0.64	0.29	-0.08	0.53	-0.64	0.53
	1	0.19	-0.26	-0.36	0.57	0.04	-0.53	0.57	0.04	-0.53	-0.33	-0.61	0.19	-0.26	0.29	-0.61	0.29
Saiha	2	0.02	-0.18	-0.48	0.69	0.07	-0.51	0.69	0.07	-0.51	0.19	-0.60	0.02	-0.18	0.48	-0.60	0.48
	1	0.02	-0.18	-0.48	0.69	0.07	-0.51	0.69	0.07	-0.51	0.19	-0.60	0.02	-0.18	0.48	-0.60	0.48

Bold values represent 5% level of significance

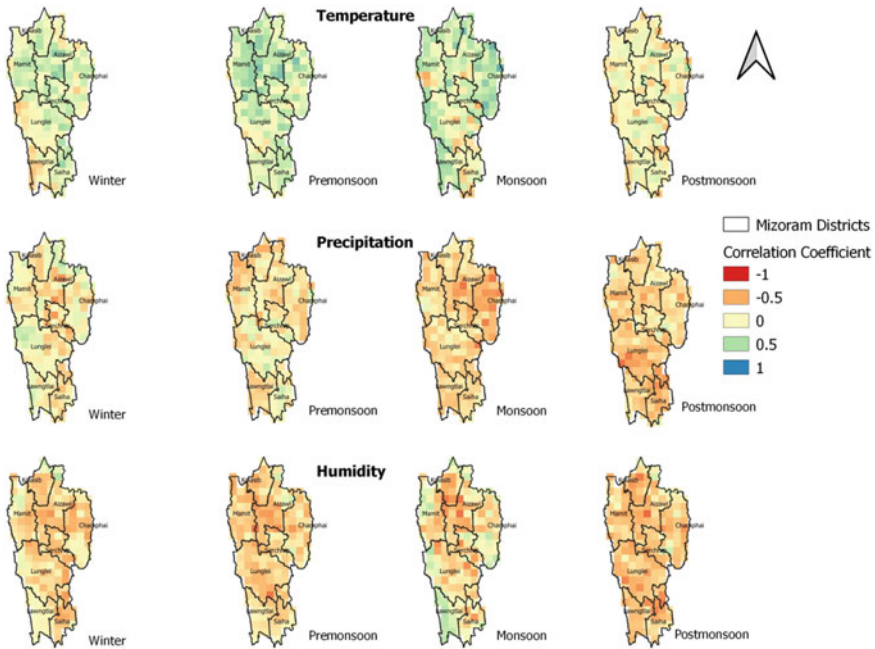


Fig. 11 Spatial correlation analysis between fire occurrence and climatic variables (temperature, precipitation and humidity) from year 2003 to 2020

the important factors in regulating climate conditions. Global annual temperature has been found to increase at an average rate of $0.08\text{ }^{\circ}\text{C}$ per decade since 1880. The rate has been found to increase over twice the rate since 1981 ($+0.18\text{ }^{\circ}\text{C}$) compared to previous one. The year 2020 was found to have recorded highest northern hemisphere land temperature in 141 year, i.e. $+1.28\text{ }^{\circ}\text{C}$ above average [38]. There are studies show that changes in climate increases the chance of forest fire occurrence [16]. The present study also reveals the trend in the change of climate condition over Mizoram. Temperature, precipitation and specific humidity were considered for the trend analysis, since these are important factors affecting forest fire the most.

The first objective of the study was to analyse the trend of climatic variables in the study area which showed very less significant results. Temperature trend from year 2003 to 2020 showed significant positive result of MK test. However, it was found only for September month (1.97–3.03) and few districts (Lawngtlai, Lunglei, Mamit, Saiha and Serchhip) in monsoon season. The spatial trend analysis using MK test also found to be significant only in monsoon season. In the other seasons trend results were not significant. Earlier study by Jain et al. [23] also showed positive or no trend from year 1901 to 2003 for entire north east India. They used monthly surface air temperature data provided by IITM, Pune for their analysis. Global trend analysis results show increase in temperature from 1990 to 2020 for the north eastern states of India [38]. The non-significant trend of temperature in winter season was

completely negative which means there is decrease in temperature over a given period of time. Similar results were also obtained by Jain et al. [23] on trend analysis of temperature from 1951 to 2003 over north east India where winter and premonsoon season showed negative trend while monsoon and post-monsoon results were positive. However, statistical significance trend results were found to be increasing. The correlation analysis between temperature and fire occurrence showed positive relation for annual mean temperature for all the districts and state as well. Kale et al. [29] also investigated role of climate extremities on forest fire refines in India and they found forest fire was significantly correlated with dry days and maximum average temperature from 2003 to 2013. In the present study, temperature relation with fire occurrence was positive in winter and premonsoon season for entire state except south eastern part of state. The region is under Lunglei and Lawngtlai districts. The region was also found to have increasing fire occurrence trend while rest of the state had negative trend for fire occurrence.

Precipitation trend analysis using MK test was found to have almost no significance, only Lawngtlai and Mamit districts showed significant negative trend. The spatial trend analysis at grid level also showed no significant results. The analysis of trend of rainfall from year 1913–2012 in 9 stations of north east India also showed negative or no trend [34]. The rainfall trend for India from 1901 to 2015 was also mostly negative [40]. Kumar et al. [32] also analysed trend for long-term rain in India for 135 year (1871–2005), for which, India was divided into subdivisions. The results showed that half of the subdivisions were having increasing trend and others including north east India having negative trend. The relation of precipitation with fire occurrence was found to be positive as well as negative, however, it was mostly negative. The effect of precipitation in monsoon season is found to affect mostly Champhai district, where highest negative correlation coefficient value is obtained.

Humidity trend was found to have more number of statistical significant results than temperature and precipitation. Humidity was found to be increasing over a period of time in the present study. Singh et al. [46] in their study on changes in relative humidity over northwest and central India found positive in 100 years of time interval. Spatial trend analysis in the present study was also found to be positive for entire state however, the magnitude of slope varies. Recent study by Putatunda [41] also showed positive trend using ERA-interim data over Indian land from year 1980 to 2017. The study also showed that humidity is increasing at all the pressure level. Premonsoon season which is critical for forest fire occurrence did not have any significant trend for humidity. Postmonsoon season and January month was found to have high significant results for humidity except Lunglei and Lawngtlai districts. The spatial trend analysis using MK test was also found to be insignificant in parts of these districts, which highlights the difference in climatic condition in these districts. Jaswal and Koppar [24] also studied trend in humidity over a time period from 1969 to 2007 and showed a positive trend in the Mizoram and nearby area. The correlation analysis also showed negative relation which indicates that lower the humidity and higher the forest fire occurrence. This relation is almost negative for all the districts except the parts of western border districts, which has inconsistent results.

The prime cause of forest fire in north eastern region is mainly because of traditional practice of jhum cultivation [11, 28, 33]. Jhum cultivation and human interference in forest with addition to climate change scenario can increase the chances of spread of forest fire. Overall climate variables trend favours forest fire however, annual trend of forest fire in the study showed decrease fire occurrence from year 2003 to 2020. Only south eastern and eastern region (part of Lunglei, Lawngtlai and Mamit districts) of the state showed positive trend for fire occurrence which are also having favouring trend for climate variables. However, the correlation analysis results over this region had low correlation coefficient values compared to other parts of the state at for different climate variable and in different season.

Overall it can be concluded from the study there is significant inclusion of human interference and climate condition in the forest fire occurrence in the state. However, the sole reason cannot be attributed to cause of forest fire and its danger on environment and society. There are few pockets in the state which is in response to the climate variable while few are not following the trend of natural phenomenon. It can be inferred from the present study that in addition to the anthropogenic factors, climatic conditions also crucial for forest fire and alteration in these conditions may affect the forest fire incidences. It may also be suggested from that local level study in this region can be carried out to find out the ambiguities in the study.

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Appendix 1

Results of the MK trend test (Z) of various climatic variables over different districts of Mizoram and state as well on monthly, seasonal and annual basis

District	Climate Variable	Month												Annual				Season		
		January	February	March	April	May	June	July	August	September	October	November	December	Annual	Winter	Pre monsoon	Monsoon	Post monsoon		
Aizawl	Temperature	0	-0.61	-1.21	0.37	1.14	0.76	0.68	2.20	0.68	1.89	-0.76	0.61	-0.45	-0.76	1.74	0.91			
	Precipitation	1.83	-0.11	-0.23	1.18	-0.11	0.72	-0.87	-0.04	0.99	0.84	0.92	0.34	1.06	-0.19	0	1.18			
	Humidity	2.50	0.98	1.06	0.76	0.87	0.37	1.85	1.77	1.44	2.35	2.95	2.20	0.87	2.12	0.21	0.29	3.18		
Champhai	Temperature	-0.38	-0.61	-0.53	-1.06	0.21	1.44	0.23	0.68	2.12	1.67	-0.68	0	-0.45	-0.83	1.89	0.83			
	Precipitation	0.98	1.14	0	1.59	-0.76	0.83	0.68	0	1.52	0.83	0.45	0.61	1.36	-0.15	0.23	1.14			
	Humidity	2.50	1.06	1.36	0.84	0.45	0.37	1.19	1.61	2.13	2.55	1.67	0.87	1.69	0.21	-0.21	3.03			
Kolasib	Temperature	-0.38	-0.76	-0.53	-1.14	-0.37	0.91	0.83	0.61	2.50	1.59	-0.91	0.3	-0.61	-0.91	1.82	0.83			
	Precipitation	1.36	0.61	-0.61	1.14	0	0.98	-1.22	0	-0.87	1.14	0.83	0.38	1.59	-0.11	-0.38	1.06			
	Humidity	2.42	0.68	1.03	0.34	0.21	0	1.61	2.21	1.85	2.55	2.96	1.28	1.89	0.37	0.78	3.03			
Lawngtlai	Temperature	-0.61	-0.68	-0.45	-0.15	1.44	1.21	0.76	1.28	2.18	1.74	-0.83	0.61	-1.06	0.53	2.58	1.36			
	Precipitation	1.25	0.45	0.15	0.15	-1.52	0.91	0.3	0	-2.05	0.98	0.61	0.15	1.52	-0.83	-0.45	1.36			
	Humidity	2.12	1.06	0.95	0.46	-0.12	0.99	1.69	1.61	1.94	1.14	1.06	1.03	1.69	0.54	0.45	1.89			
Lunglei	Temperature	-0.15	-0.61	-0.68	-0.38	1.06	1.21	0.91	1.36	3.03	1.44	-0.61	0.38	-0.68	0.3	2.58	0.53			
	Precipitation	1.29	0.83	0	0	-0.98	0.3	-0.23	-0.23	-1.21	0.76	0.61	-0.38	1.36	-1.06	-1.06	1.67			
	Humidity	2.28	1.14	1.14	0.72	0.37	0.99	1.85	1.24	3.01	1.03	1.14	0.78	1.85	0.45	0.82	1.71			
Mamit	Temperature	-0.23	-0.61	-0.68	-0.76	0.04	0.91	0.91	1.14	2.88	1.74	-0.98	0.45	-0.38	-0.61	1.97	0.68			
	Precipitation	0.91	0.98	-0.61	0.45	-0.08	0.38	-0.98	0	-1.97	1.14	0	-0.3	1.44	-0.23	-1.44	0.98			
	Humidity	2.35	0.76	0.91	0.76	1.36	0.21	2.52	1.61	2.73	2.41	1.82	1.03	1.93	0.37	1.65	2.54			
Saiba	Temperature	-0.61	-0.45	-0.76	-0.23	1.36	1.36	0.83	1.36	2.18	1.59	-0.3	0.68	-1.29	0.3	2.58	0.76			
	Precipitation	1.29	0.45	-0.08	0.08	-1.36	1.44	0.53	0.45	-1.44	1.06	0.76	0.38	1.82	-1.21	0	1.74			
	Humidity	2.12	0.98	1.14	0.49	0.33	0.54	1.53	1.81	1.77	1.33	1.44	0.95	1.61	0.54	0.62	2.12			
Serehiph	Temperature	-0.15	-0.53	-0.61	-0.76	0.78	1.52	0.91	1.36	2.35	1.82	-0.3	0.38	-0.45	-0.3	2.27	0.68			

(continued)

(continued)

District	Climate Variable	Month												Annual				Season		
		January	February	March	April	May	June	July	August	September	October	November	December	Annual	Winter	Pre monsoon	Monsoon	Post monsoon		
Mizoram	Precipitation	0.91	0.83	0	0.83	-1.29	0.15	0.53	-0.23	-0.53	1.67	0.83	0.68	0	1.36	-0.61	-0.23	1.14		
	Humidity	2.42	1.14	1.21	0.91	0.54	0.5	1.85	1.81	1.36	1.75	2.32	1.67	0.7	1.69	0.37	-0.16	2.73		
	Temperature	-0.23	-0.61	-0.68	-0.61	1.03	1.21	0.61	1.29	2.80	0.53	1.67	-0.68	-0.57	-0.23	2.08	0.72	0.46		
	Precipitation	1.14	0.61	-0.15	0.61	-0.98	0.98	-0.23	0.23	-1.29	1.36	1.14	0.61	1.52	-0.53	-0.61	1.36	0.08		
	Humidity	2.50	1.06	1.14	0.69	0.62	0.45	1.81	1.9	1.69	1.9	1.71	1.69	0.37	0	2.58	0.78			

Bold values represent 5% level of significance

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