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AN ANALYSIS OF FOREST FIRE AND CLIMATIC PARAMETERS' TREND USING GEOSPATIAL TECHNOLOGY: A CASE STUDY IN THE STATE OF CHHATTISGARH, INDIA

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It is essential to study forest fire occurrences and the climate of any region to address the issue of forest fire vs global warming and global climate change. Studies at regional and global level help to understand the forest fire characterization microscopically. The present study has made an assessment of the long-term forest fire events in the state of Chhattisgarh, India and identified forest fire hotspot areas. We have generated a spatial pattern of climate data and made a statistical analysis. Cramer V coefficient (CVC) was calculated and its relationship with forest fire events was suggested. The study revealed that the Bastar and Dantewada districts of Chhattisgarh state of India show the highest forest fire percentage equivalent to 24 and 33 %, respectively. Generally, three forest fire hotspot zones were identified. In January, February and March zone 1 received less rainfall and showed relatively high maximum temperature and potential evapotranspiration when compared with zone 2 and 3. The number of rainy days in January and February in Dantewada and Bastar district (zone 1) was 0.72 to 0.92 and was found lowest among all districts of the state. The climate parameters were more favorable to forest fire events over zone 1 compared to other zones. The evaluation of CVC value of climate data with forest fire events showed that rainfall, maximum temperature, the number of rainy days and potential evapotranspiration were in decreasing order and in the range from 0.74 to 0.32. The highest value (0.74) showed that was closely related with forest fire events. In June, these areas receive adequate rainfall (90–177 mm) which leads to an increase in the moisture content and hinders forest fuel burning capacity. Geospatial technology proved capable of analyzing thematic datasets and various modules/algorithms used in mapping, allowing to draw logical conclusions in solving various research problems.

Keywords: forest fire, hotspots, climate data, kriging, Cramer V coefficient.

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INTRODUCTION

Fire is an important component of the Earth's System that is tightly linked with climate, vegetation, biogeochemical cycles and human activities since it influences the global ecosystem patterns and processes (Harrison et al., 2010). The forest fire does not only destroy the existing vegetation and reduce the forest cover (Roy, 2004), but also burns costly timber (Rodríguez y Silva et al., 2012), de-

stroys the wildlife habitat (Engstrom, 2010) of an ecosystem, deteriorates soil and water condition (Ferreira et al., 2008), ruins and reduces biodiversity (Impacts..., 2001) of forest, intensifies air pollution (Srivastava and Singh, 2003; Vadrevu et al., 2011) in atmosphere, leads to vegetation succession and alters the nutrient and global carbon cycles (Kutiel and Inbar, 1993; Capitanio and Carcaillet, 2008) bringing about the climate change (Crutzen and Andreae, 1990; Ramanathan et al., 2005).

Fire activity is generally maneuvered by four factors: fuel characteristics and its amount (Finney, 2001), local climate/weather (Flannigan and Harrington, 1988), source of ignition agents (Malamud et al., 2005) and human activity (Flannigan et al., 2005), while the drier the climate the higher is the risk of forest fire due to fuel moisture by and largely determines whether fuels can sustain/withhold ignition and therefore it determines the spread of fire (Blackmar, 1972; Wotton et al., 2010).

Due to the advancement in technology especially in the satellite sensors, it is possible to map fire patterns globally (Dwyer et al., 1998, 2000; Csiszar et al., 2005) and locally (Ahmad and Goparaju, 2018; Ahmad et al., 2018). Satellite data based fire monitoring/mapping thus offers a reliable source of fire occurrence data that can largely overcome various limitations of the traditional fire records (Flannigan and Vonder Haar, 1986; Eva and Lambin, 1998; Korontzi et al., 2006).

Forest Survey of India uses MODIS datasets for active forest fire detection by masking fire points by country forest boundary/mask. MODIS is a key instrument on Terra and Aqua satellites. Terra satellite orbit around the Earth is fixed in such a way that it passes from north to south covering the equator in the morning, while Aqua satellite passes south to north over the equator in the afternoon. Terra MODIS and Aqua MODIS having 36 spectral bands or groups of wavelengths observe the whole earth's surface every one to two days.

As per Forest Survey of India Report (Forest Survey..., 2017) about 50 % of forest areas in the country are prone to fire. Chhattisgarh is one of the state of India with 41.12 % forest cover of its geographical area retaining ample variety of forests with a rich diversity of floral and faunal life forms. Along with various factors, forest fires are a major cause of degradation of Chhattisgarh forests. Fires are reported to damage the regeneration of important tree species including sal *Shorea robusta* Roth trees (Maithani et al., 1986) in sal mixed dry deciduous forest of these areas.

Several studies have been carried out in the developed countries on the forest fire events and their relationship/association/linkage with various environmental parameters. Wotton et al. (2010) made the prediction for Canada and suggested an increase in fire occurrence due to the impact of climate change. Tian et al. (2012) studied climate change and forest fire events in China and suggested that the potential burned areas would increase in future due to climate change. Krusel et al. (1993) studied wildfire activity in southern Australia. They suggested that mean

maximum daily temperature is one of the factors to represent high fire activity. Antonovsky et al. (1989) showed that probability of fire was strongly correlated to the mean air temperature, total rainfall and the maximum period between two successive rains over fire season. The study of fire events in the Indian region were analyzed by a few researcher, such as Vadrevu et al., 2008, 2013; Giriraj et al., 2010; Reddy et al., 2017.

Ahmad and Goparaju (2017a) studied the decadal fire events using the Forest Survey of India (2017) forest fire datasets and identified fire hotspot districts and concluded that high forest fire grids need to be given high priority for conservation and fire prevention and control. Ahmad et al. (2017) studied spatial and temporal perspectives of forest fire events from the year 2005 to 2016 in the Jharkhand state of India and few forest fire hotspots were identified. Furthermore, they analyzed forest fire events using climate data sets such as maximum temperature, wind velocity, relative humidity, solar radiation and rainfall using Cramer's V coefficient (CVC). They found that rainfall has the highest association with forest fire events because as it retains the highest value whereas relative humidity, maximum temperature, solar radiation, and wind velocity are in decreasing order in the relationship with forest fire events. There are very few comprehensive studies on forest fire regime analysis, and its relationship with climate and weather parameters, which results in a conspicuous research gap.

We have used the nine year forest fire data for the state of Chhattisgarh in India and analyzed them in GIS domain to visualize and evaluate the spatial/temporal dimension of fire pattern with the following objectives:

- 1) temporal variation forest fire and trend were studied year wise, month wise (from January to June) and high forest fire areas were identified;
- 2) spatial forest fire pattern was analyzed and forest fire hotspots were identified;
- 3) climate parameters and their spatial pattern and trend were analyzed, and their relation to forest fire events were evaluated by statistical methods.

MATERIALS AND METHODS

The study area. The study area is located between 17°46'11"–24°04'51" northern latitude, and 80°15'57"–84°84'10" eastern longitude (Fig. 1).

The total geographical area is 135 194 km² (Balasubramanian, 2013) bounded on the northwest by Madhya Pradesh, on the southwest by Maharashtra, on the south by Telangana, on the southeast by

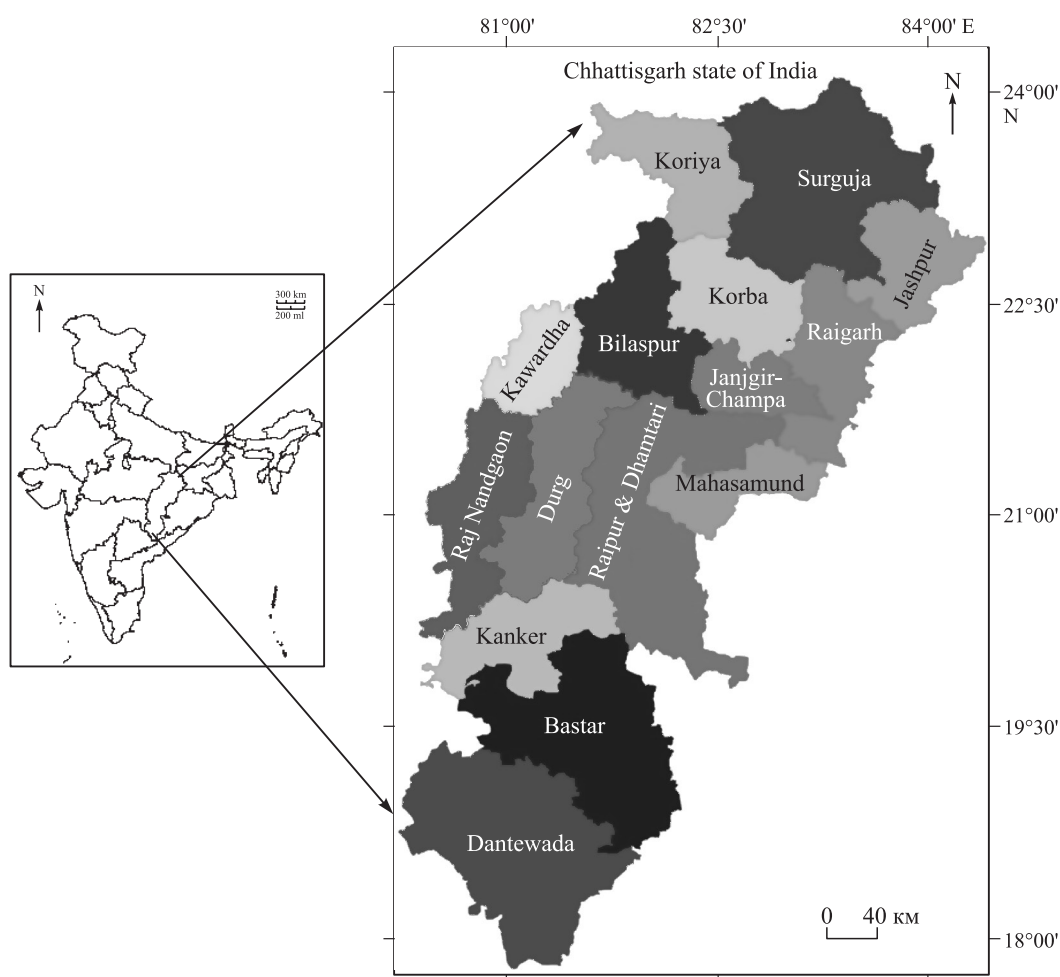


Fig. 1. The location of the study area.

Orissa, on the northeast Jharkhand, and on the north by Uttar Pradesh. The major rivers are Mahanadi, Godavari, Indravati, Hasdeo and Son. Chhattisgarh has a tropical climate with an average rainfall of 1292 mm and air temperatures vary from 0 °C to 25 °C in winter while in summer the temperatures range from 30 to 45 °C.

In general, three forest types (tropical moist deciduous, tropical dry deciduous, and subtropical broad-leaved hill forests) are available in the state of Chhattisgarh. The forests retain the species like sal *Shorea robusta*, teak *Tectona grandis* Linn. f. and miscellaneous other species including bamboo. Several non-wood forest products (NWFPs) including tendu *Diospyros melanoxylon* Roxb. leaves, sal seeds, mahua *Madhuca longifolia* (J. Konig) J. F. Macbr. flowers and seeds, amla *Emblica officinalis* L., harra *Terminalia chebula* Retz., gum, lac (Indian shellac), tamarind and mahul *Bauhinia* spp. leaves are found in these forest.

The state of Chhattisgarh retains tribal culture of a unique race mainly inhabiting the dense forests of Bastar. Actually, more than 70 % of Bastar pop-

ulation make up 26.76 % of Chhattisgarh's entire tribal population.

Data preprocessing and analysis. Administrative boundary of the state of Chhattisgarh and its districts was downloaded from the DIVA GIS Spatial Data (2018). District wise forest cover data percent for the state of Chhattisgarh were utilized for visualization purpose. To analyze the forest fire trend and spatial pattern in the state of Chhattisgarh, forest fire data were downloaded from the Forest Survey of India (2017) from 2008 to 2016. Forest fire points from MS Excel file were downloaded with latitude and longitude. These were exported using ArcGIS software into a shape file. The point density module of Spatial Analyst tool of ArcGIS was applied for analyzing forest fire spatial pattern using forest fire point data, which calculate a magnitude per unit area from point features that fall within a neighborhood around each cell. The *Calculate Density* tool generates a forest fire density map using fire point data and classified from least dense forest fire to most dense forest fire. Finally, by this process we produced maps that exhibit forest fires

hotspot areas based on historical point locations of forest fires. The district monthly rainfall, maximum temperature, number of rainy days and potential evapotranspiration data from 1993 to 2002 were downloaded from the Indian Water Portal Meteorological Data (2016). The average annual monthly data from January to June were used to generate spatial rainfall, maximum temperature, potential evapotranspiration pattern (continuous surface) by the Kriging Interpolation Method (2018), with the graph constructed for the number of rainy days.

Statistical analysis. The Cramer's V coefficient (CVC) was used to quantify the relationship between different parameter calculated based on the equation obtained by Liebetrau (1983). Here we have evaluated the relationship of driving factor on forest fire events:

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

where, ϕ is the coefficient of contingency, χ is derived from Pearson's chi-squared test, n is the grand total of observations, k is the number of columns and r is the number of rows per month at forest fire frequency. CVC has a value between 0 and 1 (inclusive), and a value close to 1 indicates that a driving factor is likely to be an explanatory variable.

RESULTS AND DISCUSSION

Forest fire frequency assessment. Year wise. The frequency of forest fire in Chhattisgarh (annually) from 2008 to 2016 is presented in Fig. 2.

The total occurrence of forest fires from 2008 to 2016 (9 years) was 18 220 out of which 3445 forest fires was noticed in 2012 alone (Fig. 2).

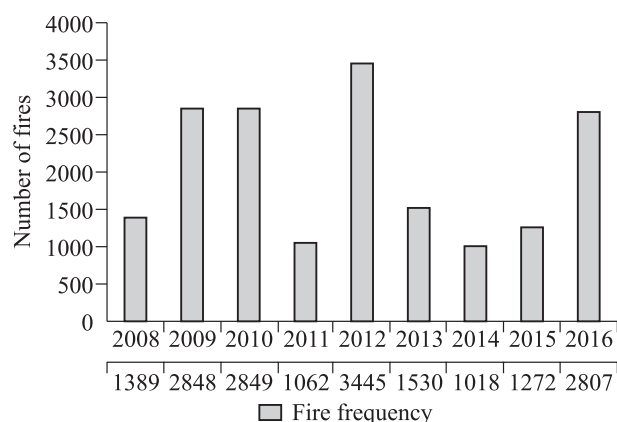


Fig. 2. Annual frequency and number of forest fires in the state of Chhattisgarh, 2008–2016.

Month wise. The forest fire frequency was analyzed (2008 to 2016) monthly, it was observed 80 % of forest fire occurs in March and April, during the summer season (Fig. 3).

District wise forest fire frequency analysis, with respect to forest cover percent. All forest fire frequency data (2008 to 2016) was analyzed district wise and found that Baster and Dantewada districts are subjected to 24 and 33 % of forest fire respectively when considering the whole Chhattisgarh forest fire as 100 %.

Baster and Dantewada together represent 57 % of state forest fire frequency. We have integrated forest fire percent and forest cover area percent district wise (based on Forest Survey..., 2017). Dantewada represents roughly 20 % of Chhattisgarh forest area whereas it represents 33 % of Chhattisgarh forest fire frequency (Fig. 4).

Forest fire trend analysis. Spatial pattern and its trend of forest fire are crucial (Taylor and Skinner, 2003; Yang et al., 2008; Konoshima et al., 2010) for policy-related decision in its prevention, mitigation, and control. Forest fire data were analyzed in GIS domain to understand the spatial variation and pattern. Forest fire frequency from January to June (every month) were considered for the analysis and maps were generated from the year 2008 to 2016. The forest fire roughly started in February from the southern part of the state (zone 1 and 2) and showed its peak in March in all zones. Furthermore, in April fires were decreasing mostly in zone 1 and 3, while they were concentrated in small packets of zone 1 during May onwards (Fig. 5).

Forest fire hotspot analysis. The increasing availability of detailed and accurate spatial datasets of forest fire (Stocks et al., 2002) enables us to identify forest fire hotspot, its extent and fire scales. To analyze the forest fire hotspot and its

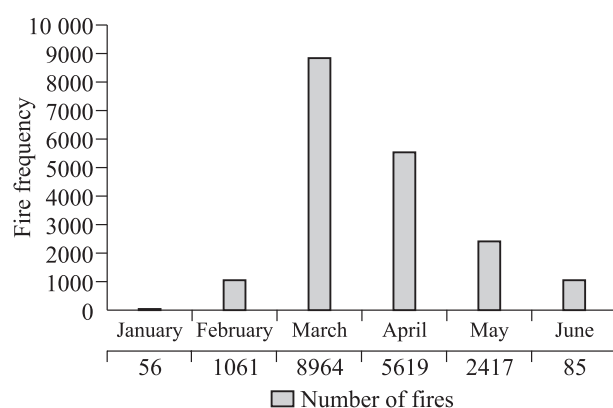


Fig. 3. Monthly frequency and number of forest fires in the state of Chhattisgarh, 2008–2016.

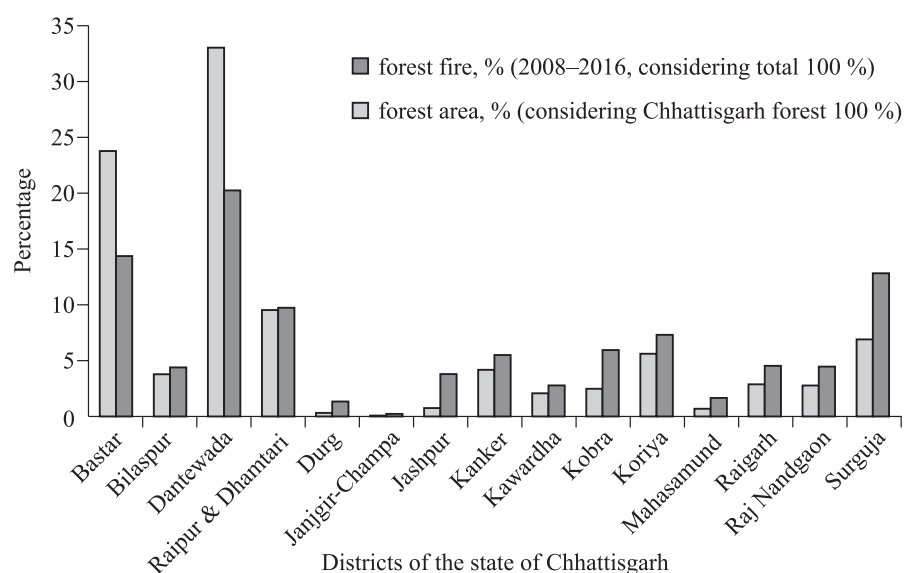


Fig. 4. District forest fire (%), with respect to forest cover (%) in the state of Chhattisgarh, 2008–2016.

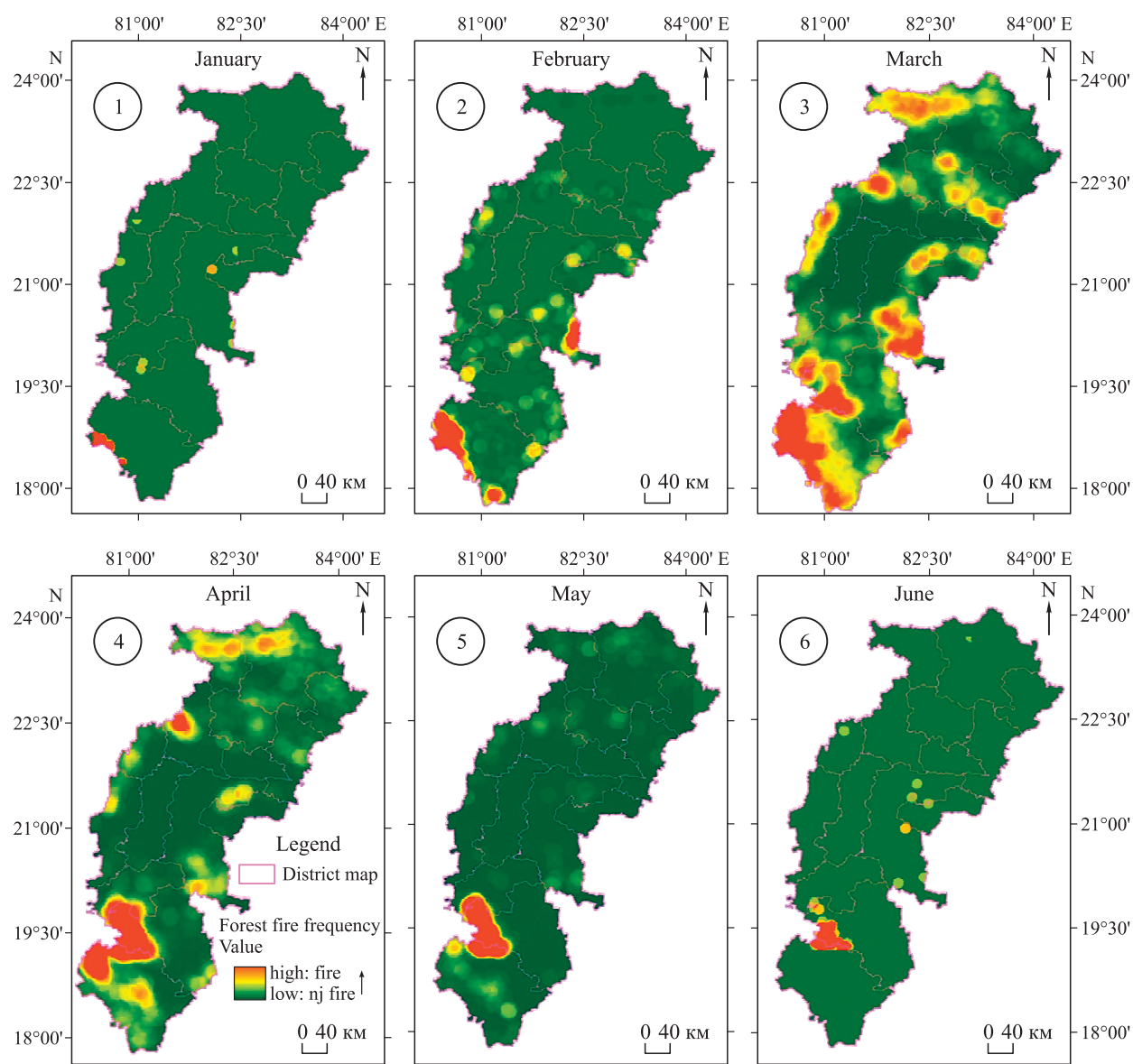


Fig. 5. The fire trends (1–6 are monthly trends in increasing order from January to June).

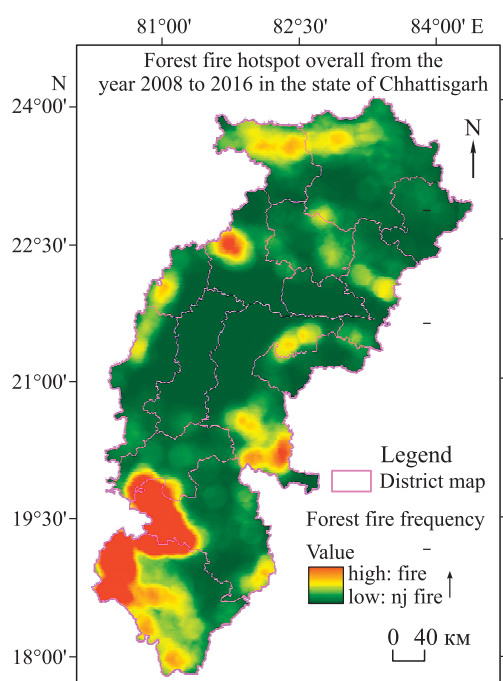


Fig. 6. The forest fire hotspot map of the state of Chhattisgarh.

spatial pattern in the state of Chhattisgarh, all forest fire data were integrated and analyzed in ArcGIS software simultaneously. Finally, using the process as a density tool, we generated forest fire hotspot maps (Fig. 6). In general, three hotspot locations (Table 1) were identified demonstrating a higher risk of forest fire.

Climate parameter trend. The forest fire is an ecological disturbance and more or less heterogeneous in nature which is controlled by climate and weather (Flannigan and Harrington, 1988; Bessie and Johnson, 1995), so it becomes important for further study and evaluation. Fire weather conditions must be evaluated on daily basis (Van Wagner, 1987) and during the fire season provide the valuable input of its trend to help to alert the forest department of that region. The spatial rainfall pattern month wise was analyzed monthly from January to June throughout the Chhattisgarh state for better visualization of forest fire trend and its relationship

with other climatic factors. The decadal average rainfall (mm) month wise (January to June) spatial distribution pattern was found in the range of 7 to 28, 6 to 20, 9 to 23, 5 to 21, 14 to 44, and 90 to 177, respectively. In January, February and March zone 1 received less rainfall whereas zones 2 and 3 receive relatively more rainfall (Fig. 7).

The evaluation of maximum temperature revealed that the value ranges in January were lowest (24–30 °C) among all months whereas southern portion of Chhattisgarh (zone 1) showed relatively high temperature during January, February, and March. The maximum temperature was as high as 41 °C in March and April. The significant increase in temperature was observed in March, whereas high temperature concentrated was observed over the southern part of the state. The highest temperature of 43 °C was registered in May (highest among all months) with high concentration mostly in the northern part of the state (Fig. 8).

Furthermore, a decreasing trend in temperature was observed after May. Higher evapotranspiration dries the existing vegetation and soil during the summer season by reducing the moisture on it. The situation was further aggravated when the area received less rainfall and exhibited more fire occurrence (Pausas, 2004). The precipitation and evapotranspiration are significant parameters widely used for modeling drought index (Vicente Serrano et al., 2010) and highly useful for forest fire analysis (Wells et al., 2004; Flannigan et al., 2005). The average monthly potential evapotranspiration over the area during the summer season was analyzed and depicted in Fig. 9.

The decadal average potential evapotranspiration month-wise (January to June) and its spatial distribution pattern were found in the range of 4 to 7, 5 to 8, 6 to 9, 8 to 9, 8 to 9, and 6 to 9, respectively and it was found lowest in the month of January. The potential evapotranspiration in January, February, and March was found relatively high in the southern area (zone 1) of the state, whereas these areas exhibit relatively low potential evapotranspiration in May and June.

Table 1. Hotspot location description

Hotspot, zone	Location description
1	South of Chhattisgarh (West of Baster and North West of Dantewada district)
2	East of Chhattisgarh (South East of Raipur and Dhamtari district)
3	North-West of Chhattisgarh (North-West of Bilaspur district)

These high risk forest fire zones were evaluated with respect to climatic datasets.

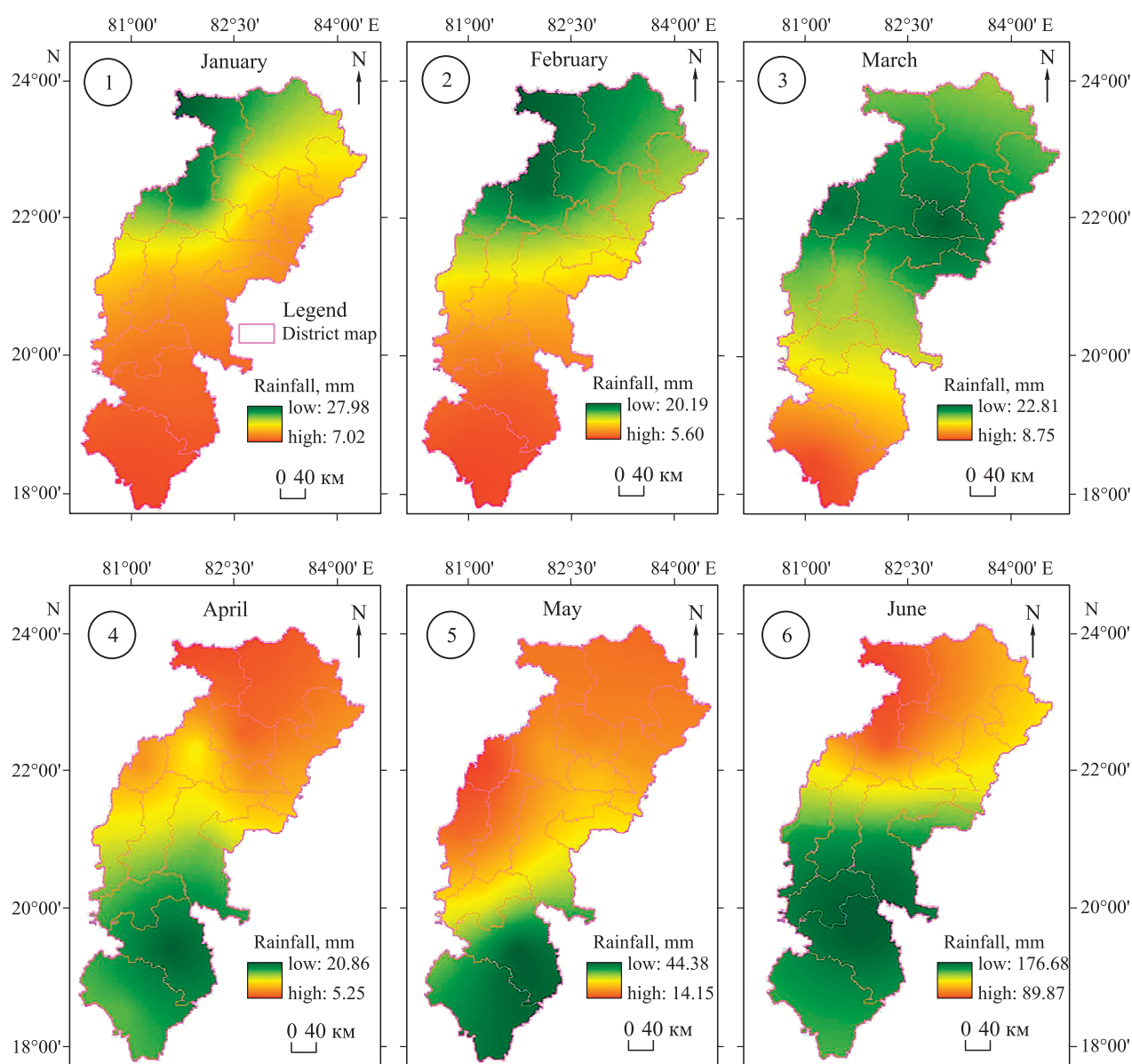


Fig. 7. The rainfall trend (1–6 are January, February, March, April, May, and June, respectively).

The number of wet/dry days analyses of precipitation regime have an impact on the occurrence and severity of forest fires (Chen et al., 2014). The average decadal monthly (January–June) number of rainy days of each district is presented in Fig. 10.

The number of rainy days in January and February in Dantewada and Bastar districts (zone 1) were in the range of 0.72 to 0.92 and found lowest among all districts. These values were also lowest in all months (January to June), whereas these districts showed the high number of rainy days in June in the range from 8.3 to 9.2. The number of rainy days from January to June in Bilaspur district was found in the range of 1.3 to 3.6. Furthermore, the Raipur and Dhamtari districts showed roughly low number

of rainy days from January to April whereas it was found high in June.

Data statistical analysis. Here our objective is to find the relationship of climate data with forest fire events. The Crammer's V coefficient (CVC) was obtained and its value was calculated (Table 2).

Here CVC value of rainfall, maximum temperature, the number of rainy days and potential evapotranspiration were in decreasing order and in the range of 0.74 to 0.32. The CVC value of climatic parameters showed rainfall (0.74) to have a strong relationship (among all) with fire events, whereas potential evapotranspiration (0.32) was least. W. Wang et al. (2016) in their study considered the CVC value greater than 0.3 to show strong

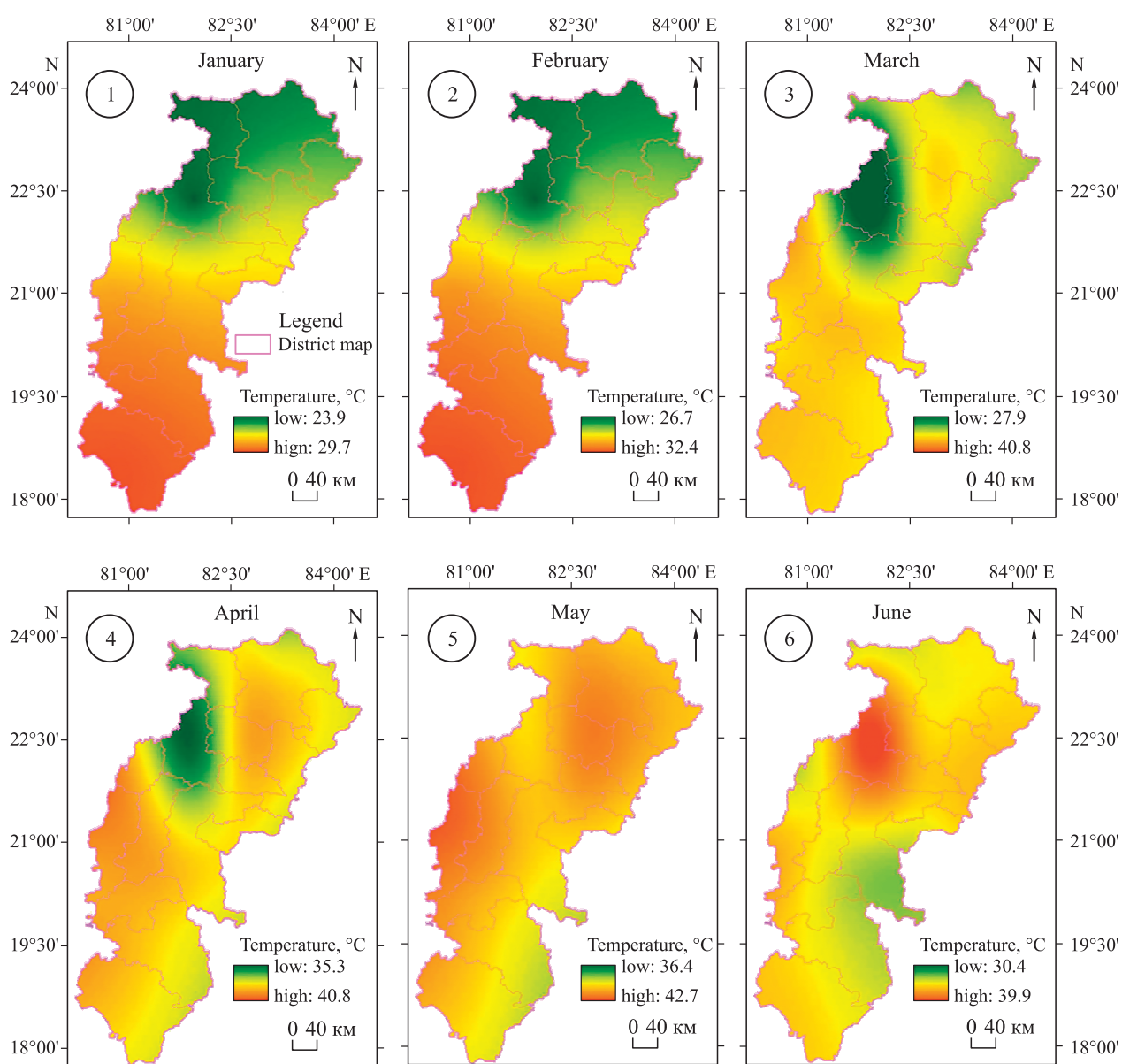


Fig. 8. Maximum temperature trend (1–6 are January, February, March, April, May, and June respectively).

relationships. A similar finding of climate data and their relationship with forest fire events has been observed by F. Ahmad et al. (2017) for the state of Jharkhand.

Fire characterization and climate anomalies. Climate being an important parameter drives the fire behavior (Flannigan et al., 2000; Fried et al., 2004), whereas climate change anomalies are an important factor attributed to forest fire events (Stephens, 2005; Westerling et al., 2006). Several studies in developed countries highlight these relationships, whereas very few studies are found in the Indian states. A recent study by F. Ahmad et al. (2017) revealed that weather and climate parameters had a strong association with forest fire events. Sever-

al studies (Piñol et al., 1998; Wotton et al. 2010; Tian et al., 2012) suggested that forest fire events will increase in the future due to climate change. A study conducted by Y. Vorob'yov (2004) revealed that an average temperature increase due to climate change will increase the duration/span of wildfire season. The temperature in summer maneuvered the local climate, thus leading to the influences on forest fire regime in direct or indirect ways (Wells et al., 2004). A warmer climate leads to higher rates of evapotranspiration. These processes, along with a changing pattern of precipitation, will affect the spatial and temporal distribution of soil moisture, relative humidity and increase the frequency of droughts. Drought severity plays a major role in

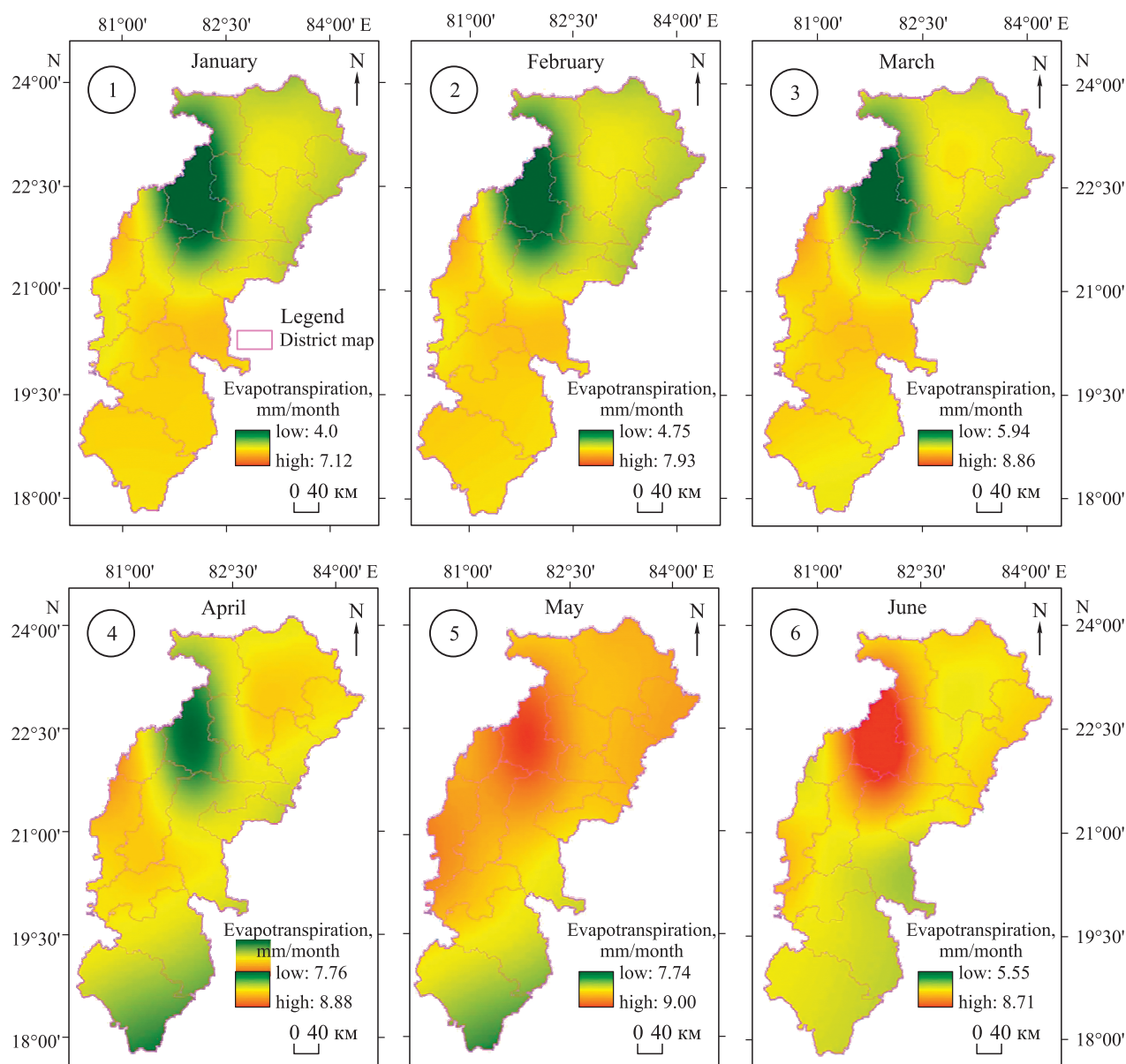


Fig. 9. Potential evapotranspiration trend (1–6 are January, February, March, April, May, and June, respectively).

wildfire frequency and extent of damage (Wells et al., 2004). The future climatic change, though, will have its impact globally and will act severely in developing countries like India. Sinha Ray and De (2003) study of climate change in India suggested the occurrence of extreme events in future, whereas the study by Lal et al. (1995) predicted an increase of 0.7–1.0 °C annual mean maximum and minimum surface air temperatures in comparison to the 1980s for the year 2040. Some studies (Khan et al., 2000; Shrestha et al., 2000; Mirza, 2002; Lal, 2003; Goswami et al., 2006; Dash et al., 2007) also consider the number of rainy days and annual precipitation has decreased. The area of central part of India including the state of Chhattisgarh

is largely occupied by deciduous trees and seems to be forest fire hotspot during the summer season; it also experiences decline in rainfall, number of rainy days (Kumar and Jain, 2011) and is extremely prone to climate change (O'Brien et al., 2004), which is a major future challenge for policymakers. The forest fire is a threat to many forest ecosystems (Ahmad and Goparaju, 2017a, b). Dry deciduous forests are more liable with danger of forest fire (FRA..., 2001). A study conducted by Chaturvedi et al. (2011) on the impact of climate change in India based on an assessment on climate projections for A2 and B2 scenarios showed that many forest dominant states of the central part of India, including Chhattisgarh, are to undergo changes. Finally,

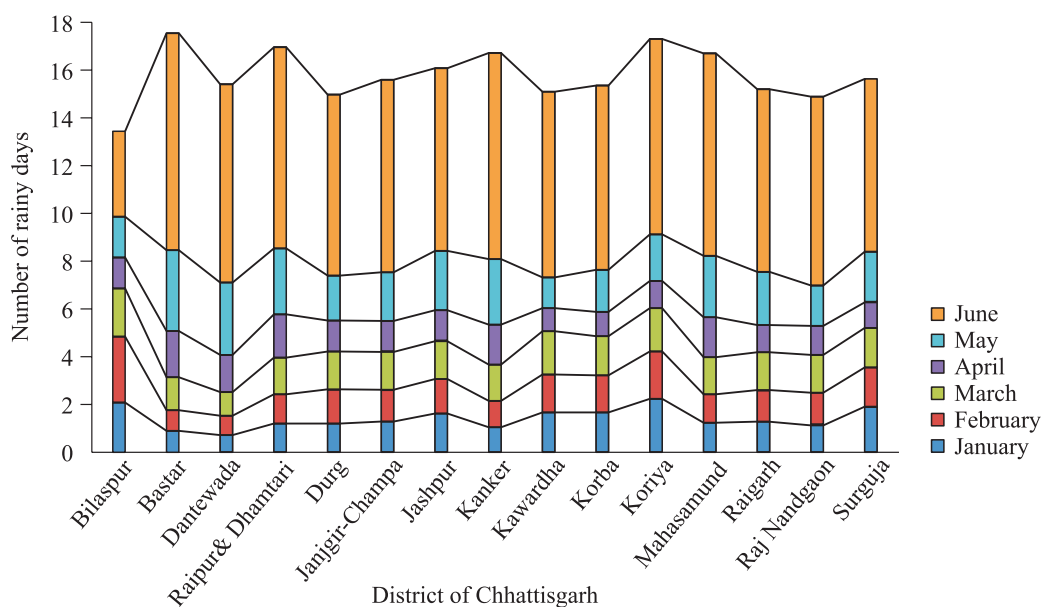


Fig. 10. Number of rainy days in Chhattisgarh districts from January to June.

Table 2. Crammer's V coefficient (CVC) values of forest fire driving factors

Metrological variable (driving factors)	Forest fire frequency Crammer's V coefficient (CVC)
Maximum temperature	0.4274
Number of rainy days	0.3550
Evapotranspiration	0.3227
Rainfall	0.7449

we can summarize that more studies are required to address the climate change anomalies and forest fire events characterization in this region. A proper understanding would help in achieving long-term strategies.

CONCLUSION

The above study used the decadal forest fire data and analyzed them in GIS domain to visualize the spatial dimension of fire trend and pattern analysis and identify the forest fire hotspots in Chhattisgarh and to analyse their interrelationship with climate parameter trend. This research revealed that the climate parameters and their trends are strongly correlated with forest fire occurrence, especially in summer. This is well supported by our statistical analysis based on the values of CVC. There is a need to monitor climate parameters regularly during summer with special care towards forest fire hot spot zone to be able to mitigate forest fire. In addition, there is a need to formulate and implement the

forest fire policy based on the evaluation of the socio-economic condition of ethnic tribes, which are dependent on the forest. It is important to encourage them to combat forest fires using community participation approach, such as Joint Forest Management (Khare et al., 2000). Furthermore, there is a need to develop a fire predictive model utilizing fire events, climate and other dependent parameters in the Indian region, as there is a potential research gap here. Whereas similar studies have been adequately represented by in research findings of developed countries. Harrison et al. (2010) rightly wrote: «Climate is the principal control of fire regimes, although human activities have had an increasing influence on the distribution and incidence of the forest fire in recent centuries».

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REFERENCES

- Ahmad F., Goparaju L. Geospatial assessment of forest fires in Jharkhand (India) // Ind. J. Sci. Technol. 2017a. V. 10. Iss. 21. P. 1–7.
- Ahmad F., Goparaju L. Assessment of threats to forest ecosystems using geospatial technology in Jharkhand state of India // Curr. World Environ. 2017b. V. 12. N. 2. P. 355–365.
- Ahmad F., Goparaju L. Climate change and its impact on forest fire in the state of Himachal Pradesh and Uttarakhand states of India: Remote sensing and GIS

- analysis // *Contemp. Trends. Geosci.* 2018. V. 7. N. 2. P. 229–246.
- Ahmad F., Goparaju L., Qayum A., Quli S. M. S. Forest fire trend analysis and effect of environmental parameters: a study in Jharkhand state of India using geospatial technology // *World Sci. News.* 2017. V. 90. P. 31–50.
- Ahmad F., Uddin M. M., Goparaju L. Spatial analysis of fire characterization along with various gradients of season, administrative units, vegetation, socio economy, topography and future climate change: A case study of Orissa state of India // *Ecol. Questions.* 2018. V. 29. N. 4. P. 9–22.
- Antonovsky M. Ya., Ter-Mikhaelian M. T., Furyaev V. V. A spatial model of longterm forest fire dynamics and its applications to forests in Western Siberia. IIASA WP-89-109. Laxenburg, Austria: IIASA, 1989. 26 p.
- Balasubramanian A. Chhattisgarh at a glance, 2013. https://www.researchgate.net/publication/320735605_Chhattisgarh-At_a_Glance
- Bessie W. C., Johnson E. A. The relative importance of fuels and weather on fire behavior in subalpine forests // *Ecology.* 1995. V. 76. N. 3. P. 747–762.
- Blackmarr W. H. Moisture content influences ignitability of slash pine litter. Res. Note SE-173. Asheville, NC: USDA, For. Serv., Southeastern For. Exp. St., 1972. 7 p.
- Capitaino R., Carcaillet C. Post-fire Mediterranean vegetation dynamics and diversity: a discussion of succession models // *For. Ecol. Manag.* 2008. V. 255. Iss. 3–4. P. 431–439.
- Chaturvedi R. K., Gopalakrishnan R., Jayaraman M., Bala G., Joshi N. V., Sukumar R., Ravindranath N. H. Impact of climate change on Indian forests: a dynamic vegetation modeling approach // *Mitig. Adapt. Strateg. Glob. Change.* 2011. V. 16. Iss. 2. P. 119–142.
- Chen F., Niu S., Tong X., Zhao J., Sun Y., He T. The impact of precipitation regimes on forest fires in Yunnan Province, Southwest China // *The Sci. World J.* 2014. V. 2014. Article ID 326782. 9 p.
- Crutzen P. J., Andreae M. O. Biomass burning in the tropics: Impact on atmospheric chemistry and biogeochemical cycles // *Science.* 1990. V. 250. N. 4988. P. 1669–1678.
- Csiszar I., Denis L., Giglio L., Justice C. O., Hewson J. Global fire activity from two years of MODIS data // *Int. J. Wildland Fire.* 2005. V. 14. N. 2. P. 117–130.
- Dash S. K., Jenamani R. K., Kalsi S. R., Panda S. K. Some evidence of climate change in twentieth-century India // *Climat. Change.* 2007. V. 85. Iss. 3–4. P. 299–321.
- DIVA GIS Free Spatial Data, 2018. <http://www.diva-gis.org/Data>
- Dwyer E., Gregoire J. M., Malingreau J. P. A global analysis of vegetation fires using satellite images: Spatial and temporal dynamics // *Ambio.* 1998. V. 27. N. 3. P. 175–181.
- Dwyer E., Pinnock S., Gregoire J. M., Pereira J. M. C. Global spatial and temporal distribution of vegetation fire as determined from satellite observations // *Int. J. Rem. Sens.* 2000. V. 21. Iss. 6–7. P. 1289–1302.
- Engstrom R. T. First-order fire effects on animals: review and recommendations // *Fire Ecol.* 2010. V. 6. Iss. 1. P. 115–130.
- Eva H., Lambin E. F. Burnt area mapping in Central Africa using ATSR data // *Int. J. Rem. Sens.* 1998. V. 19. Iss. 18. P. 3473–3497.
- Ferreira A. J. D., Coelho C. O. A., Ritsema C. J., Boulet A. K., Keizer J. J. Soil and water degradation processes in burned areas: Lessons learned from a nested approach // *Catena.* 2008. V. 74. Iss. 3. P. 273–285.
- Finney M. A. Design of regular landscape fuel treatment patterns for modifying fire growth and behavior // *For. Sci.* 2001. V. 47. N. 2. P. 219–228.
- Flannigan M. D., Harrington J. B. A study of the relation of meteorological variables to monthly provincial area burned by wildfire in Canada (1953–80) // *J. Appl. Meteorol.* 1988. V. 27. P. 441–452.
- Flannigan M. D., Logan K. A., Amiro B. D., Skinner W. R., Stocks B. J. Future area burned in Canada // *Climat. Change.* 2005. V. 72. Iss. 1–2. P. 1–16.
- Flannigan M. D., Stocks B. J., Wotton B. M. Climate change and forest fires // *Sci. Total Environ.* 2000. V. 262. N. 3. P. 221–229.
- Flannigan M. D., Vonder Haar T. H. Forest fire monitoring using NOAA satellite AVHRR // *Can. J. For. Res.* 1986. V. 16. N. 5. P. 975–982.
- Forest Survey of India. State of Forest Report. Dehradun, India: Forest Survey India, 2017. 52 p. <http://fsi.nic.in/forest-report-2017>
- FRA 2000 Global Forest Fire Assessment 1990–2000. FAO For. Res. Ass. Progr. WP 55. Rome, Italy, 2001. http://gfmcc.online/programmes/un/fao/Wp55_eng.pdf
- Fried J. S., Torn M. S., Mills E. The impact of climate change on wildfire severity: a regional forecast for northern California // *Climatic Change.* 2004. V. 64. Iss. 1–2. P. 169–191.
- Giriraj A., Babar S., Jentsch A., Sudhakar S., Murthy M. S. R. Tracking fires in India using Advanced Along Track Scanning radiometer (A)ATSR data // *Rem. Sens.* 2010. V. 2. Iss. 2. P. 591–610.
- Goswami B. N., Venugopal V., Sengupta D., Madhusoodanan M. S., Xavier P. K. Increasing trend of extreme rain events over India in a warming environment // *Science.* 2006. V. 314. Iss. 5804. P. 1442–1445.
- Harrison S. P., Marlon J. R., Bartlein P. J. Fire in the Earth System In: J. Dodson (Ed.). *Changing Climates, Earth Systems and Society.* Int. Year of Planet Earth. Dordrecht, London: Springer Nature, 2010. P. 21–48.
- Impacts of human-caused fires on biodiversity and ecosystem functioning, and their causes in tropical, temperate and boreal forest biomes. Montréal, Québec, Canada: Secretariat of the Convention on Biological Diversity, 2001. 42 p. (CBD Tech. Ser. N. 5).
- Indian Water Portal Meteorological Data, 2016. http://www.indiawaterportal.org/met_data/
- Khan T. M. A., Singh O. P., Sazedur Rahman Md. Recent sea level and sea surface temperature trends along the Bangladesh coast in relation to the frequency of intense cyclones // *Marine Geodesy.* 2000. V. 23. Iss. 2. P. 103–116.

- Khare A., Sarin M., Saxena N.C., Palit S., Bathla S., Vania F., Satyanarayana M. Joint forest management: policy, practice and prospects. Policy that works for forests and people / J. Mayers and E. Morrison (Eds.). Ser. N. 3. India Country Study. New Delhi, India: World Wide Fund for Nature-India: London, UK: Int. Inst. Environ. Develop., 2000. 130 p. <http://pubs.iied.org/pdfs/7535IIED.pdf>
- Konoshima M., Albers H. J., Montgomery C. A., Arthur J. L. Optimal spatial patterns of fuel management and timber harvest with fire risk // *Can. J. For. Res.* 2010. V. 40. N. 1. P. 95–108.
- Korontzi S., McCarty J., Loboda T., Kumar S., Justice C. Global distribution of agricultural fires in croplands from 3 years of Moderate Resolution Imaging Spectroradiometer (MODIS) data // *Glob. Biogeochem. Cycles*. 2006. V. 20. Iss. 2. GB2021. 15 p.
- Kriging Interpolation Method, 2018. <https://en.wikipedia.org/wiki/Kriging>; <https://gisgeography.com/kriging-interpolation-prediction/>
- Krusel N., Packham D., Tapper N. J. Wildfire activity in the mallee shrubland of Victoria, Australia // *Int. J. Wildland Fire*. 1993. V. 3. N. 4. P. 217–227.
- Kumar V., Jain S. K. Trends in rainfall amount and number of rainy days in river basins of India (1951–2004) // *Hydrol. Res.* 2011. V. 42. Iss. 4. P. 290–306.
- Kutiel P., Inbar M. Fire impacts on soil nutrients and soil erosion in a Mediterranean pine forest plantation // *Catena*. 1993. V. 20. Iss. 1–2. P. 129–139.
- Lal M. Global climate change: India's monsoon and its variability // *J. Environ. Stud. Policy*. 2003. V. 6. N. 1. P. 1–34.
- Lal M., Cubasch U., Voss R., Waszkewitz J. Effect of transient increases in greenhouse gases and sulphate aerosols on monsoon climate // *Curr. Sci.* 1995. V. 69. N. 9. P. 752–763.
- Liebetrau A. M. Measures of association. Series: Quantitative applications in the social sciences (Book 32). Newbury Park, CA, USA: SAGE Publ., Inc., 1983. 96 p.
- Maithani G. P., Bahuguna V. K., Lal P. Effect of forest fires on the ground vegetation of a moist deciduous sal (*Shorea robusta*) forest // *Ind. For.* 1986. V. 112. Iss. 8. P. 646–678.
- Malamud B. D., Millington J. D. A., Perry G. L. W. Characterizing wildfire regimes in the United States // *PNAS*. 2005. V. 102. N. 13. P. 4694–4699.
- Mirza M. M. Q. Global warming and changes in the probability of occurrence of floods in Bangladesh and implications // *Glob. Environ. Change*. 2002. V. 12. Iss. 2. P. 127–138.
- O'Brien K., Leichenko R., Kelkar U., Venema H., Aandahl G., Tompkins H., Javed A., Bhadwal S., Barg S., Nygaard L., West J. Mapping vulnerability to multiple stressors: climate change and globalization in India // *Glob. Environ. Change*. 2004. V. 14. Iss. 4. P. 303–313.
- Pausas J. G. Changes in fire and climate in the eastern Iberian Peninsula (Mediterranean Basin) // *Climat. Change*. 2004. V. 63. Iss. 3. P. 337–350.
- Piñol J., Terradas J., Lloret F. Climate warming, wildfire hazard, and wildfire occurrence in coastal eastern Spain // *Climat. Change*. 1998. V. 38. Iss. 3. P. 345–357.
- Ramanathan V., Chung C., Kim D., Bettge T., Buja L., Kiehl J. T., Washington W. M., Fu Q., Sikka D. R., Wild M. Atmospheric brown clouds: impacts on South Asian climate and hydrological cycle // *PNAS*. 2005. V. 102. N. 15. P. 5326–5333.
- Reddy C. S., Padma Alekhya V. V. L., Saranya K. R. L., Athira K., Jha C. S., Diwakar P. G., Dadhwal V. K. Monitoring of fire incidences in vegetation types and Protected Areas of India: Implications on carbon emissions // *J. Earth Syst. Sci.* 2017. V. 126. N. 11. P. 1–15.
- Rodríguez y Silva F., Molina J. R., González-Cabán A., Machuca M. A. H. Economic vulnerability of timber resources to forest fires // *J. Environ. Manag.* 2012. V. 100. P. 16–21.
- Roy P. S. Forest fire and degradation assessment using satellite remote sensing and geographic information system // *Satellite Rem. Sens. & GIS Appl. Agr. Meteorol. Proc. Training Workshop*, 7–11 July, 2003, Dehra Dun, India / M. V. K. Sivakumar, P. S. Roy, K. Harmsen, and S. K. Saha (Eds.). Geneva, Switzerland: World Meteorol. Org. Publ., 2004. AGM-8, WMO/TD N. 1182. P. 361–400.
- Shrestha A. B., Wake C. P., Dibb J. E., Mayewski P. A. Precipitation fluctuations in the Nepal Himalaya and its vicinity and relationship with some large scale climatological parameters // *Int. J. Climatol.* 2000. V. 20. Iss. 3. P. 317–327.
- Sinha Ray K. C., De U. S. Climate change in India as evidenced from instrumental records // *World Meteorol. Org. Bull.* 2003. V. 52. N. 1. P. 53–59.
- Srivastava R. K., Singh D. Forest fire, haze pollution and climate change // *Ind. For.* 2003. V. 129. Iss. 6. P. 725–734.
- Stephens S. L. Forest fire causes and extent on United States Forest Service lands // *Int. J. Wildland Fire*. 2005. V. 14. N. 3. P. 213–222.
- Stocks B. J., Mason J. A., Todd J. B., Bosch E. M., Wotton B. M., Amiro B. D., Flannigan M. D., Hirsch K. G., Logan K. A., Martell D. L., Skinner W. R. Large forest fires in Canada, 1959–1997 // *J. Geophys. Res. Atmospheres*. 2002. V. 108. Iss. D 1. P. FFR 5–1–FFR 5–12.
- Taylor A. H., Skinner C. N. Spatial patterns and controls on historical fire regimes and forest structure in the Klamath Mountains // *Ecol. Appl.* 2003. V. 13. Iss. 3. P. 704–719.
- Tian X., Shu L., Zhao F., Wang M. Forest fire danger changes for southwest China under future scenarios // *Sci. Silv. Sin.* 2012. V. 48. N. 1. P. 121–125 (in Chinese with English abstract).
- Vadrevu K. P., Badarinath K. V. S., Anuradha E. Spatial patterns in vegetation fires in the Indian region // *Environ. Monit. Assess.* 2008. V. 147. Iss. 1. P. 1–13.
- Vadrevu K. P., Csizsar I., Ellicott E., Giglio L., Badarinath K. V. S., Vermote E., Justice C. Hotspot analysis of vegetation fires and intensity in the Indian region //

- IEEE J. Sel. Top. Appl. Earth Obs. Rem. Sens. 2013. V. 6. Iss. 1. 224–238.
- Vadrevu K. P., Ellicott E., Badarinath K. V. S., Vermote E. MODIS derived fire characteristics and aerosol optical depth variations during the agricultural residue burning season, north India // Environ. Pollut. 2011. V. 159. Iss. 6. P. 1560–1569.
- Van Wagner C. E. Development and structure of the Canadian forest fire weather index system. For. Tech. Rep. 35. Ottawa, Canada: Can. For. Serv., 1987. 35 p.
- Vicente-Serrano S. M., Beguería S., López-Moreno J. I. A multiscalar drought index sensitive to global warming: The Standardized Precipitation Evapotranspiration Index // J. Climat. 2010. V. 23. N. 7. P. 1696–1718.
- Vorobyov Y. Climate change and disasters in Russia // Proc. World Climate Change Conf., Moscow, Russia / Y. Izrael, G. Gruza, S. Semenov, and I. Nazarov (Eds.). Moscow, Russia: Inst. Glob. Climat. Ecol., 2004. P. 293–298.
- Wang W., Zhang C., Allen J. M., Li W., Boyer M. A., Segerson K., Silander J. A. Analysis and prediction of land use changes related to invasive species and major driving forces in the state of Connecticut // Land. 2016. V. 5. N. 3: 25. 22 p.
- Wells N., Goddard S., Hayes M. J. A self-calibrating Palmer Drought Severity Index // J. Climat. 2004. V. 17. N. 12. P. 2335–2351.
- Westerling A. L., Hidalgo H. G., Cayan D. R., Swetnam T. W. Warming and earlier spring increase Western U. S. forest wildfire activity // Science. 2006. V. 313. Iss. 5789. P. 940–943.
- Wotton B. M., Nock C. A., Flannigan M. D. Forest fire occurrence and climate change in Canada // Int. J. Wildland Fire. 2010. V. 19. N. 3. P. 253–271.
- Yang J., He H. S., Shifley S. R. Spatial controls of occurrence and spread of wildfires in the Missouri Ozark Highlands // Ecol. Appl. 2008. V. 18. Iss. 5. P. 1212–1225.

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АНАЛИЗ ТРЕНДОВ ЛЕСНЫХ ПОЖАРОВ И КЛИМАТИЧЕСКИХ ПАРАМЕТРОВ С ИСПОЛЬЗОВАНИЕМ ГЕОПРОСТРАНСТВЕННОЙ ТЕХНОЛОГИИ: ИССЛЕДОВАНИЯ В ШТАТЕ ЧАТТИСГАРХ, ИНДИЯ

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Для решения проблемы лесных пожаров важно изучать связь случаев их возникновения с климатом региона, а также с его глобальными изменениями и потеплением. Исследования на региональном и глобальном уровнях помогают изучать особенности лесных пожаров в деталях. В нашем исследовании выполнена долговременная оценка лесопожарной динамики и выявлены районы наибольшей пожарной опасности в штате Чаттисгарх в Индии. Создана пространственная структура климатических данных, выполнен статистический анализ коэффициента Крамера V (CVC) для установления его связи с лесными пожарами. Исследование показало, что на округа Бастер и Дантевада в штате Чаттисгарх приходится наибольшая доля лесных пожаров – 24 и 33 % соответственно. Выявлены 3 зоны очагов лесных пожаров. В январе, феврале и марте в зоне 1 выпало меньше осадков и были относительно высокие максимальная температура воздуха и потенциальное суммарное испарение по сравнению с зонами 2 и 3. Количество дождливых дней в январе и феврале в округах Дантевада и Бастер (зона 1) было в диапазоне от 0.72 до 0.92 и оказалось самым низким среди всех округов штата. Степень суровости климата в большей степени способствовала возникновению лесных пожаров в зоне 1 по сравнению с другими зонами. Оценка связи значений CVC климатических данных с лесными пожарами показала, что количество осадков, максимальная температура, количество дождливых дней и потенциальное суммарное испарение располагались в порядке убывания и находились в диапазоне от 0.74 до 0.32. Наибольшее значение CVC (0.74) показало, что с лесными пожарами в большей степени связано количество выпадающих на исследованной территории осадков. В июне в этих округах выпадает достаточное количество осадков (90–177 мм), что приводит к увеличению содержания влаги и препятствует горению лесов. Технология геопространственного анализа позволяет изучать различные по тематике наборы данных и применять различные модули/алгоритмы, используемые при составлении тематических карт, что в итоге позволяет делать правильные логические выводы и решать различные исследовательские и практические задачи.

Ключевые слова: лесной пожар, горячие точки, климатические данные, крикинг, коэффициент V Крамера.