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## Forest fire trend analysis and effect of environmental parameters: A study in Jharkhand State of India using Geospatial Technology

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### ABSTRACT

Forest fires are a major threat to the existence of forests these days due to climate change and global warming scenario. The present study utilizes geospatial techniques to analyze the incidences of forest fires events from the year 2005 to 2016 in the Jharkhand state of India. Forest fire hotspot areas within the state were identified. The analysis of the datasets reveals that approximately 89% of the forest fires occur in the month of March and April. From 1<sup>st</sup> March to 10<sup>th</sup> March the fire starts in North East part of Jharkhand forest because of high wind speed and it continues till the end of March. Later, it intensifies to the south of Jharkhand in Paschim (west) Singhbhum district from 11<sup>th</sup> to 20<sup>th</sup> March. From 21<sup>st</sup> to 31<sup>st</sup> March the forest fire starts in North West part of Jharkhand in Palamu district which it continues along with Paschim (west) Singhbhum district till the end of April. Three major locations were identified in Jharkhand forest as forest fire hotspot. Statistical analysis (Cramer's V coefficient) was performed to test the scale / magnitude of association of forest fire with driving factor (meteorological parameters). The range of CVC value varied between 0.74 to 0.32 whereas rainfall retain the highest value 0.74 means it is one of the strongest driving factor among all other environmental parameter contribute to forest fire events. The study of forest fire event analysis, its correlation of trend and its interrelationship with environmental/meteorological parameters gives better comprehension for forest fire events thus helps in mitigation, control and prevention to safeguard our precious forest and the environment.

**Keywords:** Forest fire, Cramer's V coefficient, Kriging, Meteorological data, Jharkhand

## 1. INTRODUCTION

Fire is a major hazard for the world's forests. Every year, millions of hectares of the world's forests are destroyed by fire, leading to loss of human and animal life and substantial economic damage by destruction of the wood and non-wood forest products, loss of biodiversity, release of carbon to the atmosphere, high costs of fire suppression, and damage to other environmental, recreational and amenity values (Davidenko and Eritsov, 2003; FAO, 2005; FAO, 2001).

Climate plays very important role as it exhibits the severity of weather during summer. Recent increasing trend in the size and extent of wildfires across the world (Bowman et al. 2009) is a major policy and management concern because of their ongoing and potentially escalating the effects on the ecological integrity (Pausas and Keeley 2009). Forest fire occurrence and its spread can be attributed to the weather and climate (Flannigan and Harrington 1988), landscape fuel conditions (Finney 2001), ignition agents (Malamud et al. 2005), and human influence (Rollins et al. 2001; Yang et al. 2007). There is also a stochastic aspect to the forest fire associated with the variability in local weather conditions e.g., surface moisture and wind speed (Bessie and Johnson, 1995). Summer season plays a major role in the birth and growth of forest fire whereas drought leads to extremely favorable conditions for forest fires (Kostopoulou and Jones 2005; Koutsias et al. 2012), and winds aid forest fire in bamboo mixed forest (due to collusion of dry bamboo pole) and forest fire progresses as it spreads faster to cover more area of land, making the job of firefighting more difficult.

The state of Jharkhand, with a forest cover of 29.45% of the geographic area (FSI, 2015) has a very rich biodiversity. According to a Forest Survey of India report, about 50 % of forest areas in the country are prone to fire. CPC Report (2017) has predicted more severe dry weather (El Nino) using dynamical model for March-May 2017, in the Northern Hemisphere. Indian states faced several droughts in past few years and the state of Jharkhand also witnessed the same with extreme weather conditions.

The increasing population pressure has caused the forest cover of the state to deteriorate at an alarming rate. Along with various factors, forest fires are a major cause of degradation of Jharkhand forests. The fire is reported to damage the regeneration of important tree species including Sal (*Shorea robusta*), which is a pioneer species of most of the forests of Jharkhand. Study of forest fire statistics for the generation of forest fire maps becomes essential when the historical forest fire data of a certain area is available (Daiz-Delgado et al. 2004; Chuvieco et al. 2008). The forest fire trend, risk analysis and frequency of fire are important factors for taking preventive measures and post fire degradation assessment and effective future planning of fire management strategies to minimize the loss.

Geospatial techniques are powerful tools to assess the forest fire risk, fire trend analysis (Roy, 2003; Thompson et al. 2015) and help in better visualization and understanding of the causes of fire ignition (Loepfe et al. 2011). Several studies have been carried out in developed country over forest fire events and its relationship with various environmental parameters. Wotton et al. 2010 study in Canada reveals an increase in fire events of 25% by 2030. Tian et al. 2012 study of forest fire events in china suggested that the potential burned areas would

increase in future due to temperature and precipitation variation. Pinol et al., 1998 study in Europe suggest climate warming will leads to increase number of wildfires in future. Tapper *et al.* 1993 study considered temperature, relative humidity, wind speed and preceding rainfall when combined with fuel characteristics plays major role in modeling fire risk. Krusel *et al.* (1993) study of wildfire activity in southern Australia suggested mean maximum daily temperature and maximum relative humidity are the good parameter to represent high fire occurrence. The study of Antonovsky *et al.* 1989 shows that chance of fire is strong association to the mean air temperature and rainfall.

Very few studies have addressed the issue of forest fire trend and its relationship with the environmental driving factors in India. A study was conducted by Sastry (2009) in GIR forest of Saurashtra Peninsula in the Gujarat state of India which is also a home for the Asiatic lions. Forest fire risk area/disaster maps were prepared at regional level by taking into consideration various factors like risk, hazard, meteorological factors and anthropogenic intervention. Spatial and non-spatial data were utilized for spatial modelling in GIS. Areas vulnerable to fire were identified and further response routes were clarified for extinguishing forest fires (Jain *et al.*, 1996 and Porwal *et al.*, 1997). Vadrevu *et al.*, (2013) had quantified vegetation fire activity in India by utilizing the MODerate resolution Imaging Spectro-radiometer (MODIS) active fire datasets. They also analyzed various fire regime attributes, i.e., fire frequency, seasonality, intensity and the type of vegetation burnt in diverse geographical regions of India. Forest fire regime analysis and its relationship with environmental parameter are scarce in India which creates a conspicuous research gap for policy implementation.

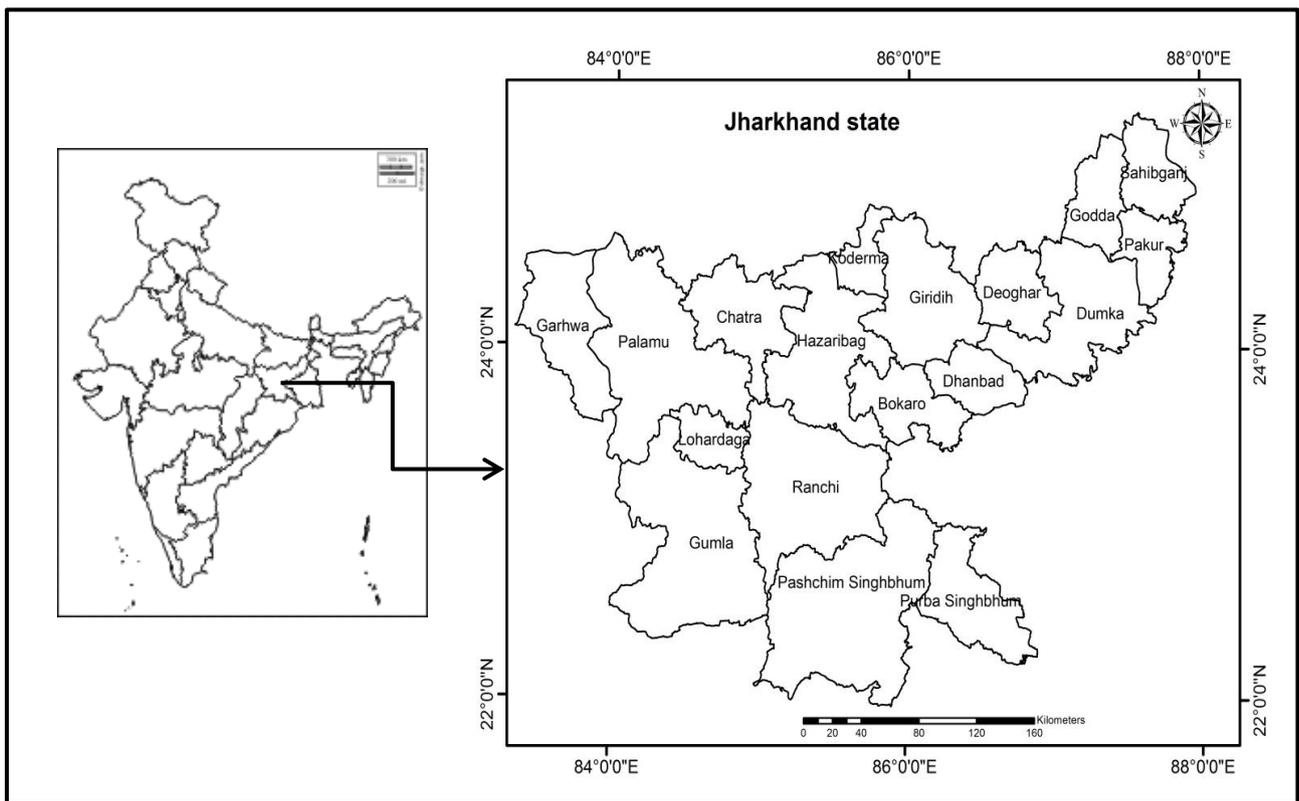
The present study area is the Jharkhand state of India is a known forest fire prone state due to preponderance of dry deciduous forest, inhabited mostly by tribal population, who in course of deriving their livelihoods are blamed to cause the forest fire. The study has utilized the decadal forest fire data of Jharkhand (point data of location forest fire) and analyzed it GIS domain towards visualization and evaluating the spatial/temporal dimension of fire pattern and its trend, with the following objectives.

1. Temporal variation and trend were studied year wise, month wise and for every 10 day interval for the month of March and April.
2. Spatial forest fire trend and pattern was analyzed and forest fire hotspots were identified.
3. Environmental parameter and its influence on forest fire and their correlation with occurrence of forest fire were studied.

## **2. MATERIALS AND METHODS**

### **2. 1. The Study area**

The study area (Fig. 1) having total geographical area 79,714 km<sup>2</sup> accounted (about 2.4 % of total geographical area of the country of lies between 21° 58' 02" N to 25° 08' 32''N latitude and 83° 19' 05"E to 87° 55' 03 " E, longitude, surrounded by West Bengal on the east, Chhattisgarh on the west, Bihar on the north and Orissa on the south. The major rivers are Sone, Koel, Damodar and Subarnarekha. The elevation varies from 6 m to 1366 m from the mean sea level. Jharkhand has a tropical climate with average moderate rainfall (945 to 1297 mm) temperature variations of 6 °C to 47 °C.



**Fig. 1.** The location of the study area

## 2. 2. Data Preprocessing and analysis

### 2. 2. 1. Forest fire trend analysis

The understanding of the spatial pattern of forest fire is important (Konoshima *et al.* 2010; Yang *et al.* 2008; Taylor and Skinner 2003) as it helps in its prevention and control. Administrative boundary of Jharkhand state and district were downloaded from DIVA GIS (<http://www.diva-gis.org/Data>). To analyze the forest fire trend in the state of Jharkhand, the forest fire data was downloaded from Forest Survey of India (<http://fsi.nic.in/forest-fire.php>) from 2005 to 2016. The forest fire point file downloaded was in MS-EXCEL file with latitude and longitude. It was exported into shape file (year wise) using ARC/ GIS Software. To analyze the spatial pattern of forest fire, we used the point density module of Spatial Analyst tool of ARC/ GIS which calculates a magnitude per unit area from point features that fall within a neighborhood around each cell. The Calculate Density tool creates a forest fire density map from fire point features and was classified from the least dense forest fire to most dense forest fire. Finally by this process maps were generated which show forest fire hotspot areas based on the decadal historical locations of forest fires.

### 2. 2. 2. Rainfall trend and intensity analysis

Rainfall intensity and frequency in the summer is an important factor that affects the forest fire (Pausas 2004). The district wise monthly rainfall data from 1990 to 2002 was

downloaded from Indian Water Portal 2016 ([http://www.indiawaterportal.org/met\\_data/](http://www.indiawaterportal.org/met_data/)). The average annual monthly rainfall from January to June for 10 years was used to generate spatial rainfall pattern (continuous surface) by Kriging Interpolation method.

### 2. 2. 3 Meteorological data analysis

Meteorological data such as low humidity, high temperatures and strong winds are considered the major factor in fire weather forecasting (Cardil *et al.* 2014), whereas meteorological indexes evaluating specific changes in the meteorological conditions are important for forest fire trend analysis. The meteorological data (daily time series) in comma separated values (.csv) file format was downloaded from the National Center for Environmental Prediction (NCEP) Climate Forecast System Reanalysis (CFSR) dataset ([globalweather.tamu.edu](http://globalweather.tamu.edu)). The 11years meteorological data of 3 nearest forest fire hot spot location (Table 1) from 2004 to 2014 daily basis exported into ARC/GIS shape file for further analysis. The four parameters (maximum temperature, wind velocity, relative humidity and solar radiation) were evaluated month wise from January to June.

**Table 1.** The meteorological location station

Meteorological Station location id	Forest fire hot spot zone	Latitude	Longitude
248875	Zone-1	24° 49' 20" N	87° 29' 59 " E
239841	Zone-2	23° 53' 07" N	84° 03' 44" E
226853	Zone-3	22° 38' 11" N	85° 18' 44" E

### 2. 2. 4. Statistical analysis

The swing of the driving factor (environmental/climate/weather parameter) on forest fire was evaluated based on the Cramer’s V coefficient (CVC). The Cramer’s V coefficient (CVC) was used to quantify the associations between forest fire frequency month wise and the driving factors. The CVC value was calculated using the following equation given by Liebetrau, (1983):

$$V = \sqrt{\frac{\phi^2}{\min(k-1, r-1)}} = \sqrt{\frac{\chi^2/n}{\min(k-1, r-1)}} \quad (1)$$

where  $\phi$  is the coefficient of contingency,  $\chi$  is derived from Pearson’s chi-squared test, n is the grand total of observations and k represent number of columns and r represent number of rows in the month wise forest fire frequency. CVC has a value between 0 and 1 (inclusive), and a value close to1 indicates that a driving factor has a high potential of being an explanatory variable.

### 3. RESULTS AND DISCUSSION

#### 3. 1. Forest fire frequency assessment

##### (a) Year wise

The frequency of forest fire in Jharkhand (annually) from 2005 to 2016 is represented in the graph. Total occurrence of forest fire from 2005 to 2016 (12 year) was 5426 out of which 1318 forest fire was noticed in the year 2010 alone (Fig. 2), with highest (1318) and lowest (140) frequencies during 2010 and 2007 respectively.

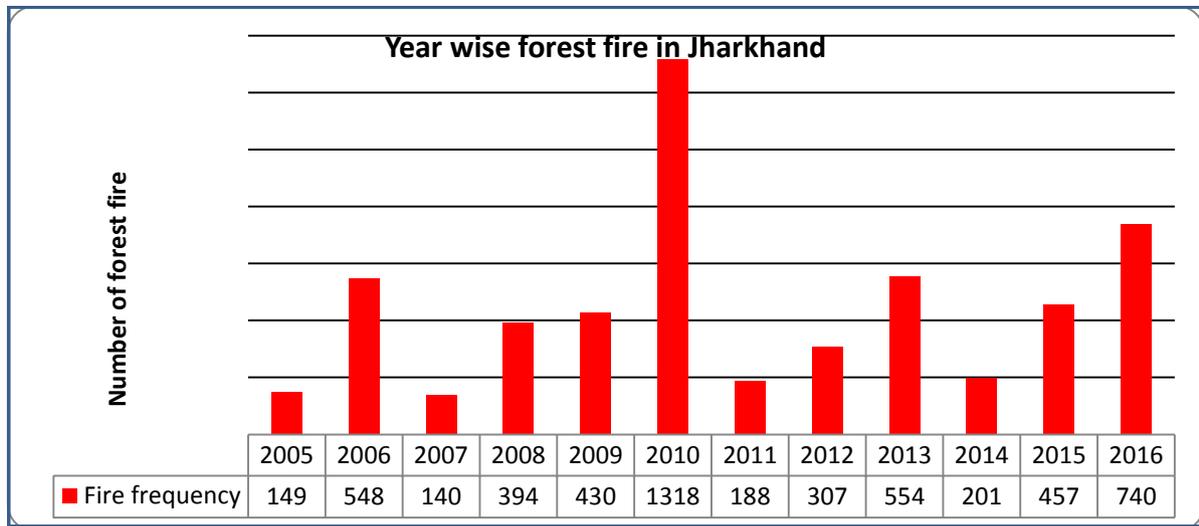


Fig. 2. Annual forest fire frequency from 2005 to 2016

##### (b) Month wise

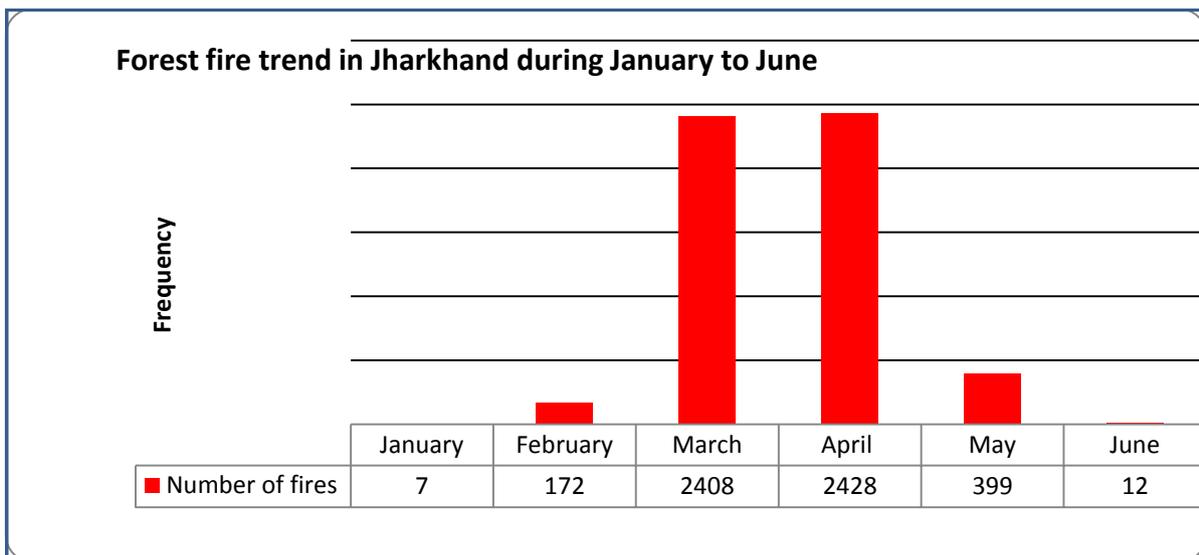
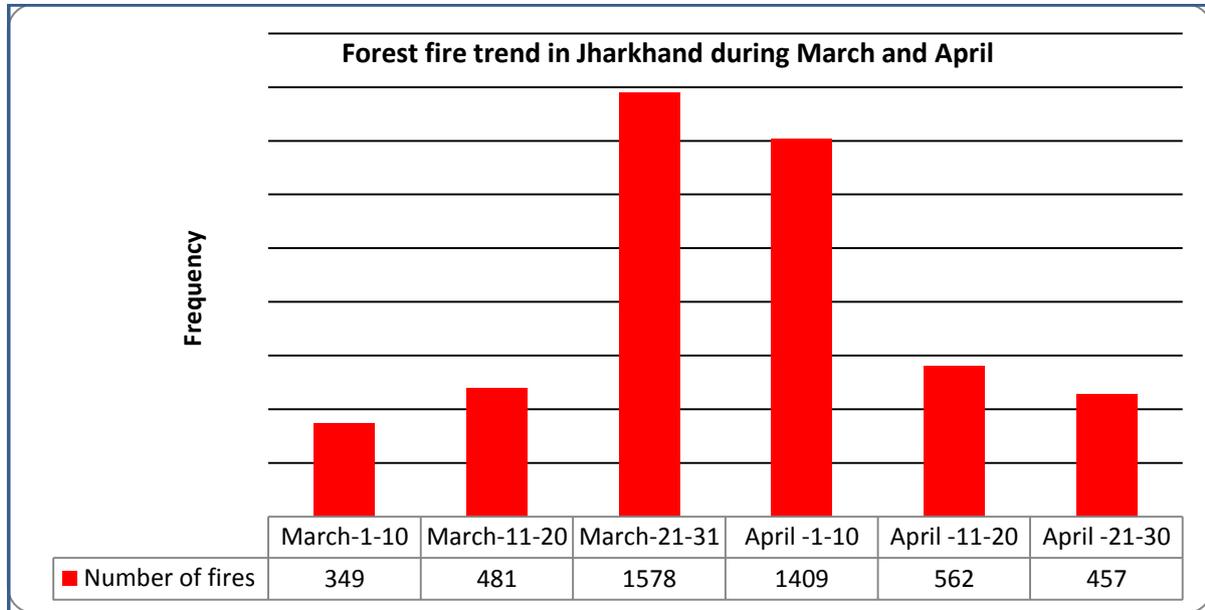


Fig. 3. Monthly forest fire frequency from 2005 to 2016

The forest fire frequency was analyzed (2005 to 2016) monthly, it was observed 89 % of forest fire occurs in the month of March and April, during the beginning of summer season (Fig 3).

**(c) Interval of 10 days for the month of March and April**

The forest fire frequency was observed for every 10 days in March and April month (Fig. 4). The results revealed that 55% of forest fire occurred from 21<sup>st</sup> March to 10<sup>th</sup> April (within a span of 21 days).

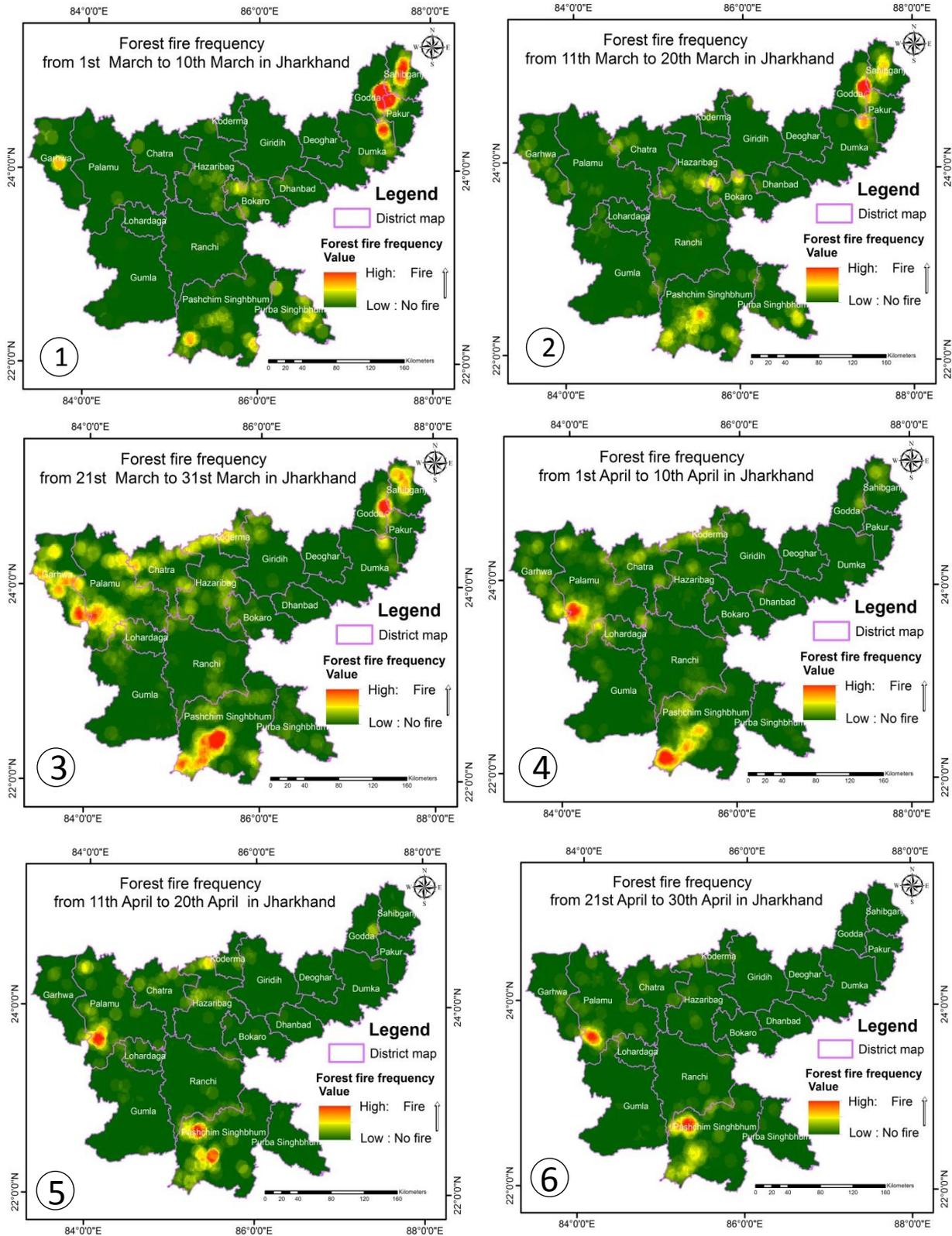


**Fig. 4.** March and April forest fire (at the interval of 10 days)

**3. 2. Forest fire trend analysis**

Forest fire data was analyzed in GIS domain to understand the spatial variation and pattern. March to April data were analyzed at every 10 days interval were considered for the analysis and maps were generated (Fig. 5)

In the beginning of March the fire starts from north east part Jharkhand forest and it continues till the end of March and finally disappeared in April. It further intensifies to the new area (in south Jharkhand) of Pachim (west) Singhbhum from 11<sup>th</sup> to 20<sup>th</sup> March. From 21<sup>st</sup> to 31<sup>st</sup> of March the forest fire starts in north-west part of Jharkhand (Palamu) and it continues along with Pachim (west) Singhbhum forest fire till the end of April.



**Fig. 5.** The fire trend (1, 2,3,4,5 and 6 is each 10 days trend in increasing order from March to April)

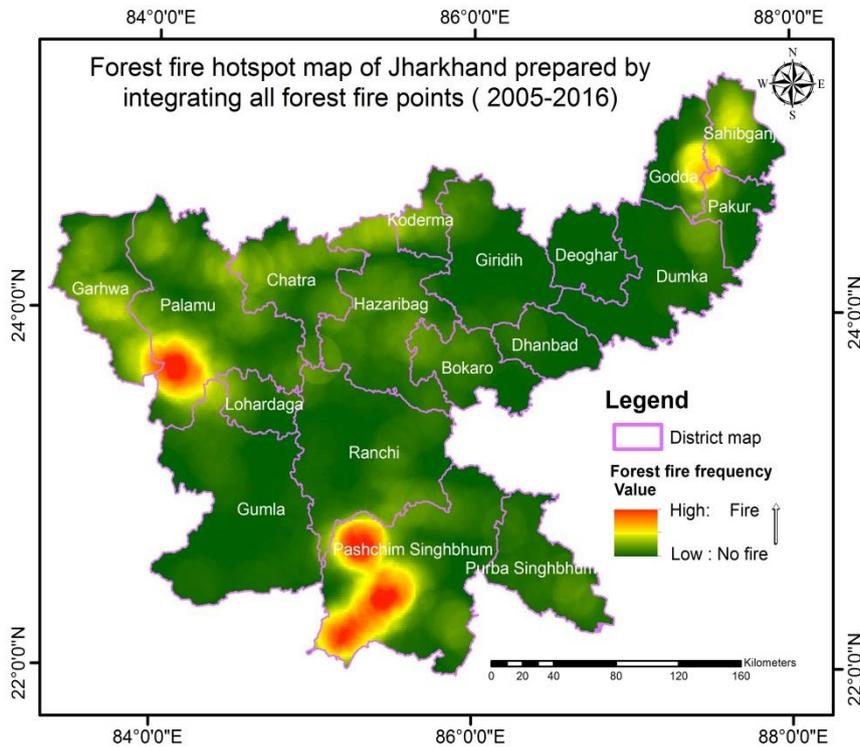
### 3. 3. Forest fire hotspot analysis

The increasing availability of detailed and accurate spatial datasets of forest fire (Stocks *et al.* 2002) enable us to identify forest fire hotspot and its extents and fine scales. To analyze the forest fire hotspot and its spatial pattern in the state of Jharkhand, the whole forest fire data was integrated and analyzed in ARC/ GIS Software simultaneously. Finally by this process of density tool we generated forest fire hotspot maps (Fig. 6). Broadly three hotspot location areas were identified having high risk of forest fire given in Table 3.

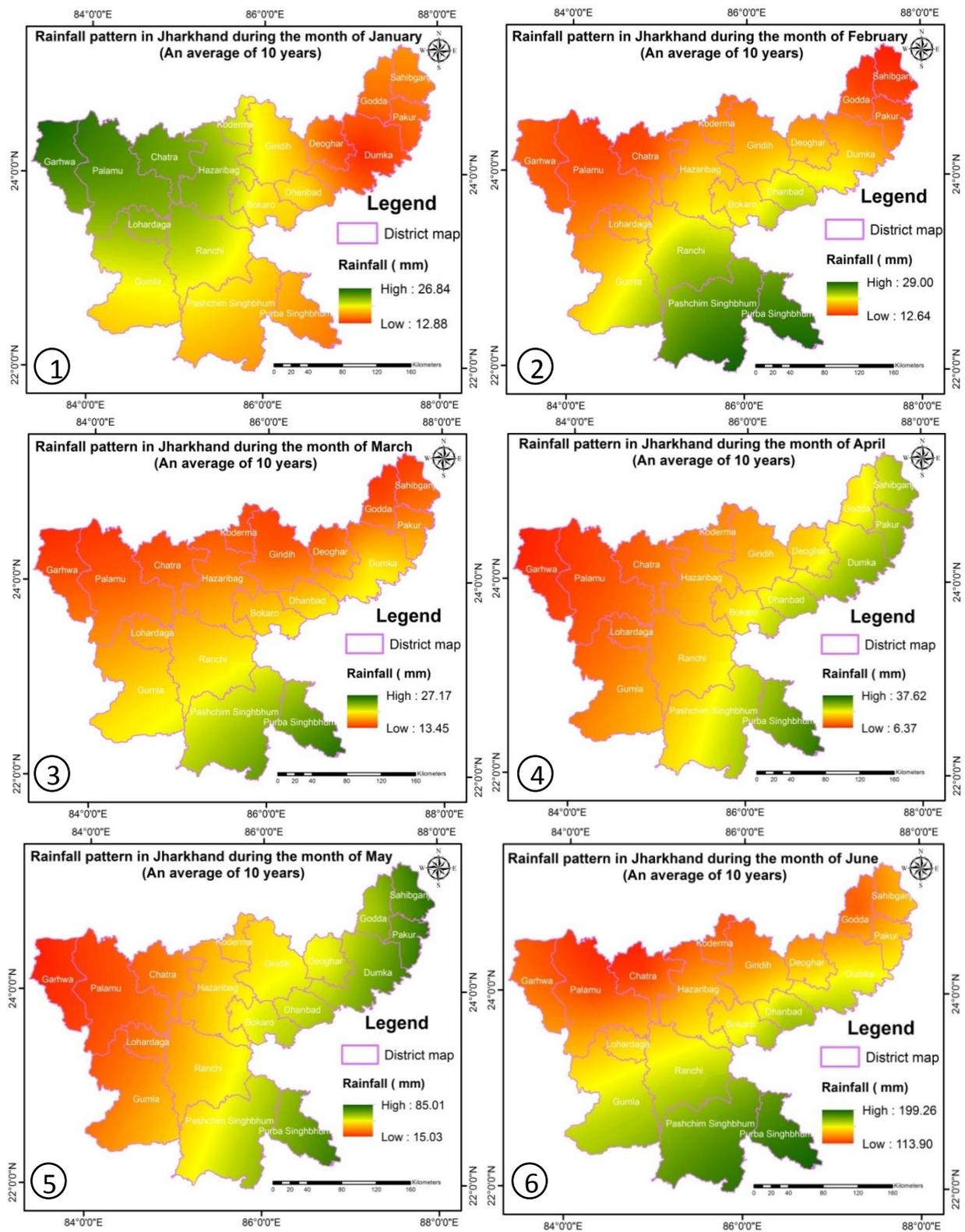
**Table 3.** Hotspot location description

Hotspot	Location description
Zone-1	North-east of Jharkhand at the junction of Pakur, Sahabganj and Godda district.
Zone-2	North-west of Jharkhand, south of Palamu and Garhwa district area.
Zone-3	South of Jharkhand, Pachim (west) Singhbhum district area.

These high risk forest fire zones were evaluated with respect to meteorological/ environmental datasets.



**Fig. 6.** The forest fire hotspot map of Jharkhand



**Fig. 7.** The rainfall trend (1, 2, 3, 4, 5 and 6 is Jan, Feb, March, April, May and June respectively)

### 3. 4. Environmental parameters and their variation with respect to the forest fire

Forest fire is a heterogeneous, ecological disturbance process that is controlled by climate and weather (Bessie and Johnson 1995; Flannigan and Harrington 1988) thus become important for further study. Fire weather conditions based on temperature, relative humidity, wind speed and rainfall must be evaluated at daily basis (Van Wagner 1987) during the fire season provide the input of its trend with specific location and helps to alert forest department.

#### 3. 4. 1. Rainfall trend and intensity analysis

The forest fire trend has been evaluated based on the average monthly rainfall one of the strong driving factor using CVC formula. The overall CVC value (Table 5) describe fire frequency month wise (February to June) and the quantitative level of association with rainfall (driving factor). The high CVC value (0.7449) means the rainfall variable is strong driving factor leads to forest fire events. Similar result has been reported by Antonovsky *et al.* 1989 for their study.

The spatial rainfall pattern month wise was analyzed monthly from January to June throughout the Jharkhand state for better understanding of forest fire trend and its relationship. In the month of January zone-1 receives less rainfall whereas zone-2 receives more rainfall. In the month of February the zone-1 and zone -2 receives less rainfall whereas zone-3 receives more rainfall. In the month of March, except zone-3 all other part receives relatively less rainfall.

#### 3. 4. 2. Meteorological data analysis

The meteorological station data such as maximum temperature, wind velocity, relative humidity and solar radiation used to analyze the relationship with forest fire. Each meteorological station point data retain the daily basis all four parameter from 1<sup>st</sup> January 2004 to 31<sup>st</sup> December 2014. The average monthly basis observation from January to June is recorded in Table 4. The trend analysis of meteorological parameters such as mean maximum temperature, mean relative humidity, mean wind velocity and mean solar radiation for each month from February to May was evaluated based on forest fire frequency using Crammer's V coefficient (CVC) is given in Table 5.

**Table 4.** Meteorological average data on monthly basis from January to June.

Average of 11 years (2004-2014)	Forest fire hotspot (zones)	Jan.	Feb.	March	April	May	June
Maximum Temperature (°C)	1	25.06	29.56	36.15	40.66	41.24	38.29
	2	25.39	29.33	35.41	41	42.93	40.25
	3	26.73	30.68	36.9	41.57	42.9	38.69

Wind Velocity (m/s)	1	2.44	2.66	2.68	2.57	2.66	2.65
	2	3.06	1.93	2.03	2.13	2.25	2.3
	3	1.93	2.14	2.18	2.14	2.2	2.5
Relative Humidity (fraction)	1	0.52	0.423	0.284	0.3087	0.4294	0.608
	2	0.56	0.453	0.289	0.225	0.256	0.429
	3	0.5	0.39	0.266	0.256	0.3348	0.527
Solar Radiation (MJ/m <sup>2</sup> )	1	15.84	18.74	22.36	23.93	21.53	19.61
	2	16.34	19.12	22.57	24.92	24.93	20.9
	3	16.84	19.57	21.95	23.5	20.88	17.87

The forest fire relationship has been evaluated, based on the average monthly Meteorological variables (driving factors) using CVC formula. The overall CVC value (Table 5) describes fire frequency month wise (February to June) and its association with maximum temperature, wind velocity, relative humidity and solar radiation (driving factors). The high CVC value means the variable is strong driving factor leads to forest fire. Here relative humidity, Maximum Temperature, Solar Radiation and Wind Velocity are in decreasing order has strong relationship with forest fire events. Here CVC value of relative humidity, maximum temperature, solar radiation and wind velocity are in decreasing order and in the range of 0.32 to 0.52 exhibit strong relation with forest fire. Wang *et al.* (2016) also considered greater than 0.3 CVC value for strong relationships with driving factor for their study. Our study shows the agreement with various researcher such as Wotton et al 2010; Tian et al 2012; Tapper et al., 1993 where they used these parameter for analysis/prediction of forest fire events/occurrence.

**Table 5.** Crammer’s V coefficient (CVC) values of forest fire driving factors

Meteorological variable (Driving factors)	Forest fire frequency Crammer’s V coefficient (CVC)
Maximum Temperature	0.4274
Solar Radiation	0.355
Wind Velocity	0.3227

Relative Humidity	0.5213
Rainfall	0.7449

### 3. 4. 3 Forest fire characterization and trend over Jharkhand

The forest cover of Jharkhand state which accounts for 29 % of its geographical area is prone to degradation from fire hazards leading to the loss of green cover and biodiversity. Large numbers of medicinal and other commercial important plant species are lost. Wildlife habitat too is lost, especially for small animals (reptiles and insects). More important is that large number of tribal population living inside the forest still face poverty, life is extremely miserable as the threat to their livelihood is increasing day by day since they are fully dependent on forests.

The onset of the summer season increases the occurrence of forest fires which start and increase in frequency when the summer is at peak due to favorable environmental parameters. In Jharkhand, the average of forest fires per year from 21<sup>st</sup> March to 31<sup>st</sup> March (an interval of 10 days) as derived from the above study was 132, whereas as number of fire reported by Forest Survey of India (<http://weblines.co.in/smsalerts/search.php>) for the same period in the year 2017 was 334. Further, during the first five days of April that is from 1<sup>st</sup> April 2017 to 5<sup>th</sup> April 2017, it was observed that the number of occurrences of forest fire was 441, which is roughly more than five times higher when compared with the 12years forest fire average. In Figure 9 and video the prevalence of forest fire on dated 3<sup>rd</sup> April 2017 can be seen in Samariya block of Chatra district, Jharkhand. (*Photo courtesy: Ajeet Kumar Das*).



**Figure 8.** Forest fire in Samariya block, Chatra district, Jharkhand

The forest fire spatial and temporal pattern were evaluated and correlated with the environmental parameters and some interesting trends were observed which are discussed below.

#### 4. HIGH FOREST FIRE FREQUENCY IN THE YEAR 2010

The extreme weather conditions (rainfall, temperature, relative humidity and solar radiation) were the reason for the high frequency of forest fire in the year 2010. It was also observed by analyzing meteorological data of three station the mean maximum temperature and mean solar radiation in the month of March and April in the year 2010 were high, were as mean relative humidity was low when compared to 11 years average. Mean maximum temperature and mean solar radiation shows an increase by 2.49 to 3.07 °C and 0.98 to 1.65 (MJ/m<sup>2</sup>) respectively, whereas mean relative humidity shows a decrease by 0.022 to 0.023 (Table 7). Similar finding was endorsed by Koutsias *et al.* 2012.

**Table 7.** Trend (difference) of meteorological data in 2010 compared with 11year average

Difference in MMT, MSR and MRH in the year 2010 when compared with 11years average. (+ Increase, - Decrease)	March	April
Mean Maximum Temperature( MMT) (°C)	+2.49	+3.07
Mean Relative Humidity (MRH) (fraction)	-0.0219	-0.0298
Mean Solar Radiation (MSR) (MJ/m <sup>2</sup> )	+0.98	+1.65

During this year (2010) Jharkhand state received 47 % less rainfall and also the same year was declared as drought (<http://nidm.gov.in/PDF/DP/JHARKHAND.pdf>). Below average rainfall and drought in many studies have been implicated as one of the important reasons for susceptibility of forest to fires (Siegert *et al.* 2001; Roberts 2000)

##### 4. 1. Approximately 90 % of forest fire occurs in the month of March and April

Three meteorological stations data were analyzed and the monthly (January to June) trend of mean maximum temperature, mean relative humidity and mean solar radiation of Jharkhand is given in Fig 9. The slope of the trend line indicates sharp increase in of mean maximum temperature, mean solar radiation whereas a sharp decrease in relative humidity in the month of March. The relative humidity was at the lowest level in the month of March and April varies from 0.28 to 0.26. High wind velocity was noted which aggravates the situation by creating more favorable condition for forest fire spread.

##### 4. 2. The 55 % of forest fire occurs during the period of 21<sup>st</sup> March to 10<sup>th</sup> April

Three meteorological stations data were analyzed at the interval of 10 days during the month of March and April and trend of mean relative humidity and mean solar radiation of Jharkhand is given in Fig. 10.

The mean relative humidity between the period of 21<sup>st</sup> march to 10<sup>th</sup> April was lowest level varies from 0.24 to 0.25 when compared to the adjacent time period. The mean relative humidity further increased after 10<sup>th</sup> April as seen in graph.

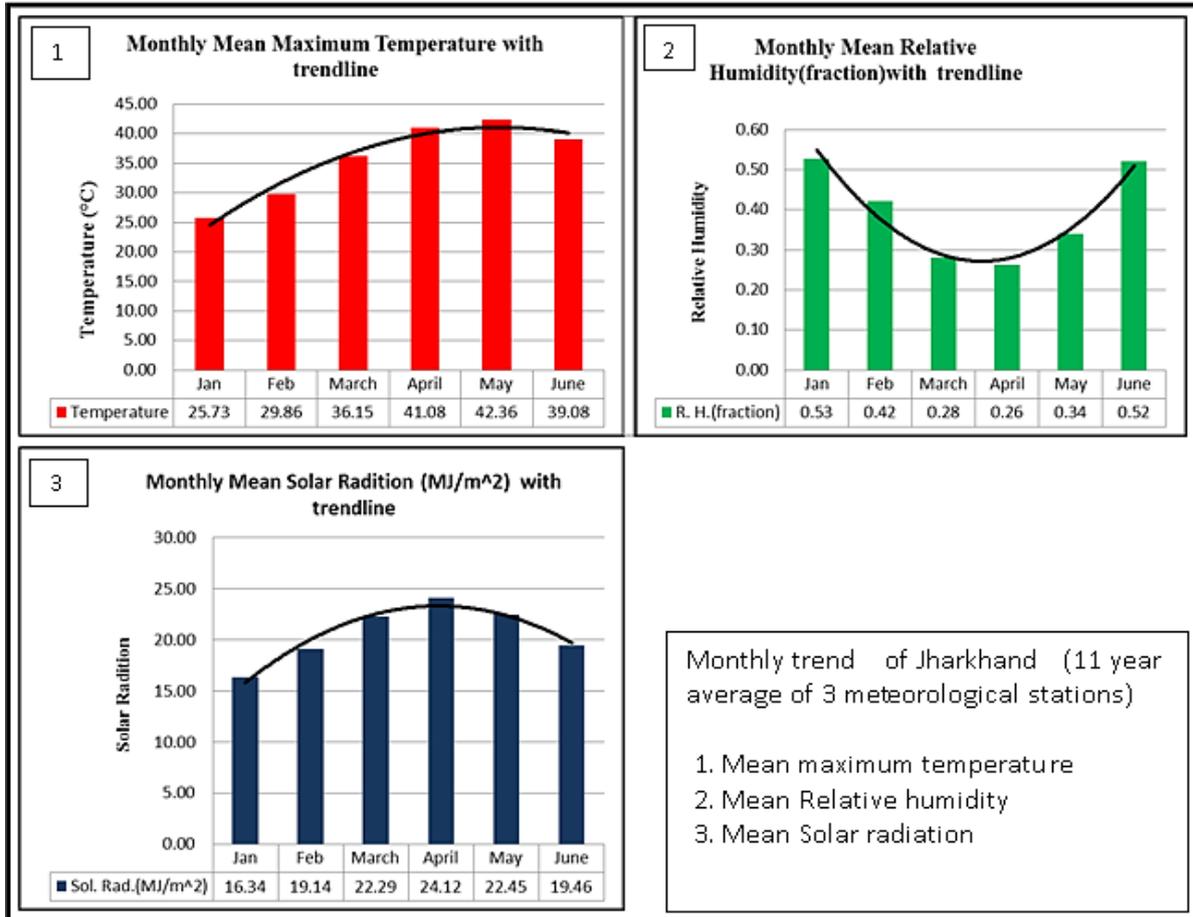


Fig. 9. Graphical representation of climatic parameter (a monthly trend) of Jharkhand.

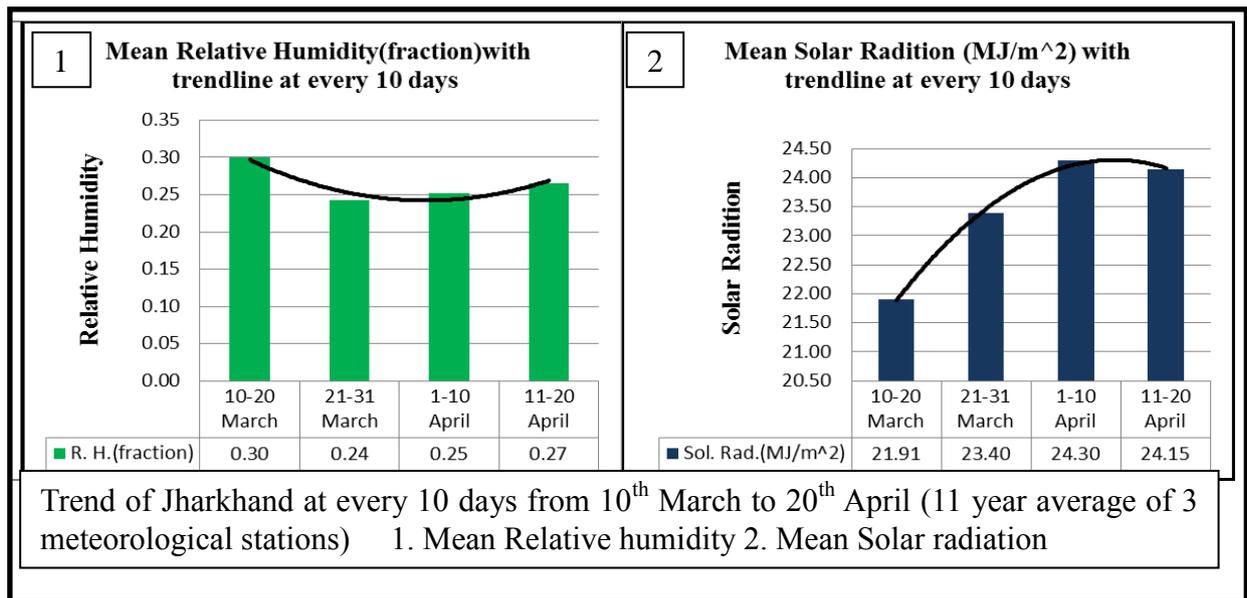


Fig. 10. Graphical representation of climatic parameter (every 10 days trend) of Jharkhand

Similarly the mean solar radiation between the period of 21<sup>st</sup> March to 10<sup>th</sup> April was highest varies from 23.40 to 24.30 (MJ/m<sup>2</sup>) when compared to the adjacent time period. The mean solar radiation further decreased after 10<sup>th</sup> April as noted in graph.

#### **4. 3. Forest fire first observed in the north eastern part of Jharkhand (zone-1) area in the beginning of March which disappeared in April. Forest fire trend with reference to identified hotspot zone-2 and zone -3 in Jharkhand.**

The forest fire starts in north east part (zone-1) first because it continuously receives less rainfall from January to March whereas this area receive relatively more rainfall in month of April (Fig. 8) which increases the relative humidity (Table 4) in the same month.

Furthermore based on meteorological data analysis it was found particularly in zone-1 area where rapid increase in mean maximum temperature as well as in mean solar radiation were found in March given in Table 4. The sudden increase in mean maximum temperature and in mean solar radiation were 6.94 (°C) and 3.62 (MJ/m<sup>2</sup>) respectively in March when compared to February data. The situation also aggravates because of the highest mean wind velocity equivalent to 2.68 (m/s) and lowest mean relative humidity equivalent to 0.284 noted in the month of March (Table 4).

The wind velocity of this area was found high during March was also validated from the website (<https://www.meteoblue.com/en/weather/forecast/modelclimate/24.827N87.220E>).

The forest fire intensifies in Zone-3 of Pachim (west) Singhbhum from 11<sup>th</sup> to 20<sup>th</sup> March whereas from 21<sup>st</sup> to 31<sup>st</sup> March the forest fire starts in zone-2 (Fig 6) and continues till the end of April. The average relative humidity during this 10 days period (11<sup>th</sup> to 20<sup>th</sup> March) in zone-3 was all time low equivalents to 0.2338 and also lowest among all months from January to June when compared with Table-4. The high temp and low relative humidity continues in this area till the end of April. Solar radiation in this area was highest equivalent to 23.5 MJ/m<sup>2</sup> during the month of April (Table 4). As per Tirkey *et al.* 2017 it was observed that the no. of summer days in this area is more.

The forest fire in north western part (zone-2) also remains dry due to continuously receiving less rainfall from February to May as compared to the other two zones (also noticed from Fig 7. During the month of March and April very high solar radiation was found when compared to the other zone which reaches its zenith (24.93 MJ/m<sup>2</sup>) in the month of May. The relative humidity also decreased by 36% in March as compared to February. Finally from the Table 4 it is deciphered zone 3 always shows mean maximum temperature high from January to April when compared to zone -1 and zone -2.

## **5. CONCLUSION**

GIS is several decade old technologies and has much more potential apart from making map. Application of GIS can be scientifically used to study forest fire dynamics both spatially and temporally. The present study has evaluated the forest fire trend spatially and also correlated with the rainfall patterns and the meteorological data. The study reveals that the environmental /climate/ weather parameter and their trend are strongly correlated with the forest fire occurrence and its trend over a period of time. This is supported by statistical analysis based on values of CVC. It is observed that the environmental parameters such as rainfall, relative humidity, maximum temperature, solar radiation and wind velocity in

chronological decreasing order have strong correlation with forest fire occurrence. On the basis of CVC values it is concluded that rainfall has the highest association/impact on forest fire events whereas wind velocity has the lowest.

Thus, from the above study, it can be inferred that in current scenario due to global warming and climate change weather/climate plays important role on forest fire events and its spread especially during summer season therefore its forecast should be warranted on daily basis during forest fire period. A special focus should be made to the forest fire hotspot areas to alert about the aggressiveness of its trend to the respective administrative headquarters which will help to take preventive measures to control the extent of its damage. In addition, there is an urgent need to formulate and implement the forest fire policy by our government as suggested by Sundaram 2017 and long back advocated by FAO 1999. Thus, an integrated approach would ensure its prevention and mitigation such that the forest and the environment are safeguarded.

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**Data Download Source:**

<http://www.diva-gis.org/Data> ( accessed on 15<sup>th</sup> March 2017)

<http://fsi.nic.in/forest-fire.php> (accessed on 15<sup>th</sup> March 2017)

[http://www.indiawaterportal.org/met\\_data](http://www.indiawaterportal.org/met_data) (accessed on 15<sup>th</sup> March 2017)

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