sustainability

MDPI

Article

Characterization of Spatial–Temporal Distribution of Forest Fire in Chhattisgarh, India, Using MODIS-Based Active Fire Data

Tapas Ray [1], Dinesh Malasiya [1], Akshkumar Verma [2], Ekta Purswani [3], Asif Qureshi [4,5], Mohammed Latif Khan [1] and Satyam Verma [6,*]

1 Forest Ecology and Eco-Genomics Lab, Department of Botany, Dr. Hari Singh Gour Vishwavidyalaya (A Central University), Sagar 470003, Madhya Pradesh, India; khanml61@gmail.com (M.L.K.)
2 School of Studies in Physics and Astrophysics, Pt. Ravishankar Shukla University, Raipur 492010, Chhattisgarh, India
3 School of Environment and Sustainable Development, Central University of Gujarat, Gandhinagar 382030, Gujarat, India
4 Department of Civil Engineering, Indian Institute of Technology (IIT) Hyderabad, Kandi 502284, Telangana, India; asif@ce.iith.ac.in
5 Department of Climate Change, Indian Institute of Technology (IIT) Hyderabad, Kandi 502284, Telangana, India
6 Department of Environmental Science and Engineering, School of Engineering and Sciences, SRM University-AP, Amaravati 522240, Andhra Pradesh, India
* Correspondence: satyamverma69@gmail.com

Abstract: Forest fires are one of the most common natural and anthropogenic events that have long-term impacts on the environment. In this study, we analyzed 17 years of data on forest fires in Chhattisgarh, India, using active fire and burned area data from the Moderate Resolution Imaging Spectroradiometer. Chhattisgarh was selected as the study area due to its high incidences of forest fires, significant forest cover, and scarce studies on forest fires. Our findings showed that the number of forest fires in the region increased over time, from 1487 forest fires in 2005 to 3074 forest fires in 2021, with the highest number of fires occurring in 2017 and 2009. Most of the fires occurred in deciduous broadleaf forests and savannas, following a consistent seasonal pattern, with the highest percentage of fires (88.88%) occurring in March, April, and May. The fire hotspot was located in the southwest region, dominated by deciduous broadleaf forests which are particularly prone to fires. These results emphasize the significance of effective fire management strategies that consider the seasonal and annual variability of forest fires, particularly in high-risk areas. Immediate attention to controlling forest fires is also critical to minimize its impact on the environment and local communities.

Keywords: MODIS; remote sensing; forest fire; Chhattisgarh

check for updates

Citation: Ray, T.; Malasiya, D.; Verma, A.; Purswani, E.; Qureshi, A.; Khan, M.L.; Verma, S. Characterization of Spatial–Temporal Distribution of Forest Fire in Chhattisgarh, India, Using MODIS-Based Active Fire Data. *Sustainability* **2023**, *15*, 7046. https://doi.org/10.3390/su15097046

Academic Editor: Michele Grimaldi

Received: 4 January 2023
Revised: 20 February 2023
Accepted: 20 April 2023
Published: 23 April 2023

1. Introduction

Forest fires are a natural or anthropogenic phenomenon that has become more frequent in the recent decades worldwide [1,2]. These fires negatively affect forest ecosystems [3]. The frequency and pattern of wildfires depend on various factors, such as vegetation types, season, and climatic conditions of the local area [4]. Fire incidences are highest during the dry season due to the high temperature, particularly in the regions where precipitation remains very low [5]. Studies of forest fires and associated biomass burning have shown that fires emit high levels of greenhouse gases and aerosol particles into the atmosphere [6–8]. Increasing greenhouse gas is a critical issue on both global and regional levels that affects global biodiversity [9–11]. According to Intergovernmental Panel on Climate Change (2014), annual greenhouse gas emissions from 0.3 to 0.6 Gt CO_2/year were attributed to the forest biomass burning in India, with emissions of CO_2 in 2012 making it one of the largest CO_2 emitting nations, accounting for about 6.8% of the world [12].

Forest fires are a common phenomenon in India, and it has been estimated that more than 90% of fires are caused by anthropogenic activities [13]. Anthropogenic fires pose a serious threat to the structure of forest ecosystems and cause land degradation, which affects seedling regeneration, and destroys the organic matter of soil needed to preserve an optimum level of soil humus on the forest floor [14]. Currently, forest fires are a major cause of forest degradation in India, especially in the dry deciduous forest region including Madhya Pradesh, Chhattisgarh, and Odisha. Seasonal (from March to May) forest burning is a very common phenomenon in these regions due to high temperature, abundant fuel load, and very low moisture content in soil surface [15]. Those frequently occurring fires have varying levels of effects on the recovery of tree species in dry deciduous forests [16]. While in the northeastern part of India forest fires are mainly associated with traditional practices such as shifting cultivation [17], in Central India, deforestation, grazing, collection of non-timber forest products, hunting, and residential interface fire are the main causes of forest fires [18–20]. Among the forest types of India, the dry deciduous broadleaf forest contributes to most of the fires compared to other forest types, possibly due to the low content of soil moisture during autumn [21]. Unsustainable development and management could also contribute to enhanced forest fires. Forest Survey of India [13] estimated that 713,789 km^2 of the country's area is currently under forest cover, and about 55% of forest areas are prone to fires annually. Therefore, the management and mapping of fires is essential to managing natural ecosystem structure.

In recent decades, geospatial technologies have been widely used for detecting of fire activities. Remote sensing data and geospatial techniques are particularly powerful tools for studying multi-scale forest fires, analyzing repetitive fire areas, providing valuable information on fire counts, as well as assisting in spatial and temporal fire detection. Remote sensing provides global fire information, at different spatial and temporal resolutions [22,23].

The state of Chhattisgarh is particularly vulnerable to forest fires, with frequent occurrences during the dry season. Despite the critical importance of studying forest fires in this region, there is a dearth of research on the subject.

The study of forest fires in Chhattisgarh is essential in understanding their spatio–temporal distribution, which is subject to change over time. Mapping and monitoring forest fires are crucial for managing natural ecosystems and minimizing the negative impacts of anthropogenic activities. Remote sensing and geospatial techniques offer valuable insights into multi-scale forest fires and can provide crucial information on fire counts, repetitive fire areas, and spatial and temporal fire detection.

The present study aims to evaluate the spatial and temporal distribution of forest fires in Chhattisgarh, using MODIS-based active fire satellite data over 17 years. Specifically, we will generate a forest fire hotspot area map using ArcGIS, as well as identify the seasonal pattern of forest fires. This study will provide a baseline understanding of forest fires in Chhattisgarh and will inform future research and management efforts in the region. Given the dynamic nature of forest fires, regular interval studies will be necessary to understand and monitor their patterns and effects over time.

2. Materials and Methods

2.1. Study Area

The study was conducted in the state of Chhattisgarh, India, which is situated between 17°46′ and 23°15′ N and 80°30′ and 84°23′ E (Figure 1). The total geographical area of Chhattisgarh is 135,192 km^2, of which 55,547 km^2 (41.09%) is recorded as forest cover. The climate of the study area is hot and humid, typical of a tropical region, with three distinct seasons: summer (March to May), rainy (June to October), and winter (November to February). During the summer, the maximum temperature ranges from 30 °C to 45 °C, while the minimum temperature during winter ranges from 0 °C to 25 °C. On average, the region receives 1292 mm of rainfall per year, with the highest precipitation occurring in July and August. Chhattisgarh can be divided into three distinct zones: Northern Hill, Bastar Plateau, and Chhattisgarh Plains. The Northern Hill and Bastar Plateau areas are covered with hilly and natural forests while Chhattisgarh Plains are primarily used for agricultural land of Chhattisgarh state. The southwestern regions of the Bastar Plateau are hilly and fall in the Maikal Range of Satpura hills of Central India. According to Champion and Seth [24], the forest of Chhattisgarh belongs to major two groups, i.e., tropical moist deciduous forest and tropical dry deciduous forest, which are further divided into 12 forest types.

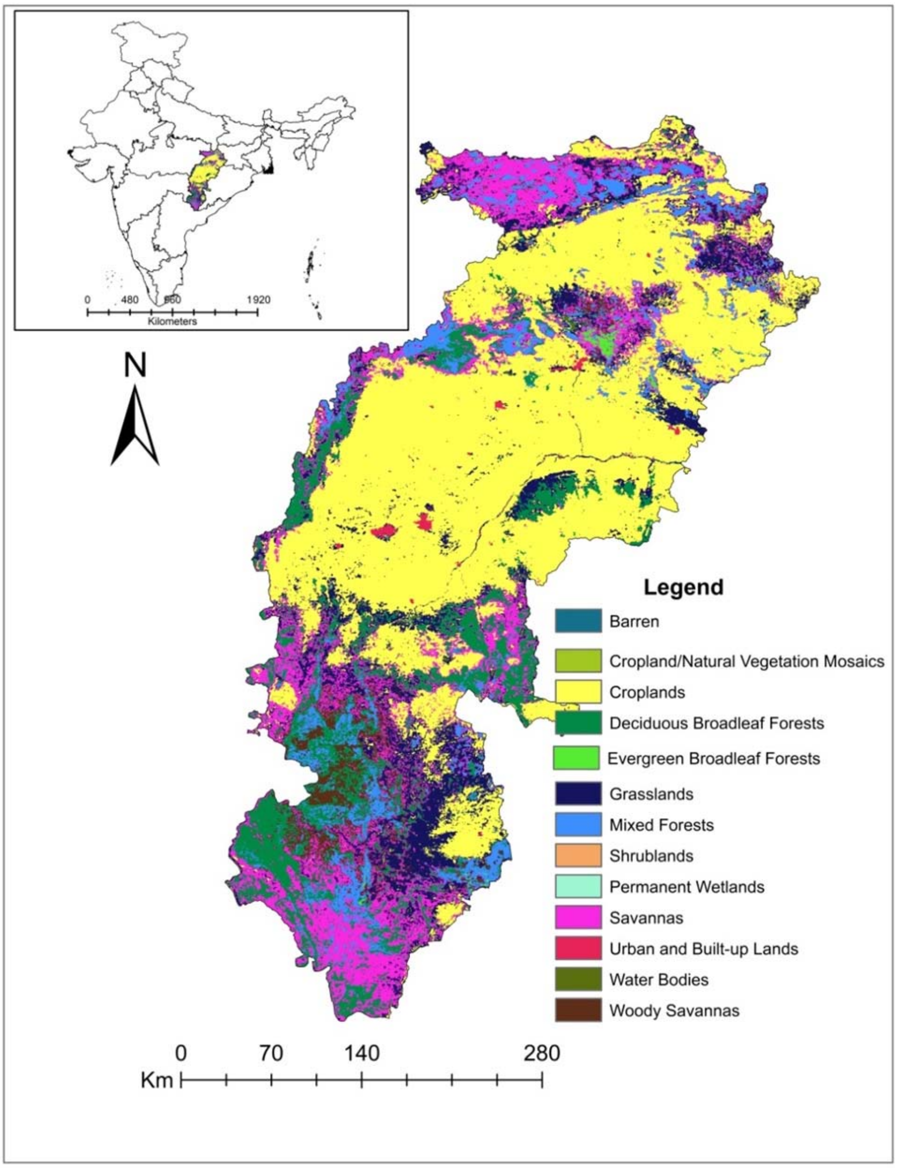

Figure 1. Location and land use land cover map of the study area.

2.2. MODIS Active Fire Data

This study used active fire data obtained from the Moderate Resolution Imaging Spectroradiometer (MODIS) satellite images. MODIS is a key instrument on board the Terra and Aqua satellites, with the Terra orbit passing from north to south across the equator in the morning and the Aqua orbit passing from south to north over the equator in the afternoon. MODIS can detect fires using its middle and thermal infrared bands and collects data in 36 spectral bands that cover the entire Earth's surface every one to two days. This study utilized data at a resolution of 1 km, obtained through the collection of 6 MODIS active fire products based on the active fire detection algorithm provided by the Fire Information for Resource Management System (FIRMS) [2]. FIRMS is a global fire monitoring and alert system that delivers MODIS active fire point data and fire imagery to natural resource managers. The daily MODIS fire products (MOD14/MYD14) used in this study were downloaded from 1 January 2005 to 31 December 2021. The use of MODIS data allows for the detection and monitoring of active fires at a global scale, providing valuable information for the analysis of fire patterns and trends. Top of Form.

2.3. Land Use Land Cover (LULC) Data

MODIS land cover data for the year 2018 was obtained at a spatial resolution of 500 m from NASA's Earth Explorer. This data is derived from the MODIS (Moderate Resolution Imaging Spectroradiometer) satellite, which uses supervised classification of MODIS reflectance data to create a land use land cover (LULC) map (MCD12Q1) [25,26]. The MCD12Q1 data is provided in tile format at the equator using a Sinusoidal grid in HDF4 file format and has been collected since 2001. For this study, the LULC map for the state of Chhattisgarh was extracted and overlaid on the satellite-based MODIS active fire data from 1 January 2005 to 31 December 2021 to identify forest fires within the state. The use of MODIS Land Cover data allows for the identification and mapping of different land use and land cover types, providing valuable information for the analysis of land use patterns and trends.

2.4. Analysis of Vegetation Fire

Initially, 13 classes of land use land cover type maps derived from the MODIS Land Cover Type Product (MCD12Q1) were converted to vector files from the raster format. To derive the forest fire distribution over the various types of land use land cover observation was combined with the 13 types of land use land cover map (Table 1). The incidences of MODIS active fire point's layer were overlaid on the vector files of different vegetation maps and attribute information of point and polygon were joined using an attribute table in ArcGIS (ArcGIS Pro 2.5, ESRI Inc. 2020, Redlands, CA, USA) to obtain the total number of fire points on the forest map. Vegetation fires were extracted from Modis active fire data using forest classes of Modis Land Cover Type Product. A regression analysis was done to ascertain the relation between temperatures, precipitation, and incidences of fires.

Table 1. The description and area under different land use land cover classes in Chhattisgarh.

S. No.	Land Use Land Cover Class	Description	Area (ha)	Area (%)
1	Evergreen Broadleaf Forests	Dominated by evergreen broadleaf and palmate trees (canopy > 2 m). Tree cover > 60%.	44,831	0.34
2	Deciduous Broadleaf Forests	Dominated by deciduous broadleaf trees (canopy > 2 m). Tree cover > 60%.	1,520,923	11.65
3	Mixed Forests	Dominated by neither deciduous nor evergreen (40–60% of each) tree type (canopy > 2 m). Tree cover > 60%.	910,261	6.97
4	Shrublands	Dominated by woody perennials (1–2 m height) 10–60% cover.	5922	0.05
5	Woody Savannas	Tree covers 30–60% (canopy > 2 m).	489,505	3.75
6	Savannas	Tree covers 10–30% (canopy > 2 m).	2,010,339	15.40
7	Grasslands	Dominated by herbaceous annuals (<2 m).	1,594,743	12.21
8	Permanent Wetlands	Permanently inundated lands with 30–60% water cover and >10% vegetated cover.	6428	0.05
9	Croplands	At least 60% of the area is cultivated cropland.	6,391,153	48.95
10	Urban and Built-Up Lands	At least 30% impervious surface area including building materials, asphalt, and vehicles.	42,808	0.33
11	Cropland/Natural Vegetation Mosaics	Mosaics of small-scale cultivation 40–60% with the natural tree, shrub, or herbaceous vegetation.	16,992	0.13
12	Barren	At least 60% of area is non-vegetated barren (sand, rock, soil) areas with less than 10% vegetation.	6868	0.05
13	Water Bodies	At least 60% of the area is covered by permanent water bodies.	14,994	0.11

3. Results

A total of 38,215 forest fire incidences were recorded in Chhattisgarh during the 17-year study period between 2005 and 2021. The maximum number of fires occurred in 2017 (4025), followed by 2009 (3756) and 2012 (3417). There was a slight drop in the number of fires in 2006 (1046) following 1487 incidents of fire in the year 2005, but the trend showed an overall increase until 2020 when only 441 fires were recorded and again increased in 2021. The annual average number of fires during this period was 2313 (Table 2). The percentage of forest fires showed year-to-year variations with an increasing trend with 2009 and 2017 having a drastic increase in mean value of fire points (Table 2). These increases were directly linked to the increase in temperature and decrease in precipitation (Figure 2a,b). The high deviation from the mean values of temperature and precipitation over the years represents more unpredictability in the occurrence of forest fires between 2005 and 2021. The scatter plot showed that there was a significant correlation between forest fire counts and both precipitation and temperature, with R^2 values of 0.071 and 0.164, respectively (Figure 3).

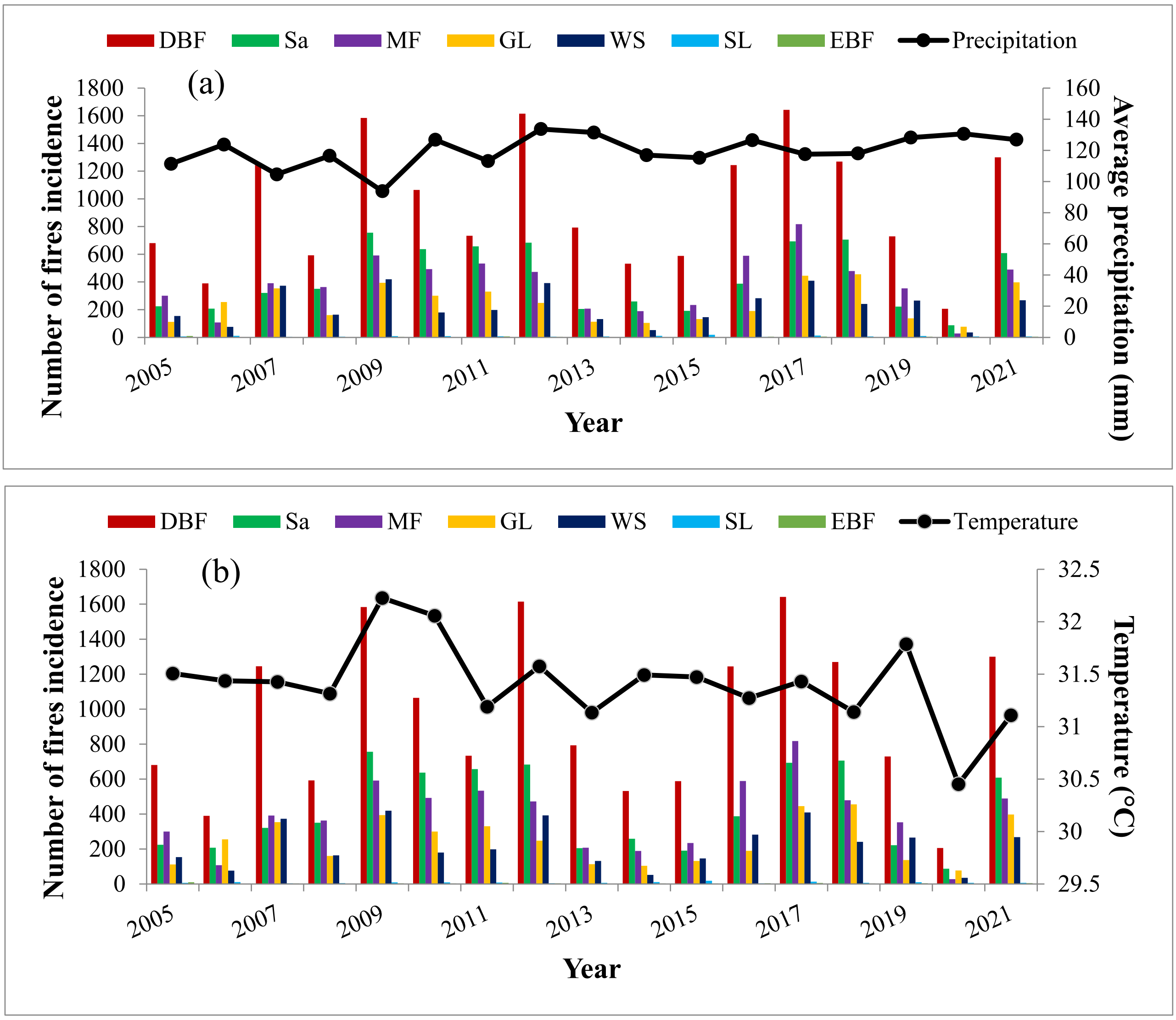

Figure 2. (**a**) Number of annual fire incidences versus annual precipitation and (**b**) annual fire incidences versus temperature in Chhattisgarh between 2005 and 2021. [DBF = Deciduous Broadleaf Forests, Sa = Savannas, MF = Mixed Forests, GL = Grasslands, WS = Woody Savannas, SL = Shrublands, EBF = Evergreen Broadleaf Forests].

Table 2. Yearly wise total number of fire incidences between 2005 and 2021 in Chhattisgarh. [DBF = Deciduous Broadleaf Forests, Sa = Savannas, MF = Mixed Forests, GL = Grasslands, WS = Woody Savannas, SL = Shrublands, EBF = Evergreen Broadleaf Forests].

Vegetation Type	**Yearly Total Number of Fire Incidences on Vegetation**																	**Total**	**Mean ± SD**
	2005	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**		
DBF	680	390	1245	592	1584	1064	733	1615	793	532	588	1244	1642	1269	729	206	1300	16,206	953 ± 449
Sa	224	207	321	350	756	637	657	683	205	259	191	387	693	706	222	87	608	6498	423 ± 231
MF	300	107	391	363	591	492	533	472	207	189	234	589	817	479	353	28	489	6117	390 ± 200
GL	112	255	354	160	394	300	330	248	113	104	132	190	445	455	137	77	397	3729	247 ± 130
WS	154	76	373	164	419	180	198	392	132	52	146	282	409	241	265	35	268	3483	223 ± 123
SL	7	11	3	5	9	9	8	4	7	11	18	3	13	7	10	7	7	125	8 ± 4
EBF	10	0	2	1	3	2	7	3	0	2	2	4	6	2	4	1	5	48	3 ± 3
Total	1487	1046	2689	1635	3756	2684	2466	3417	1457	1149	1311	2699	4025	3159	1720	441	3074	38,215	2248 ± 1049
Mean ± SD	212 ± 232	149 ± 142	448 ± 416	234 ± 214	537 ± 539	383 ± 382	352 ± 298	488 ± 554	208 ± 271	164 ± 187	187 ± 196	386 ± 432	575 ± 562	451 ± 443	246 ± 249	63 ± 71	439 ± 443	5172 ± 5493	

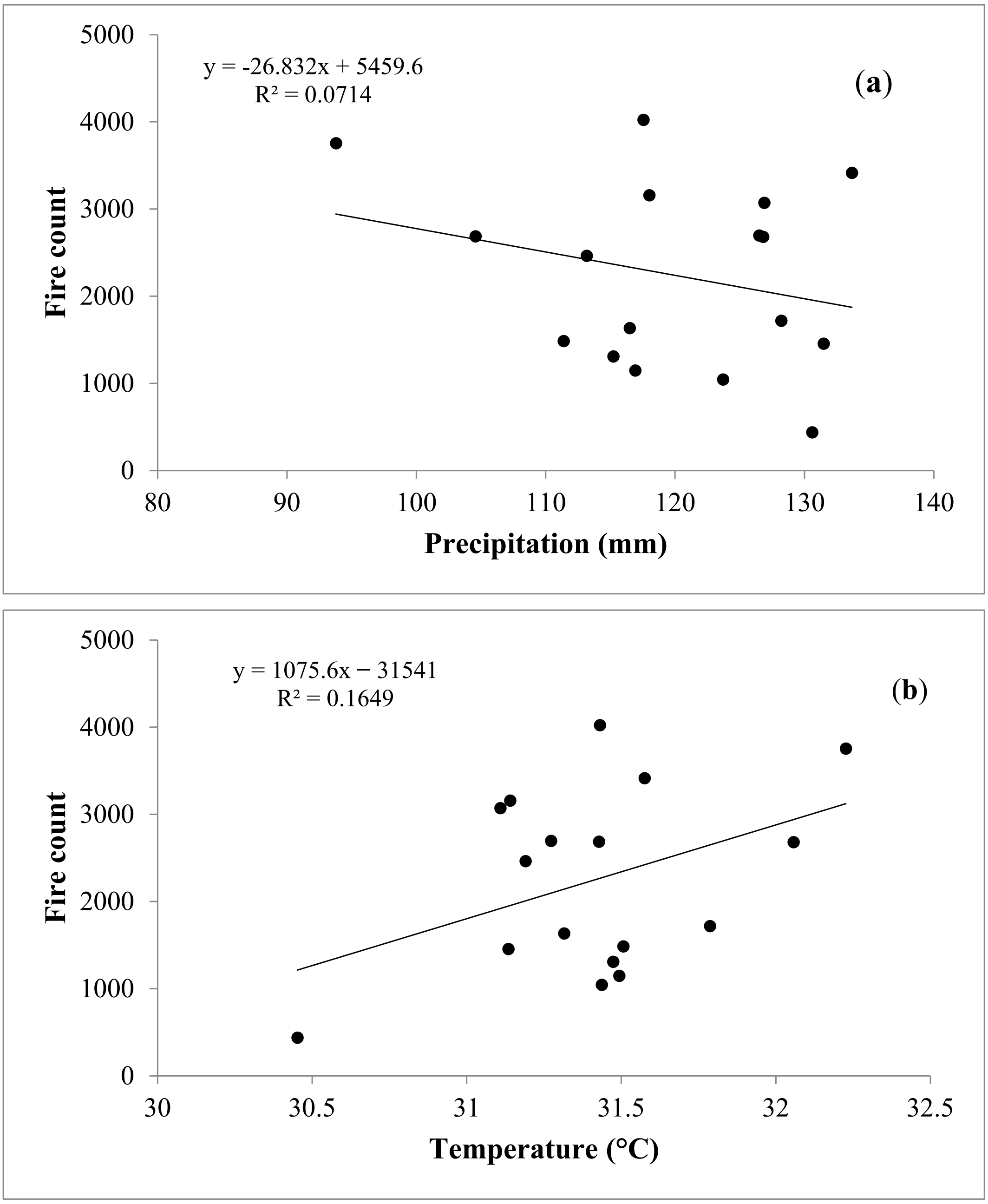

Figure 3. Scatter plot of fire counts versus (**a**) precipitation (mm) and (**b**) temperature (°C).

The monthly distribution of forest fires showed considerable variability. Figure 4 showed the variation in the number of forest fires in each month (January to December). The temporal distribution of fire showed different peaks. During the fire season, the incidences of fire were highest in March (18,000) followed by April (12,239) and May (3730), with the least fires recorded during the first and last 2 months of the summer season and gradually subsiding with the onset of monsoon, with the month of July recording the lowest number of fires (Table 3). Overall, fires increased from an average of 61 ± 82 in January, peaking at 2571 ± 2702 in March, and thereafter declining from April (1748 ± 1927) to June (27 ± 22).

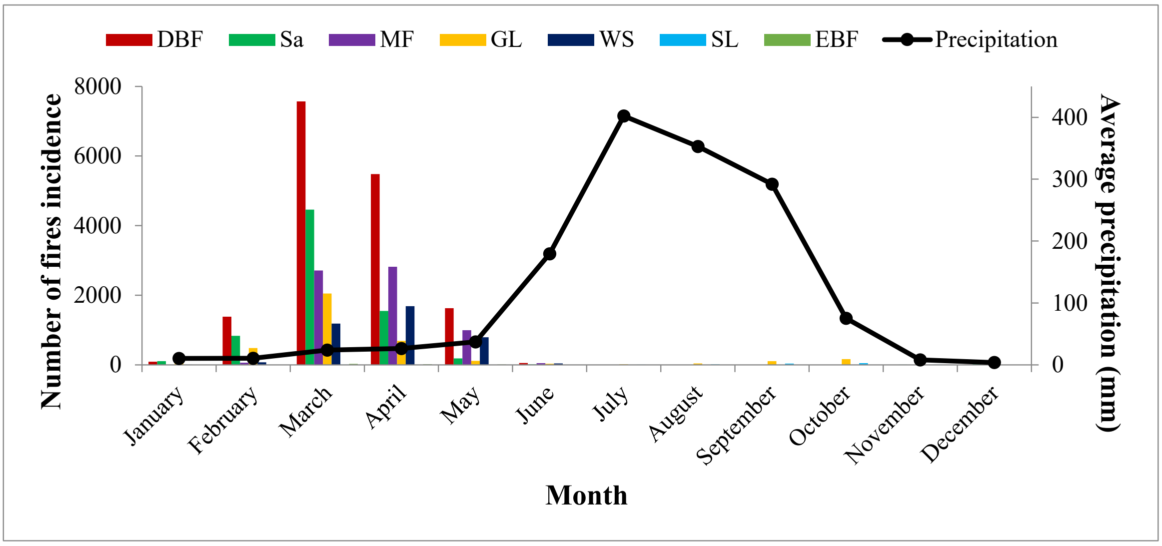

Figure 4. Distribution of month-to-month forest fires versus average precipitation in Chhattisgarh between 2005 and 2021. DBF = Deciduous Broadleaf Forests, Sa = Savannas, MF = Mixed Forests, GL = Grasslands, WS = Woody Savannas, SL = Shrublands, EBF = Evergreen Broadleaf Forests.

Geographical analysis of fire incidences over different forest types revealed that the total number of fires in deciduous broadleaf forests, savannas, mixed forests, grasslands, woody savannas, shrublands, and evergreen broadleaf forests were 680, 224, 300, 112, 154, 7, and 10, in 2005, which increased to 1300, 608, 489, 397, 268, 7, and 5, in 2021, respectively (Table 2). The total number of fires between 2005 and 2021 were recorded in DBF, Sa, MF, GL, WS, SL, and EBF were accounted as 16,206, 7193, 6634, 4203, 3786, 139, and 54, respectively (Figure 5). DBF was the most prone to fires, followed by Sa. Forest-wise mean value shows that deciduous broadleaf forests recorded 953 highest mean value followed by savannas recorded 423, whereas shrublands and evergreen broadleaf forests showed lesser mean values of 8 and 3, respectively (Table 2).

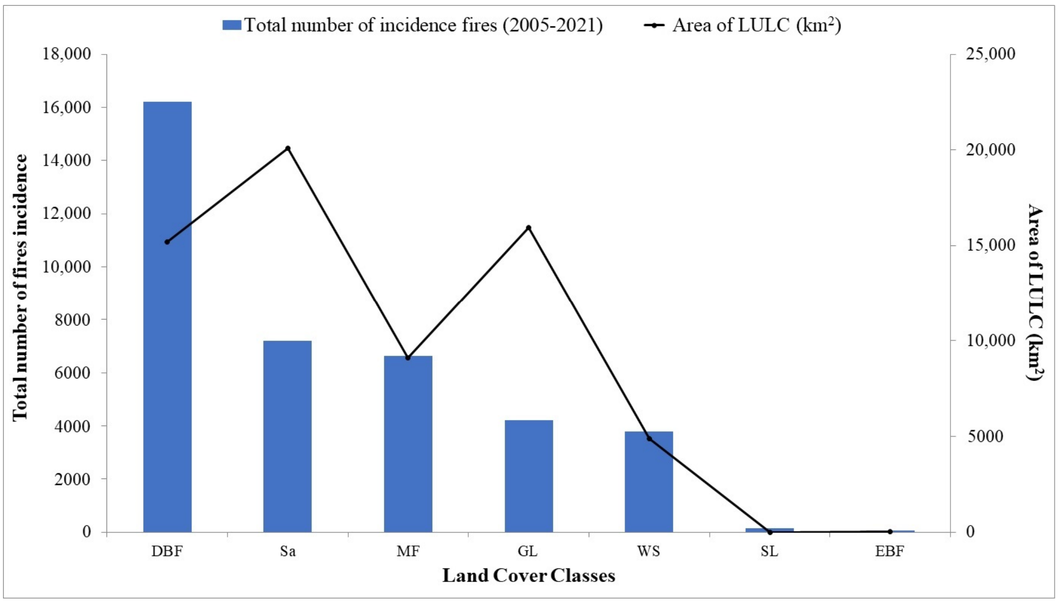

Figure 5. The total number of fire incidents in Chhattisgarh between 2005 and 2021, and the area of different forest types. DBF = Deciduous Broadleaf Forests, Sa = Savannas, MF = Mixed Forests, GL = Grasslands, WS = Woody Savannas, SL = Shrublands, EBF = Evergreen Broadleaf Forests.

Table 3. Monthly wise total incidences of forest fires between 2005 and 2021 in Chhattisgarh. [DBF = Deciduous Broadleaf Forests, Sa = Savannas, MF = Mixed Forests, GL = Grasslands, WS = Woody Savannas, SL = Shrublands, EBF = Evergreen Broadleaf Forests].

Vegetation Type	Monthly Total Number of Fires Incidence on Vegetation												Mean ± SD
	January	February	March	April	May	June	July	August	September	October	November	December	
DBF	88	1383	7568	5480	1628	54	0	0	0	0	0	5	1351 ± 2522
Sa	105	833	4458	1548	186	14	2	4	2	4	7	30	599 ± 1304
MF	3	60	2710	2817	995	49	0	0	0	0	0	0	553 ± 1071
GL	219	482	2048	688	116	31	21	39	107	163	113	176	350 ± 570
WS	8	72	1184	1687	793	40	0	0	0	0	1	1	316 ± 579
SL	4	4	6	0	3	3	7	17	37	49	7	2	12 ± 15
EBF	0	0	26	19	9	0	0	0	0	0	0	0	5 ± 9
Total	427	2834	18,000	12,239	3730	191	30	60	146	216	128	214	3185 ± 5834

The spatial distribution of forest fire maps generated for 2005 (Figure 6a) and all fire points from 2005 to 2021 (Figure 6b) revealed that fires were not evenly distributed throughout the study area. Most fire points were found in the southwest regions, which are part of the Bastar Plateau of Chhattisgarh. These regions, which are predominantly covered with DBF, were highly prone to fires, while hotspot density was lower in the northern regions, which are part of the Northern Hill of Chhattisgarh.

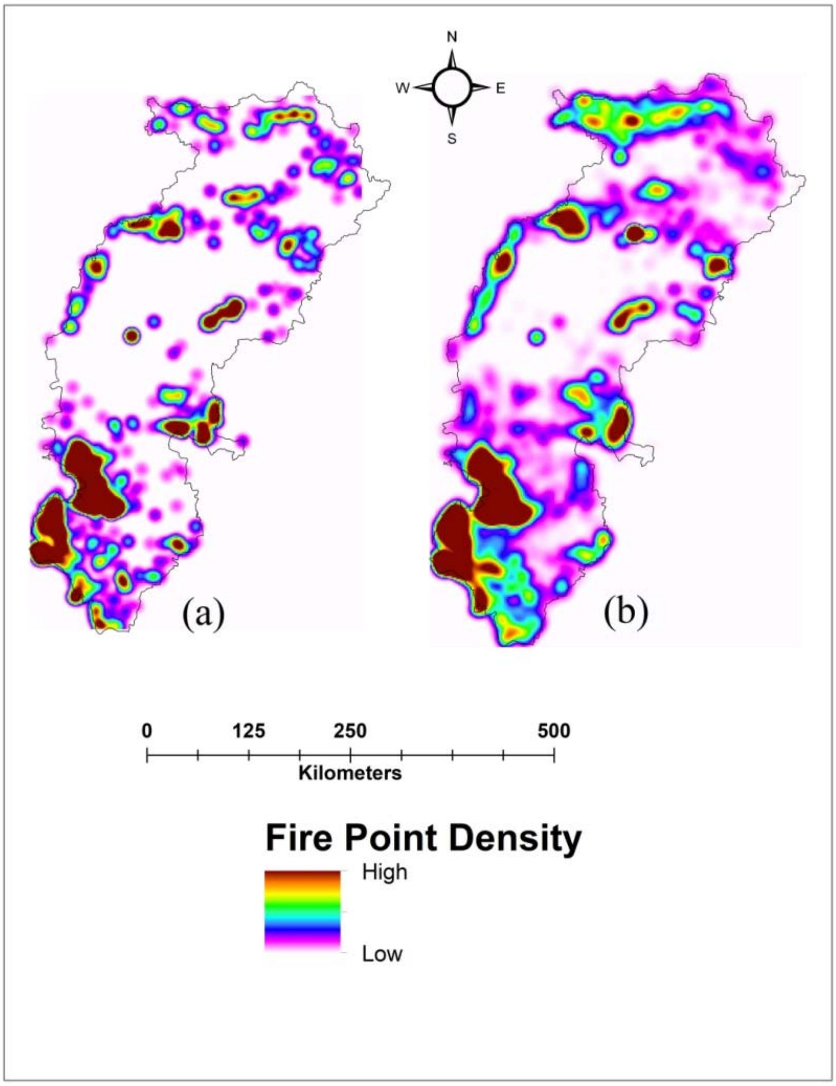

Figure 6. MODIS derived forest fire point density estimated using kernel density (**a**) for 2005 and (**b**) for the entire study period between 2005 and 2021 in Chhattisgarh.

From the analysis of the 17-year study period (2005–2021), it was observed that forest fires were consistently recorded in the regions of Bastar Plateau every year whereas forest fires were discontinuous in the regions of Northern Hill of Chhattisgarh (Figure 7). The spatial distribution of active fire points was limited to the southwest region in 2006 and 2007, whereas, from 2008, it started expanding to the northern part of Chhattisgarh. The forests of the Bastar Plateau are more prone to forest fires compared with the forest of the Northern Hill of Chhattisgarh.

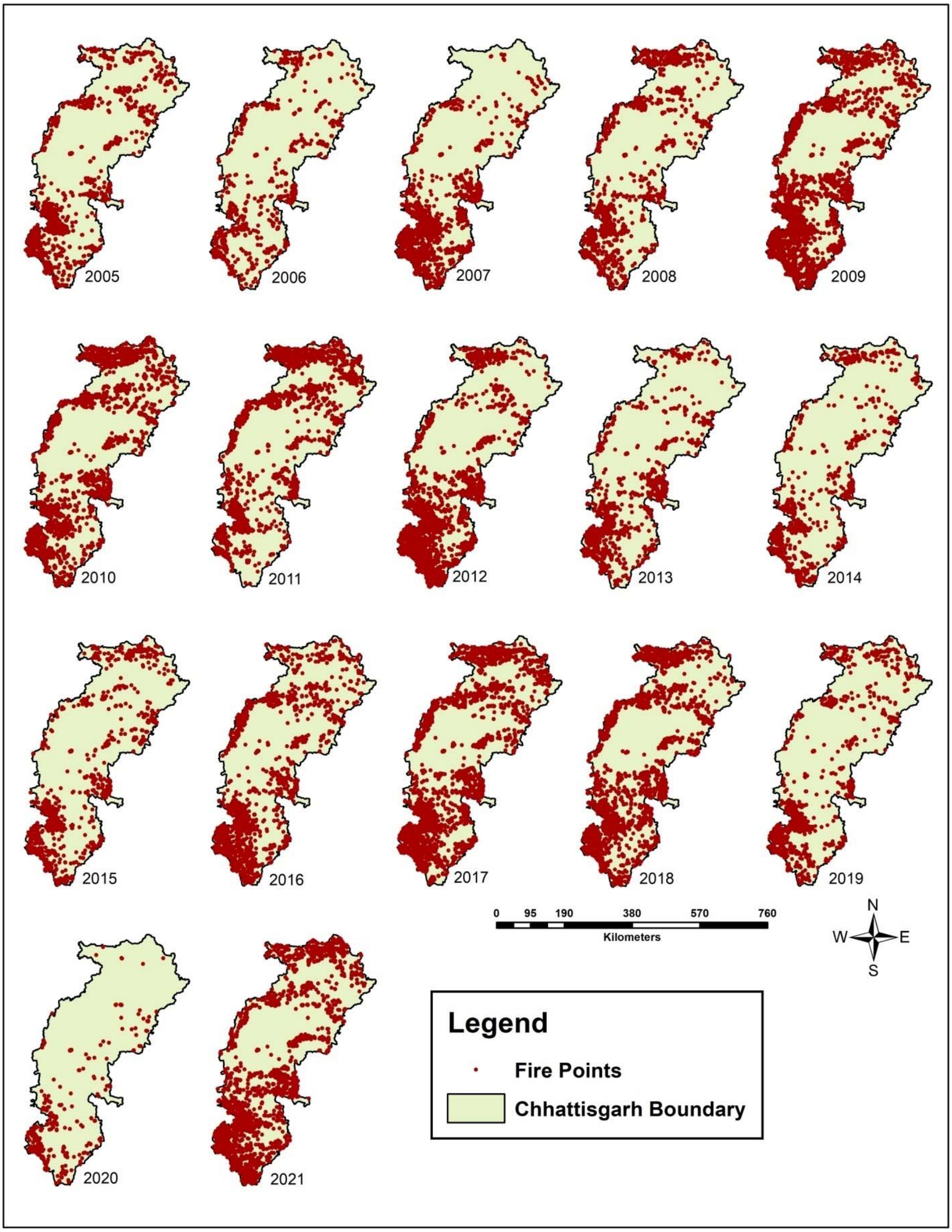

Figure 7. Spatial distribution of forest fires in Chhattisgarh between 2005 and 2021.

4. Discussion

In tropical zones, forest fires are common during the dry session when atmospheric temperatures exceed normal level and precipitation declines. This seasonality is linked to the availability of deciduous forest cover, which regulates the cooling and warming of the ground surface fuel from the direct sunlight during the summer [27]. Many forest fires occur in the dry deciduous forest due to fuel characteristics, especially the compact arrangement of grass fuel—which reaches a higher total—dead fuel loads, and greater horizontal fuel continuity [28]. This could be the possible reason for the forest fire events over large areas of Central India, especially Chhattisgarh, Madhya Pradesh, and Odisha, where seasonal forest burning is a common phenomenon due to the abundant fuel load on the soil surface [15]. Anthropogenic activities, such as the continued demand for forest resources, are a significant cause of forest fires [29]. Kale et al. [30] have estimated that about 90% of forest fires in India are human made. Continued demand for forest resources has contributed to changes in the spatio–temporal characteristics of fire regimes [31], which caused a change in the composition, structure, and regeneration of the forest.

The present study mapped yearly fire counts to characterize the fire count density in Central India's highly prone forests. Deciduous broadleaf forests recorded the highest fire count, followed by savannas, mixed forests, grasslands, woody savannas, shrublands, and evergreen broadleaf forests. Over the 17-year study period, there was an increasing trend in forest fires across the study area, and fires varied with the forest type, season, year, and month. Over the 17-year study period, forest fires increased 3-fold, with the highest fire counts recorded in 2017 and 2009. The distribution of MODIS active fire points was concentrated over Bastar Plateau, as these regions are mostly covered with deciduous broadleaf forests and are very highly susceptible to forest fires. In the areas of Bastar Plateau, most of the deciduous trees shed their leaves by the start of summer, and therefore, dried leaf litter and grasses are significantly high during summer which increases the probability of fire. A similar result was reported by Verma et al. [32], who found that about 36% (25,193) of fire points were recorded by the deciduous broadleaf forest over the 15-year study period from 2002 to 2016 in Madhya Pradesh. Srivastava and Garg [33] have also found the highest fire in the deciduous broadleaf forest in India.

The result showed that the highest forest fire counts were recorded in 2017 (4025), followed by 2009 (3756), during the study period. In 2009, there was a drastic increase in the number of forest fires which was directly linked to the increase in temperature and low precipitation. Our result is similar to Ray et al. [6], who found that the highest fire counts were recorded in 2012 (5435), followed by 2009 (4582), between 2002 and 2016 in Madhya Pradesh. Srivastava and Garg [33] have also found that the highest fire counts were recorded in 2009 (28,038) during the study period from 2001 to 2011 in India. A similar result was recorded by Reddy et al. [34] in India. The below normal rainfall, significantly warmer temperature, and severe drought in 2009 caused extremely high forest fires in Chhattisgarh. The year 2020 is interesting as it recorded disproportionately low incidences of forest fires. The Indian government imposed a national-level strict lockdown across the country in 2020 to curb the COVID-19 pandemic. This severely restricted human activities. This reason could be attributed to the decreased number of fires in Chhattisgarh in 2020. The same reason has also been reported by Jain et al. [35], who found that the forest fire significantly decreased in 2020 in Central India. Bastar Plateau showed highest density of forest fires, which is also corroborated by Vadrevu et al. [36] in their 10-year study period.

In Chhattisgarh, about 76% of the population of the state lives in rural areas and non-timber forest product collection is their primary source of income. One of the forest products collected by the forest-dependent communities is the flowers of Mahua (*Madhuca longifolia*) (from mid-March to the end of April). Before the collection of flowers of Mahua, villagers use fire as a tool for removing litter from the surface of Mahua trees, as ultimately, it helps the collection of flowers. This could be a reason for the higher number of fires recorded in March. Despite this activity, the high temperature and dry forest could also be responsible for the increasing forest fires in March. During the summer season, the dry deciduous forest becomes very dry, the surface temperature rises faster than in other months, and the strong dry wind causes the ground to become drier, which increases the possibility of ignition of a forest fire or fire spreads—or both. Lamat et al. [37] also indicate the likelihood of an increase in forest fire activity under the rising temperature. The forest fire burning showed a consistent seasonal pattern during the study period (2005–2021). The MODIS active fire records showed that there were 3 months (March, April, and May) that contributed to the highest percentage of total fire incidences over the 17 years, with a total proportion of 88.88%. The highest proportion of active fire points was in March (47.10%), followed by April (32.02%) and May (9.76%). Jain et al. [35] also found that the highest number of forest fires were recorded in March in Central India. Our results are similar to Srivastava and Garg [33], who found that incidences of fire across India were highest in March and April compared with any other month over the 11-year study period. Verma et al. [38] found that most of the fire incidences were recorded in February (58.86%), followed by March (34.78%) in Mudumalai Tiger Reserve, Western Ghats, India during the study period from 2001 to 2014. Saranya et al. [39] reported more incidences of fire from March to May due to the high temperature, low fuel moisture, and air humidity in the Similipal biosphere reserve, Eastern Ghats, Odisha, over the 10-year study period.

5. Conclusions

Forest fire analysis over the 17-year study period in Chhattisgarh, India revealed that fire points have an increasing trend. In summary, incidences of fire were higher in March and April compared with any other months, with temperatures increasing drastically and decreased precipitation. Although the total number of forest fires varied across different forest types. The highest fire density has been reported in the area of Bastar Plateau, of which this region accounts for mostly tribal communities who live in the vicinity of forest resources. About 3.89% and 8.04% of forest fires were recorded in 2005 and 2021, respectively. The findings of this study suggest that remote sensing data can be a valuable tool for monitoring forest fires and managing forest burning activities. Deeper investigations are also needed over high forest fire activity regions of Central India. While this study did not focus on forecasting or early warning systems, further research in this area could be valuable in preventing forest fires and minimizing their impact. Forest fires can cause significant damage to the environment and human populations, and it is important to continue studying their spatial and temporal distribution to inform effective management and prevention strategies.

Author Contributions: Conceptualization, M.L.K., S.V. and T.R.; methodology, S.V and T.R.; formal analysis and investigation, T.R., D.M., E.P., A.V. and S.V.; writing—original draft preparation, T.R., D.M. and S.V.; writing—review and editing, A.Q., S.V., E.P. and M.L.K.; supervision, M.L.K. and A.Q.; project administration, M.L.K.; funding acquisition, M.L.K. All authors have read and agreed to the published version of the manuscript.

Funding: The authors acknowledge the financial support of the Department of Biotechnology (DBT), Government of India under Grant No. BT/PR12899/NDB/39/506/2015dt.20/06/2017.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data can be provided on the request.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Cochrane, M.A. Fire science for rainforests. *Nature* **2003**, *421*, 913–919. [CrossRef]
2. Giglio, L.; Schroeder, W.; Justice, C.O. The collection 6 MODIS active fire detection algorithm and fire products. *Remote. Sens. Environ.* **2016**, *178*, 31–41. [CrossRef] [PubMed]
3. Pérez-Cabello, F.; Cerdà, A.; de la Riva, J.; Echeverría, M.; García-Martín, A.; Ibarra, P.; Lasanta, T.; Montorio, R.; Palacios, V. Micro-scale post-fire surface cover changes monitored using high spatial resolution photography in a semiarid environment: A useful tool in the study of post-fire soil erosion processes. *J. Arid. Environ.* **2012**, *76*, 88–96. [CrossRef]
4. Levine, J.S. Global biomass burning: Atmospheric, climatic and biospheric implications. *Eos* **1991**, *71*, 1075–1077. [CrossRef]
5. Stocks, B.J.; Fosberg, M.A.; Lynham, T.J.; Mearns, L.; Wotton, B.M.; Yang, Q.; Jin, J.-Z.; Lawrence, K.; Hartley, G.R.; Mason, J.A.; et al. Climate Change and Forest Fire Potential in Russian and Canadian Boreal Forests. *Clim. Chang.* **1998**, *38*, 1–13. [CrossRef]

6. Ray, T.; Malasiya, D.; Dar, J.A.; Khare, P.K.; Khan, M.L.; Verma, S.; Dayanandan, A. Estimation of Greenhouse Gas Emissions from Vegetation Fires in Central India. *Clim. Chang. Environ. Sustain.* **2019**, *7*, 32–38. [CrossRef]
7. Goldammer, J.G.; Price, C. Potential Impacts of Climate Change on Fire Regimes in the Tropics Based on Magicc and a GISS GCM-Derived Lightning Model. *Clim. Chang.* **1998**, *39*, 273–296. [CrossRef]
8. Levine, J.S. *Biomass Burning and Global Change: Remote Sensing, Modeling and Inventory Development, and Biomass Burning in Africa*; MIT Press: Cambridge, MA, USA, 1996.
9. van der Werf, G.R.; Randerson, J.T.; Collatz, G.J.; Giglio, L.; Kasibhatla, P.S.; Arellano, A.F.; Olsen, S.C.; Kasischke, E.S. Continental-Scale Partitioning of Fire Emissions During the 1997 to 2001 El Niño/La Niña Period. *Science* **2004**, *303*, 73–76. [CrossRef]
10. Renard, Q.; Pélissier, R.; Ramesh, B.R.; Kodandapani, N. Environmental susceptibility model for predicting forest fire occurrence in the Western Ghats of India. *Int. J. Wildland Fire* **2012**, *21*, 368–379. [CrossRef]
11. Bae, M.-S.; Skiles, M.J.; Lai, A.M.; Olson, M.R.; de Foy, B.; Schauer, J.J. Assessment of forest fire impacts on carbonaceous aerosols using complementary molecular marker receptor models at two urban locations in California's San Joaquin Valley. *Environ. Pollut.* **2019**, *246*, 274–283. [CrossRef]
12. Olivier, J.G.J.; Peters, J.A.H.W.; Janssens-Maenhout, G. *Trends in Global CO_2 Emissions. 2012 Report*; Publications Office of the European Union: Copenhagen, Denmark, 2012. [CrossRef]
13. FSI. *State of Forest Report*; Forest Survey of India: Dehradun, India, 2021.
14. Jaiswal, R.K.; Mukherjee, S.; Raju, K.D.; Saxena, R. Forest fire risk zone mapping from satellite imagery and GIS. *Int. J. Appl. Earth Obs. Geoinf.* **2002**, *4*, 1–10. [CrossRef]
15. Chandra, K.K.; Bhardwaj, A.K. Incidence of Forest Fire in India and Its Effect on Terrestrial Ecosystem Dynamics, Nutrient and Microbial Status of Soil. *Int. J. Agric. For.* **2015**, *5*, 69–78. [CrossRef]
16. Ray, T.; Malasiya, D.; Rajpoot, R.; Verma, S.; Dar, J.A.; Dayanandan, A.; Raha, D.; Lone, P.; Pandey, P.; Khare, P.K.; et al. Impact of Forest Fire Frequency on Tree Diversity and Species Regeneration in Tropical Dry Deciduous Forest of Panna Tiger Reserve, Madhya Pradesh, India. *J. Sustain. For.* **2020**, *40*, 831–845. [CrossRef]
17. Puri, K.; Areendran, G.; Raj, K.; Mazumdar, S.; Joshi, P.K. Forest fire risk assessment in parts of Northeast India using geospatial tools. *J. For. Res.* **2011**, *22*, 641–647. [CrossRef]
18. Bahuguna, V.; Upadhay, A. Forest fires in India: Policy initiatives for community participation. *Int. For. Rev.* **2002**, *4*, 122–127. [CrossRef]
19. Roy, P.S. Forest Fire and Degradation Assessment Using Satellite Remote Sensing and Geographic Information System, Satell. *Remote Sens. GIS Appl. Agric. Meteorol.* **2003**, *361*, 400.
20. 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. *Remote. Sens.* **2010**, *2*, 591–610. [CrossRef]
21. Sannigrahi, S.; Pilla, F.; Basu, B.; Basu, A.S.; Sarkar, K.; Chakraborti, S.; Joshi, P.K.; Zhang, Q.; Wang, Y.; Bhatt, S.; et al. Examining the effects of forest fire on terrestrial carbon emission and ecosystem production in India using remote sensing approaches. *Sci. Total. Environ.* **2020**, *725*, 138331. [CrossRef] [PubMed]
22. Thompson, M.P.; Haas, J.R.; Gilbertson-Day, J.W.; Scott, J.H.; Langowski, P.; Bowne, E.; Calkin, D.E. Development and application of a geospatial wildfire exposure and risk calculation tool. *Environ. Model. Softw.* **2015**, *63*, 61–72. [CrossRef]
23. Lizundia-Loiola, J.; Otón, G.; Ramo, R.; Chuvieco, E. A spatio-temporal active-fire clustering approach for global burned area mapping at 250 m from MODIS data. *Remote. Sens. Environ.* **2020**, *236*, 111493. [CrossRef]
24. Champion, H.; Seth, S. *A Revised Survey of the Forest Types of India*; Manager of Publications: Redwood City, CA, USA, 1968.
25. Friedl, M.A.; McIver, D.K.; Hodges, J.C.F.; Zhang, X.Y.; Muchoney, D.; Strahler, A.H.; Woodcock, C.E.; Gopal, S.; Schneider, A.; Cooper, A.; et al. Global land cover mapping from MODIS: Algorithms and early results. *Remote Sens. Environ.* **2002**, *83*, 287–302. [CrossRef]
26. Friedl, M.A.; Sulla-Menashe, D.; Tan, B.; Schneider, A.; Ramankutty, N.; Sibley, A.; Huang, X. MODIS Collection 5 global land cover: Algorithm refinements and characterization of new datasets. *Remote. Sens. Environ.* **2010**, *114*, 168–182. [CrossRef]
27. Hély, C.; Bergeron, Y.; Flannigan, M. Effects of stand composition on fire hazard in mixed-wood Canadian boreal forest. *J. Veg. Sci.* **2000**, *11*, 813–824. [CrossRef]
28. Kodandapani, N.; Cochrane, M.A.; Sukumar, R. A comparative analysis of spatial, temporal, and ecological characteristics of forest fires in seasonally dry tropical ecosystems in the Western Ghats, India. *For. Ecol. Manag.* **2008**, *256*, 607–617. [CrossRef]
29. Kirchmeier-Young, M.C.; Gillett, N.P.; Zwiers, F.W.; Cannon, A.J.; Anslow, F.S. Attribution of the Influence of Human-Induced Climate Change on an Extreme Fire Season. *Earth's Future* **2019**, *7*, 2–10. [CrossRef]
30. Kale, M.P.; Ramachandran, R.M.; Pardeshi, S.N.; Chavan, M.; Joshi, P.K.; Pai, D.S.; Bhavani, P.; Ashok, K.; Roy, P.S. Are Climate Extremities Changing Forest Fire Regimes in India? An Analysis Using MODIS Fire Locations during 2003–2013 and Gridded Climate Data of India Meteorological Department. *Proc. Natl. Acad. Sci. India Sect. A Phys. Sci.* **2017**, *87*, 827–843. [CrossRef]
31. Kodandapani, N.; Cochrane, M.A.; Sukumar, R. Conservation Threat of Increasing Fire Frequencies in the Western Ghats, India. *Conserv. Biol.* **2004**, *18*, 1553–1561. [CrossRef]
32. Verma, S.; Dar, J.A.; Malasiya, D.; Khare, P.K.; Dayanandan, S.; Khan, M.L. A MODIS-based spatiotemporal assessment of agricultural residue burning in Madhya Pradesh, India. *Ecol. Indic.* **2019**, *105*, 496–504. [CrossRef]
33. Srivastava, P.; Garg, A. Forest fires in India: Regional and temporal analyses. *J. Trop. For. Sci.* **2013**, *25*, 228–239.
34. Reddy, C.S.; Jha, C.S.; Manaswini, G.; Alekhya, V.V.L.P.; Pasha, S.V.; Satish, K.V.; Diwakar, P.G.; Dadhwal, V.K. Nationwide Assessment of Forest Burnt Area in India Using Resourcesat-2 AWiFS Data. *Curr. Sci.* **2017**, *112*, 1521–1532. [CrossRef]

35. Jain, M.; Saxena, P.; Sharma, S.; Sonwani, S. Investigation of Forest Fire Activity Changes Over the Central India Domain Using Satellite Observations During 2001–2020. *Geohealth* **2021**, *5*, 1–16. [CrossRef]
36. Vadrevu, K.P.; Badarinath, K.V. Spatial pattern analysis of fire events in Central India—A case study. *Geocarto Int.* **2009**, *24*, 115–131. [CrossRef]
37. Lamat, R.; Kumar, M.; Kundu, A.; Lal, D. Forest fire risk mapping using analytical hierarchy process (AHP) and earth observation datasets: A case study in the mountainous terrain of Northeast India. *SN Appl. Sci.* **2021**, *3*, 425. [CrossRef]
38. Verma, S.; Vashum, K.T.; Mani, S.; Jayakumar, S. Monitoring Changes in Forest Fire Pattern in Mudumalai Tiger Reserve, Western Ghats India, using Remote Sensing and GIS. *Glob. J. Sci. Front. Res.* **2015**, *15*, 13–19.
39. Saranya, K.; Reddy, C.S.; Rao, P.P. Estimating carbon emissions from forest fires over a decade in Similipal Biosphere Reserve, India. *Remote. Sens. Appl. Soc. Environ.* **2016**, *4*, 61–67. [CrossRef]