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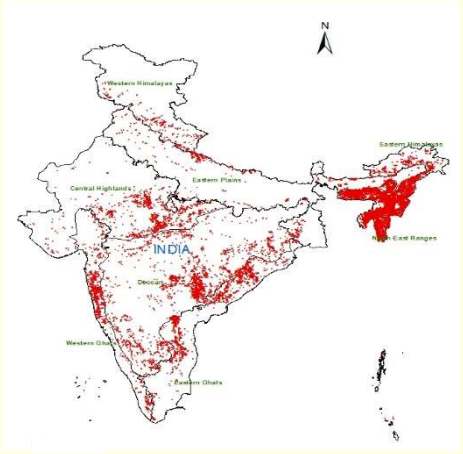
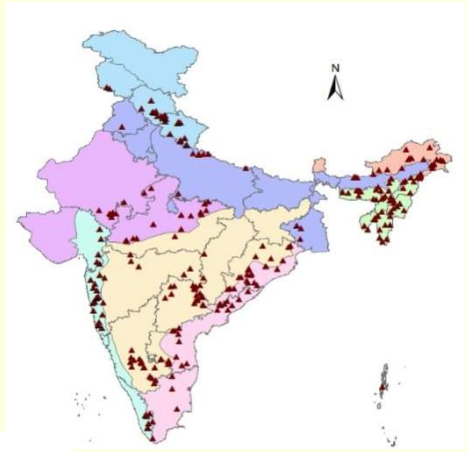
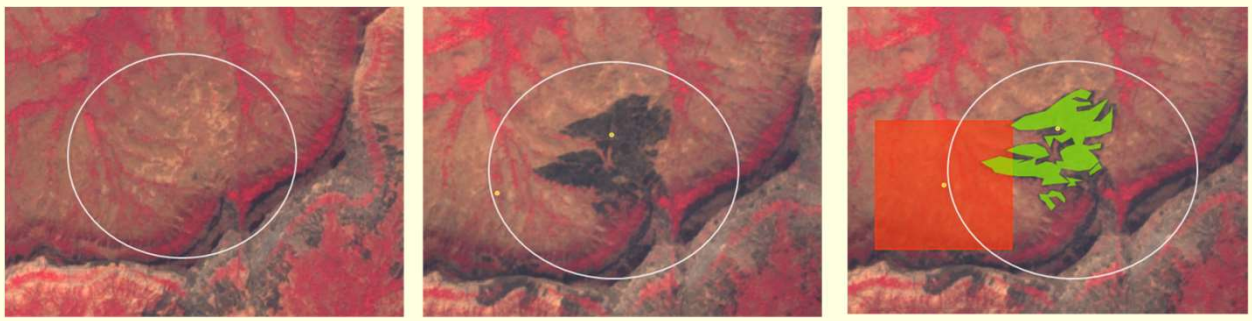
FSI TECHNICAL INFORMATION SERIES

Volume 2 No. 2 2020

Rapid Assessment of Fire affected Forest Areas in the Country based on MODIS-detections following a Sampling Approach







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Rapid Assessment of Fire affected Forest Areas in the Country based on MODIS-detections following a Sampling Approach

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Abstract

Assessment of burnt forest area provides an important input for understanding the ecological, social as well as economic impacts of forest fires. The present study aims to develop a methodology for rapid assessment of burnt forest areas at the country-wide scale based on a statistical sampling approach. Forest Survey of India issues alerts of forest fires based on near-real time detections of forest fires by MODIS sensor. Detected forest fires in the country based on MODIS data during the fire season of 2019-2020 has been used as population for assessing the burnt forest areas in the country. The total burnt forest area in India for the fire season 2019-2020 (i.e. from 01st November, 2019 to 30th June, 2020) has been assessed 11,094 sq. km with 95% confidence level, which is 1.56% of the total forest cover area of the country. Among the different physiographic zones, the maximum forest burnt area has been found in Deccan (5626 sq. km) followed by Central Highlands (2160 sq. km). These two physiographic zones together has contributed to 70% of the total forest burnt areas. In contrast, north-east region with maximum number of MODIS-detected forest fire points in the last fire season, has only 12.50% of the total forest burnt areas. The methodology developed is a simple and reliable procedure to estimate the forest burnt areas in a cost-effective and time-efficient manner. The burnt area estimation would be a useful data for damage assessment and planning restoration activities in fire affected forest areas.

Rapid Assessment of Fire affected Forest Areas in the Country based on MODIS-detections following a Sampling Approach

1. Introduction

Forests play a crucial role in the flow of ecosystem services. They are the storehouses of biodiversity (ISFR 2019) and means for survival and sustenance of a large proportion of India's population (Malik & Dhanda, 2003). Fire is one among the important components for shaping its flora and fauna. It is necessary for the proper functioning of forest ecosystems. However, protecting forests from undesirable and uncontrollable fires is a major challenge for India. More than 29,000 forest fire incidents were reported in the country in the year 2018-2019. More than 36% of the country's forest cover is prone to frequent fires, out of which, approximately 10% is extremely to very highly prone to fires (ISFR 2019). Every year 2-5 % of forests are affected by fires damaging the precious ecological resources. Severe forest fires can cause irreparable damages and long-lasting impacts on the ecosystem. The frequency as well as intensity of forest fires has increased due to escalated anthropogenic activities and changes in the climate (Overpeck et al., 1990; Roy, 2004).India needs to strengthen its efforts for efficiently managing the forest fires to achieve its goals set for green India (Dogra et al., 2018).

Remote Sensing and Geographical information system (GIS) technology-based measures have proved to be effective in control and management of forest fires (Sharma et al., 2012; Negi& Kumar, 2016; ISFR 2017). The satellite based remote sensing methods, their interpretation and analysis can be applied to monitor active fires, estimate burnt area, and understand various factors affecting the forest fire regime to formulate a robust forest fire management plan.

FSI has been carrying out forest fire monitoring at national level since 2004 using Remote Sensing and GIS technology with the main objective of detecting active forest fires at nascent stage and to inform State Forest Departments about the forest fire incidences on near real time basis (Technical Information Series, FSI, 2019a). FSI uses Moderate Resolution Imaging Spectro-radiometer (MODIS) data with 1km X 1km spatial resolution and Suomi-National Polar-orbiting Partnership (SNPP)-Visible Infrared Imaging Radiometer Suite (VIIRS) data with 375m X 375m spatial resolution.

MODIS is an instrument that is on-board two satellite platforms owned by NASA; Terra and Aqua. The MODIS instrument has 36 spectral bands available to view the Earth. The image resolution used for detection of fires is 1 km. A hotspot is detected by MODIS sensor using data from middle infrared and thermal infrared bands. The Terra MODIS instrument acquires data twice daily (10:30 a.m. and 10:30 p.m.), as does Aqua MODIS (2:30 p.m. and 2:30 a.m.). Therefore, four daily MODIS observations are available for forest. State-wise forest fire detections using MODIS-sensor in the country for last three years is given as Annexure 1. Forest fire incidences detected by MODIS in the different physiographic zones of India during the last fire season (2019-20) are shown in Figure 1.

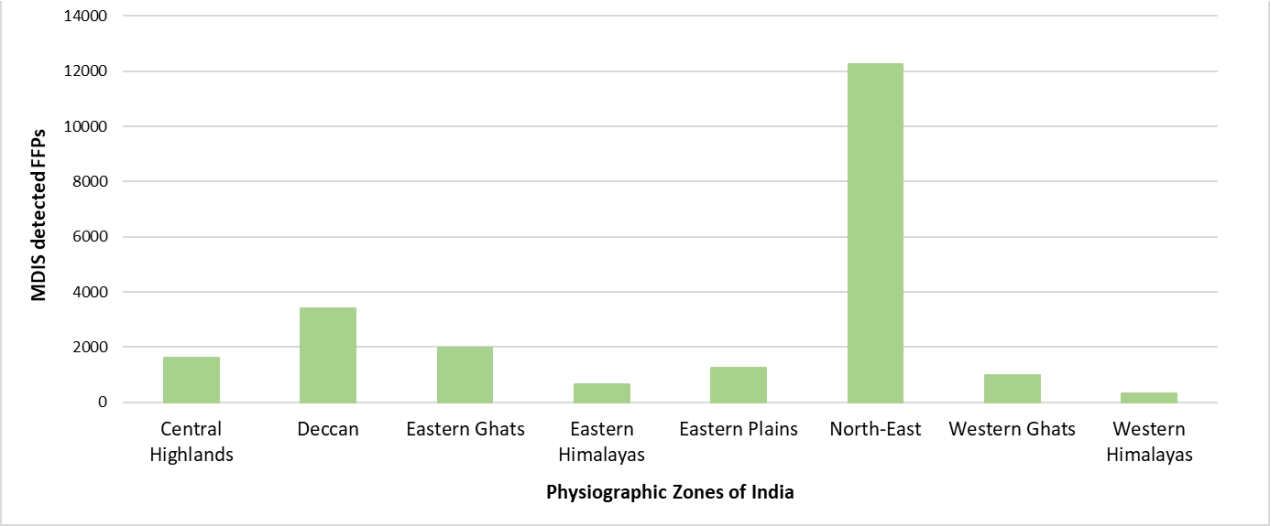

Figure 1 MODIS-based forest fire detections in the country during the fire season 2019-2020.

Forest fire alerts issued by FSI based on near-real time detections of forest fires using MODIS and SNPP-VIIRS data have helped State Forest Departments and communities in controlling forest fires in a significant manner. The database of fire detections accumulated over the years has generated valuable spatial and temporal data to understand nature and spread of forest fires in the states and UTs across the country. The database has also helped in identifying forest areas which are prone to fires (Technical Information Series, FSI, 2019b). Another information which is of significance for policy planning and management of forest fires is about its impact on forests. The foremost data to understand the impact of forest fires is the extent of burnt forest areas. The assessment of burnt forest areas is considered crucial for the following reasons-

- to understand spatial pattern of burnt areas to draw meaningful inputs
- for policy, planning and management

- for estimation of loss to flora, fauna, soil, carbon
- for recognizing appropriate rehabilitation requirements
- for formulating suitable restoration activities

Information on the extent of burnt forest areas to a reasonable accuracy is possible by burnt area mapping using appropriate remote sensing data. The burnt forest areas show a conspicuous signature on the satellite images. However, wall-to-wall mapping of the entire country is a time consuming and expensive exercise. Therefore, in the present study, a sampling-based approach taking MODIS-based near-real time forest fire points (NRT-FFPs) as a population of forest fire locations has been followed for developing a methodology for rapid assessment of burnt forest areas in the country. The results of the study present an assessment of the same for the entire country during last fire season i.e. November 2019 to June 2020.

2. Objectives

The present study has been carried out at the country level with the following objectives-

i. develop a methodology for rapid assessment of fire affected forest areas (burnt area) using sampling method of MODIS-based near-real time forest fire detections
ii. assess fire affected forest areas (burnt area) in the country during 2019-2020 forest fire season using the above sampling-based methodology in different physiographic zones.

The assessment year for the present study is the fire season 2019-2020 (01st November, 2019 to 30th June, 2020).

3. Study Area

The study has been carried out at the country level based on 8 physiographic zones of India namely Central Highlands, Deccan, Eastern Ghats, Eastern Himalayas, Eastern Plains, North-East Ranges, Western Ghats and Western Himalayas as shown in Figure 2.

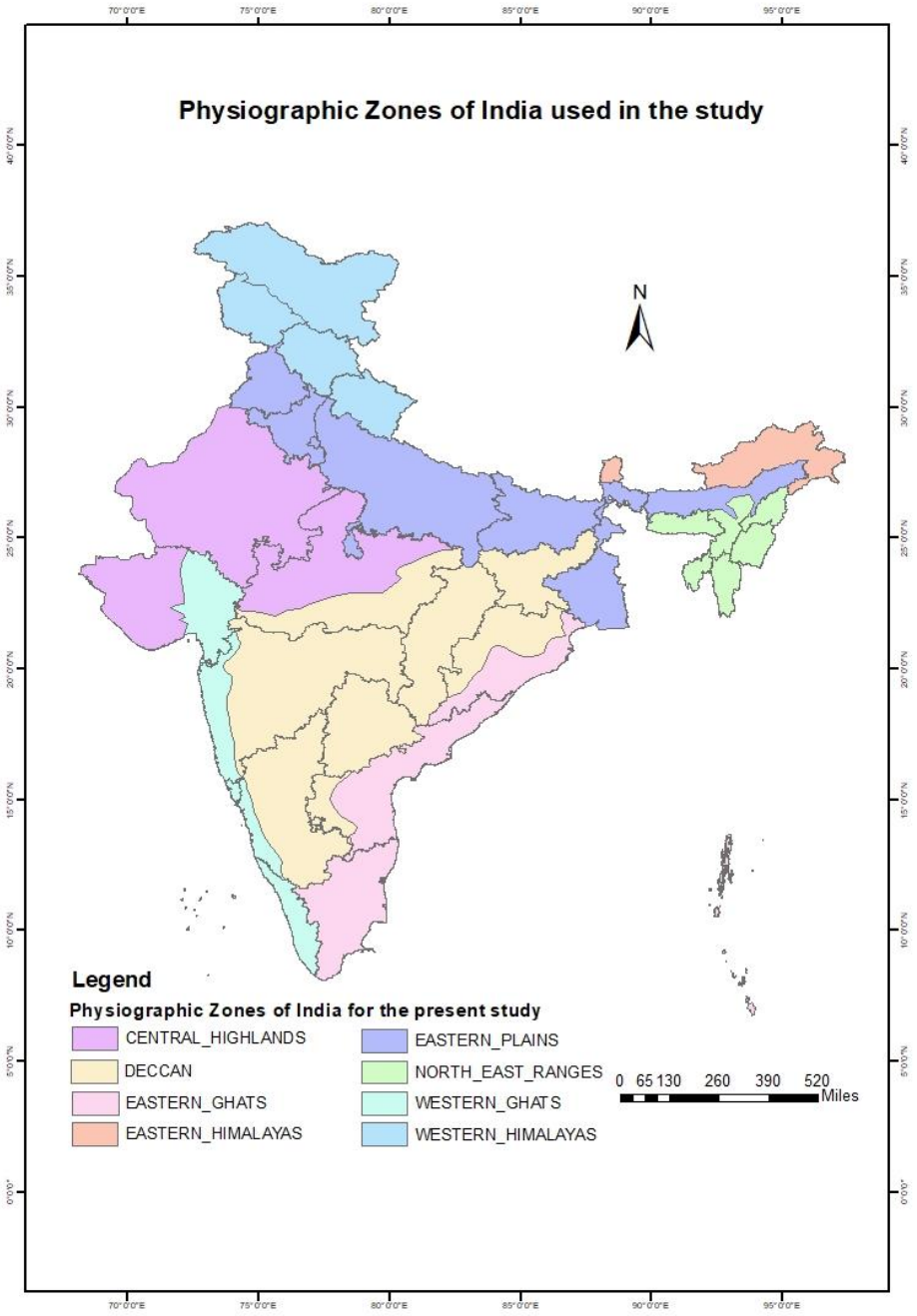

Figure 2 Map showing the eight physiographic zones of the country.

4. Material and Methods

4.1 Data and Software used

- India Physiographic Zones boundary(*Source: Forest Survey of India (FSI)*)
- Masking layer (composite of Forest Cover Map and Administrative or RFA boundaries of the country) as used in filtering process of forest fire points in the FSI's Near-real time (NRT) Forest Fire Alert System detections (*Source: FSI)*
- Forest Cover Map of India – 2019 (*Source: FSI*)
- Forest Fire Alerts database generated by FSI based on near-real time (NRT) detections by MODIS for the fire season 2019-2020(*Source: FSI*)
- Remote Sensed dataset of the study area-
  - Moderate Resolution Imaging Spectroradiometer (MODIS) – for NRT Forest Fire Points
  - Sentinel 2– Satellite Imagery for Fire affected area delineation
- Softwares - Arc GIS, Google Earth Engine, MS-Excel

4.2 Methodology

Stratified Random Selection of the MODIS-detected FSI NRT Forest Fire Points in various physiographic zones of India

i. A stratified random sampling approach was followed for the rapid assessment of the burnt area due to forest fires in the country during the last forest fire season i.e. 01st November 2019 to 30th June 2020.

ii. All the detected forest fire points (FFPs) based on MODIS-sensor during the fire season formed the population. Map showing the total forest fire detections based on MODIS by FSI in the fire season 2019-2020 is given in Annexure 2.

iii. The spatial layer of eight physiographic zones (PZ) of India namely Central Highlands, Deccan, Eastern Ghats, Eastern Himalayas, Eastern Plains, North-East Ranges, Western Ghats and Western Himalayas was used for the stratification.

iv. Stratified random sampling was used to select the sample in such a manner that number of FFPs in each strata (physiographic zone) was in proportion to the forest cover area under the strata (probability proportional to size). Random number generated using MS Excel were used to select the samples in each strata.

v. Based on a pilot study on 240 randomly selected MODIS forest fire points with coefficient of variability (CV= 161.45) and allowable error of 20%, a sample size

of 250 MODIS- detected forest fire points was selected for carrying out the present study. Table 1 details the distribution of the sample MODIS-detected FFPs in the PZs of the country. Map showing the distribution of the sample MODIS-detected FFPs in the eight physiographic zones of India is given in Annexure 3.

Table 1 Distribution of sample MODIS-detected forest fire points (FFPS) in the eight physiographic zones of India.

S. No.	Physiographic Zones	Geographic Area (in sq. km)	Forest Cover (FC) Area (in sq. km)	No. of Sample FFPs in each Zone w.r.t. FC
1	Central Highlands	655134	64059	22
2	Deccan	981219	206249	67
3	Eastern Ghats	344988	88914	33
4	Eastern Himalayas	89327	70029	26
5	Eastern Plains	576034	56846	21
6	North Eastern Ranges	115598	86348	36
7	Western Ghats	193213	76455	30
8	Western Himalayas	331956	63348	23
	Total	3287469	712249	258

Delineation of the fire affected forest area polygons using Google Earth Engine (GEE) and Count of Total MODIS detections (Sample FFPs and repeat detections intersecting the fire affected forest area polygons)

vi. Using Google Earth Engine(GEE) platform, fire affected areas corresponding to each of these randomly selected forest fire points were visually interpreted on the screen, delineated and then estimated using Sentinel-2 satellite imagery (based on pre-fire and post-fire images). Pre and post fire satellite images of the two forest fire events and their digitized fire affected area polygons have been illustrated in Annexure 4. Some polygons of fire affected forest areas showed more than one FFP due to the repeat detections by MODIS where the active fire continued till the subsequent passes of MODIS sensor. Though, there were more than one detections in such polygons but they have been referred as single 'forest fire event' (FFE).

vii. Each fire affected forest area polygon corresponds to a forest fire event corresponding to each of these randomly selected forest fire points. The terms forest fire points, fire affected forest area polygons and forest fire events have been used interchangeably in this study.

viii. For total MODIS detections for a single fire event, all the MODIS detected forest fire points intersecting with the fire affected area polygon of the fire were

considered as the total detections (sum of sample forest fire point and repeat detections) corresponding to that particular forest fire event or forest fire affected polygon.

ix. The complete dataset of 258 sample forest fire points (of the total MODIS-detected forest fire points in the country for the fire season 2019-2020) was analysed in excel and corresponding charts and tables were prepared.

Rapid Assessment of the fire affected forest areas for estimation at the country-level

x. Based on the number of detections in sample FFPs, total number of sample fire events and forest area affected by fire in the sample FFPs, an average numerical value was calculated for the estimation of total number of fire events and total fire affected forest area in different physiographic zones of the country.

xi. Based on the above calculated values, the total fire affected forest area in the country was estimated for the fire season 2019-2020.

Figure 3 depicts the flowchart for the methodology followed in the present study.

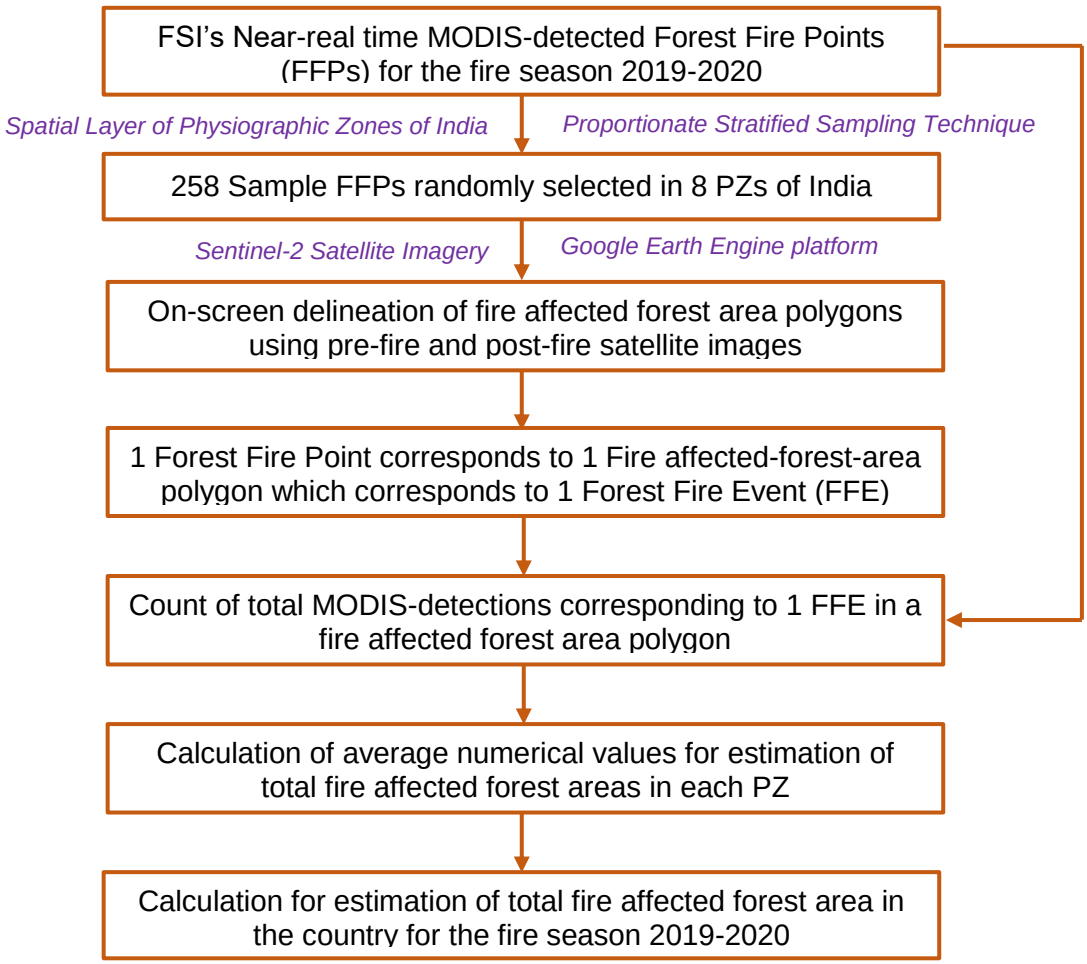

Figure 3 Methodology followed for the rapid assessment of fire affected forest area in the country based on remote sensing and sampling technique using NRT MODIS-detected forest fire points.

5. Results and Discussion

Using the Google Earth Engine platform, the burnt scars of the sample forest fire points (FFPs) selected in the sample were delineated onSentinal-2 dataset and the following statistics have been generated for the sample forest fire points (Table 2):

Table 2 Fire affected forest area (in ha) for the sample FFPs in different physiographic zones.

Physiographic Zone	Number of sample FFPs	Fire affected Forest Area (ha) in the sample	Size of the fire affected forest area (burnt area) polygon (in ha)		
			Maximum	Minimum	Average
Central Highlands	22	4992.63	1137.41	0.86	226.94
Deccan	67	24820.29	4008.82	6.21	370.45
Eastern Ghats	33	1230.46	472.78	0.05	37.29
Eastern Himalayas	26	786.00	365.91	0.62	30.23
Eastern Plains	21	4066.27	2333.17	1.99	193.63
North-East	36	633.08	126.65	0.25	17.59
Western Ghats	30	1391.90	283.81	1.99	46.40
Western Himalayas	23	1032.84	311.64	1.20	44.91

A total of 38,953.47 ha of forest area have been affected by fires at the sample forest fire points. Maximum burnt scar polygon of approximately 4009 ha was seen in Deccan physiographic zone of India.

Table 3 shows the total number of MODIS detections in the fire affected forest area polygons, each corresponding to a forest fire event. The total number of detections include the sample MODIS-fire point and its repeat detections.

Table 3 No. of sample FFPs (MODIS) and Total FFPs (including repeat detections) in the burnt scar polygon of each forest fire event in the sample in each physiographic zone.

Physiographic Zone	No. of sample FFPs (each corresponds to a single FFE)	No. of FFPs(including repeat detections) falling in the burnt scar polygons of each FFE in the sample
Central Highlands	22	37
Deccan	67	150
Eastern Ghats	33	50
Eastern Himalayas	26	30
Eastern Plains	21	55
North-East	36	56
Western Ghats	30	50
Western Himalayas	23	51
	258	**479**

Using on the above statistics, Table-4 shows the estimation of fire affected forest area in each physiographic zone for the forest fire season 2019-2020. The sample MODIS-detected forest fire points (FFPs) selected randomly for each PZ **(A)** and the corresponding total area of all the fire affected forest area polygons each of which corresponds to a single forest fire event (FFE) **(B)** were used to calculate the 'average fire affected forest area per fire event' **(P)** for each physiographic zone. The total number of MODIS-detected FFPs (sample FFPs and repeat detections) observed in these sample fire affected forest area polygons for each forest fire event **(C)** along with the total number of MODIS-detections during the entire fire season November, 2018 to June, 2020 **(D)** were used to calculate the 'average MODIS detections per forest fire event' in each physiographic zone **(Q)**. Based on the above statistics, 'Total no. of forest fire events' **(R)** in each PZ during the entire forest fire season 2019-2020 were estimated which were subsequently used to estimate the 'total fire affected forest area' in each zone during the fire season 2019-2020**(S)**. This estimation was further used to calculate the 'fire affected forest area' in the country for the fire season 2019-2020.

The combined indexing shows that at national level, with 22447 MODIS-detections in different PZs in the fire season 2019-2020,approximately 11,09,366.49 ha i.e. 11,094 sq. km of forest area was affected (burnt areas) by forest fires. The burnt forest area accounted for 1.56% of the total forest cover of the country (Table 5). Standard Error (SE) of the estimate offire affected forest areas has been calculated as 66.70 sq. km. Accordingly, limits (range) of the estimated value of fire affected forest areas during 2019-2020 fire season for the country are 10,963 sq.km to 11,224 sq. km at the 95% confidence level.

Table 5 Estimation of fire affected forest area in the country.

	Area (in sq. km)
Total Geographic Area (GA) of the country	3287469
Total Forest Cover Area in the country	712249
Estimated total fire affected forest area in the country for the fire season 2019-2020	11094
Percentage of fire affected forest area w.r.t total forest cover of the country	1.56%
Confidence interval with 95% confidence level	10963 to 11224

Table 4 Estimation of fire affected forest area in each physiographic zone of the country for forest fire season 2019-2020. (Area in hectare (ha))

Physiographic Zone	No. of sample FFPs (MODIS) (each corresponds to a single FFE) (A)	Total area of all the fire affected forest area polygons in sample FFEs (B)	No. of FFPs detections (MODIS) (sample +repeat)in sample forest fire affected area polygon for each FFE (C)	Total MODIS detections during fire season 2019-2020 (as per FSI NRT) (D)	Average fire affected forest area per FFE (P=B/A)	Average MODIS detections per FFE (Q= C/A)	Estimated no. of FF events during fire season 2019-2020 (R= D/Q)	Estimated total fire affected forest area (S=R*P)
Central Highlands	22	4992.6	37	1601	226.9	1.7	951.9	216032.3
Deccan	67	24820.3	150	3400	370.5	2.2	1518.7	562593.3
Eastern Ghats	33	1230.5	50	1965	37.3	1.5	1296.9	48357.2
Eastern Himalayas	26	786.0	30	662	30.2	1.2	573.7	17344.4
Eastern Plains	21	4066.3	55	1249	193.6	2.6	476.9	92341.4
North-East	36	633.1	56	12261	17.6	1.6	7882.1	138609.8
Western Ghats	30	1391.9	50	999	46.4	1.7	599.4	27810.1
Western Himalayas	23	1032.8	51	310	44.9	2.2	139.8	6278.1
Total in all PZs	**258**	**38953.5**	**479**	**22447**				**1109366.5**

The burnt scar polygons corresponding to the sample MODIS-detected forest fire points in different physiographic zones over the forest cover of India (as per ISFR 2019) have been depicted in the Figure 4.

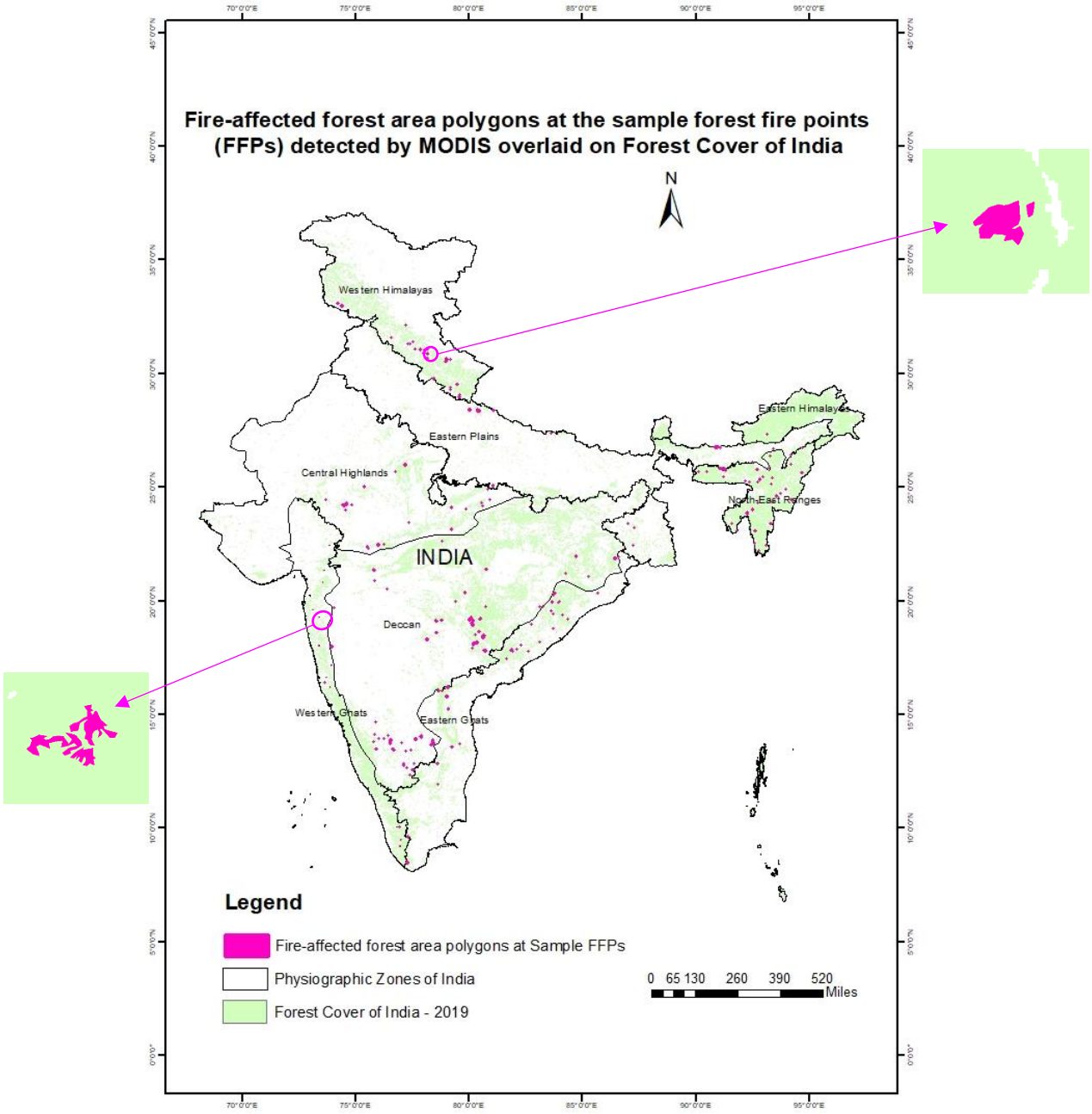

Figure 4 Map showing fire affected forest area (burnt scar) polygons at the sample forest fire points detected by MODIS overlaid on the forest cover of India (2019).

Apart from the assessment of burnt forest areas in the country, the study presents few interesting results.

i. As seen from Figure 1, the number of detected FFPs, like every year, are highest in the North-east region (12261) though the total burnt area in the region is not maximum (Figure 5). This implies that the average burnt forest area per fire event is smaller in the region (17.59 ha) as seen from Figure 6. This is possible due to the high content of moisture in the vegetation and soil in the forests of North-eastern region.
ii. On the other hand, average burnt area per fire event in the Deccan and Central Highlands is large i.e. 370.45 ha and 226.94 ha respectively (Figure 6). Also, the maximum burnt area was seen in Deccan PZ followed by Central Highlands (Figure 5). The reason for this could be preponderance of dry deciduous forest types, high temperature and dry conditions in the Deccan and Central Highlands of India which create conditions for faster spread of fires and thus, engulfing larger forest areas.
iii. Figure 7 shoes that fifty percent of the total fire affected area has been found in the Deccan physiographic zone followed by Central Highlands with 19.50%. North-eastern region with highest number of forest fire detections by MODIS (12261) has contributed 12.50% to the total fire affected forest areas. There are much lesser MODIS-based forest fires detections (5001) in the Deccan and Central Highlands PZs combined as compared to north-eastern ranges (12261), yet they have contributed to 70% of the total burnt forest area in the country

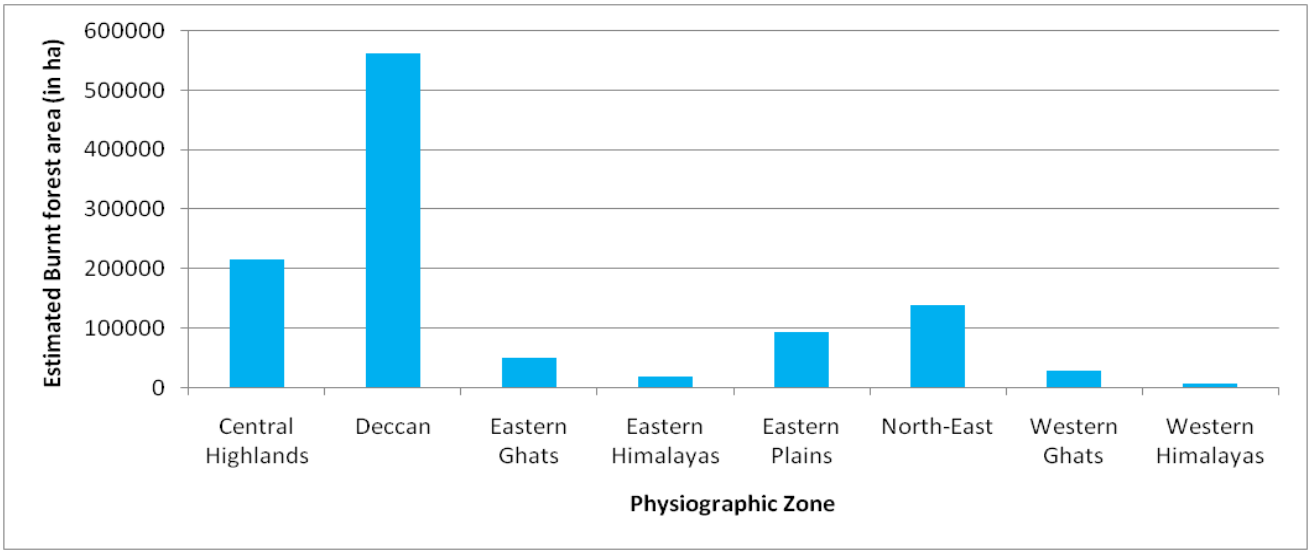

Figure 5 Graph depicting the estimated burnt forest areas (in ha) in different physiographic zones of the country during the fire season 2019-2020.

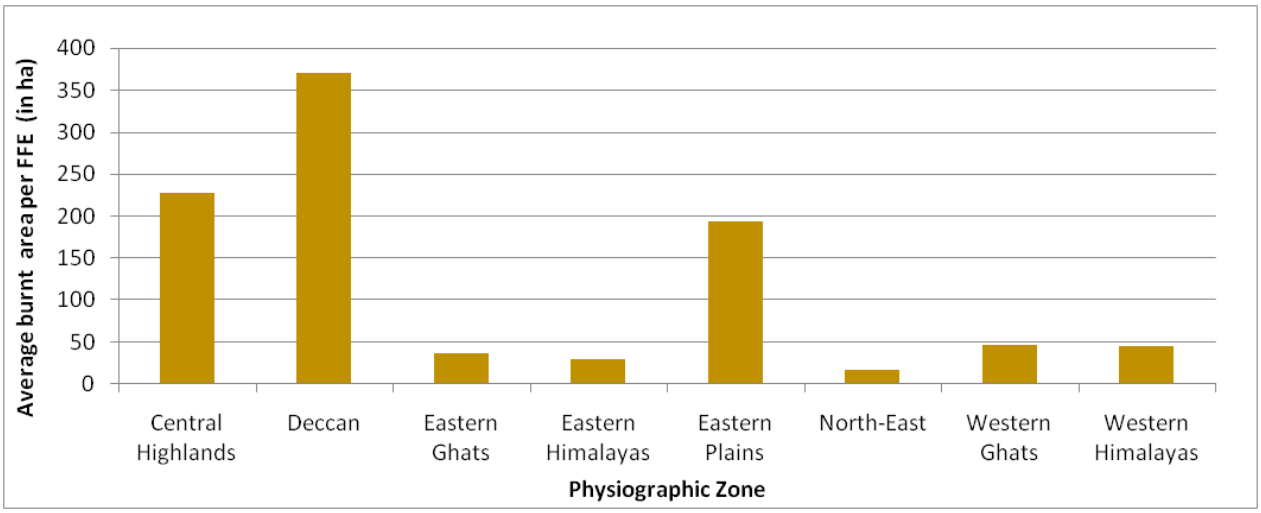

Figure 6 Graph depicting the average burnt forest area per forest fire event (in ha) in different physiographic zones of the country during the fire season 2019-2020.

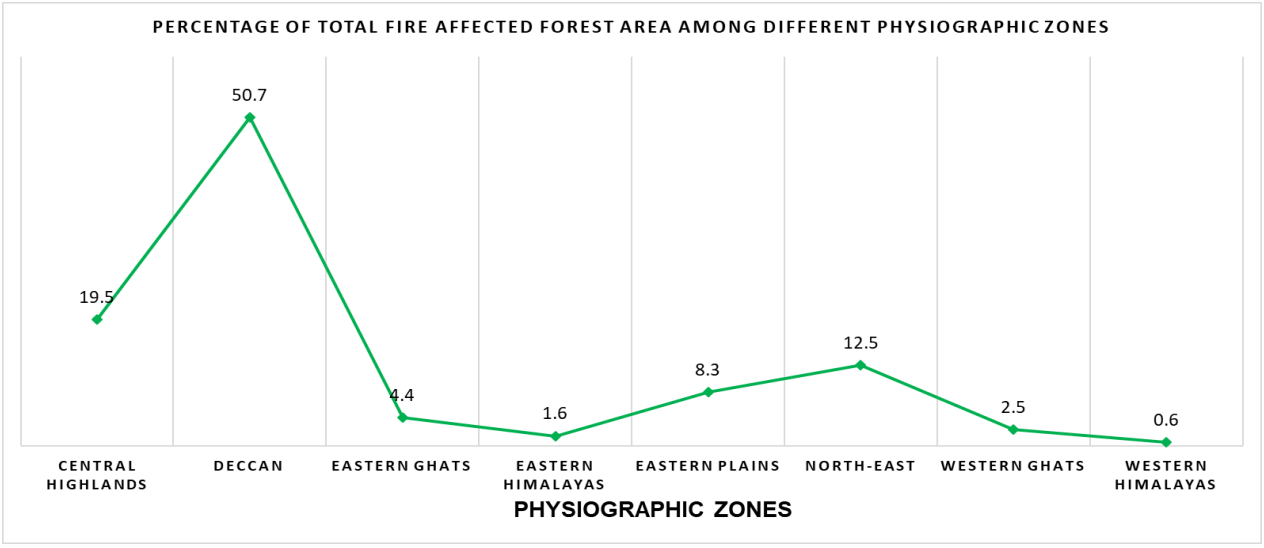

Figure 7 Graph depicting percentage of total fire affected forest area (11094 sq. km) among different physiographic zones of the country.

iv. High values of average MODIS-detections per forest fire event in fires in Deccan, Central Highlands and Eastern Plain physiographic zones (Table 4) indicate that fires in these zones persist for longer periods as compared to other PZs. Again the low moisture content in forest fuel (biomass) in these physiographic zones may be responsible for the relatively larger spread and therefore, longer duration of forest fires.

Further investigation in the plausible reasons for such a trend in the fire-affected forest areas in different physiographic zones provides a promising research area for future studies.

6. Conclusion

Forest fires are one of the major drivers of forest loss and degradation. Every year lakhs of hectares of forests are affected by fires (Satendra & Kaushik, 2014) damaging the ecological resources. There is a need to understand the effects of fire on forests for formulating forest fire management and safety plans (Eidenshink et al., 2007). Assessment of fire affected forest areas is crucial to estimate loss to flora, fauna, soil and carbon for recognizing appropriate rehabilitation requirements to minimise the damage (Vallejo et al., 2000). Suitable restoration activities and future fire management policies can be planned accordingly (Jakubauskas et al., 1990).

Ground-based estimation of burnt area on annual basis is a cumbersome, time intensive and expensive exercise which requires huge manpower and resources. In recent times, geospatial technology has made great strides in addressing forest fire situation in the country by providing data for monitoring active fires and post-fire burnt area assessment. However, for the country of India's size, wall-to-wall burnt area mapping using satellite data will also involve huge time and resources.

The study presents a sampling based methodology in which the detected forest fires by MODIS based fire detection system from the country during 2019-2020 fire season has been used as population. Burnt area delineation using satellite images (Sentinel-2) on randomly drawn sample in a statistical manner using physiographic zones as strata represents the total forest fires occurred in the country and gives an estimate of the total forest burnt area in the country during a year (2019-2020 fire season). The methodology demonstrated through this study offers a cost-effective and time efficient method of rapid assessment of burnt areas of forests due to fires with a reasonably good accuracy.

In a wall-to-wall burnt area mapping exercise using AWiFS satellite data was undertaken at FSI during the year 2015. The total burnt forest area mapped in the exercise was 11,033 sq. km which was 1.60% of the forest cover of the country as per the ISFR 2017. This was against the 15937forest fire detections based on MODIS. The exercise involved on-screen interpretation of 21 scenes of AWiFS satellite data of IRS P6 and Resourcesat2 in which approximately 200 man-weeks were devoted.

The present study based on sampling approach compares well in terms of burnt forest area assessment against the total number of MODIS-based forest fire detections in the country. However, the exercise involved only 10 man-weeks of work. This fact highlights the time and cost effectiveness of the methodology followed in this study.

The present study reports that 11,09,366.49 ha i.e. 11,094 sq. km of forest area was affected by fires in India during the forest fire season 2019-2020 with 95% confidence level. The study augments the information on fire affected forest areas in a simpler, cost-effective and efficient fashion which could be extremely beneficial for the fire managers and policy makers to monitor the health and rejuvenation of the fire affected forests.

7. Acknowledgments

Contributions of Sh. Prakash Lakhchauara, DDG; Dr. Sourav Ghosh, Scientist and Sh. H.K. Tripathi, Consultant are gratefully acknowledged.

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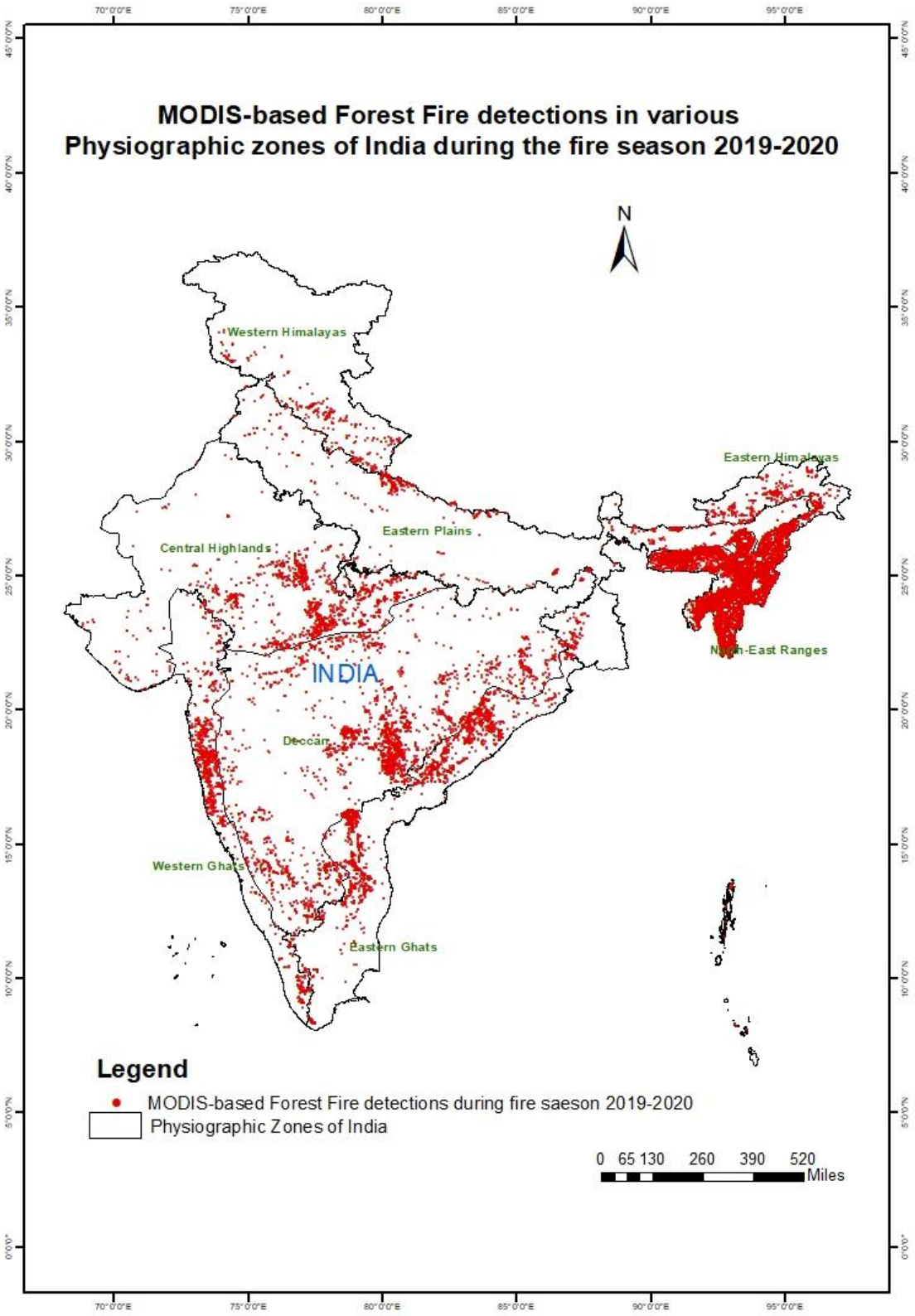
Annexure1

State-wise forest fire detections using MODIS-sensor in the country for last three fire seasons by FSI Near-real time Forest Fire Alert System.

STATE	January,2018-June, 2018	November,2018-June,2019	November,2019-June,2020
ANDAMAN & NICOBAR Is.	3	6	15
ANDHRA PRADESH	1785	1748	1080
ARUNACHAL PRADESH	491	926	660
ASSAM	1660	1940	3000
BIHAR	223	203	50
CHANDIGARH	0	0	0
CHHATTISGARH	3331	1608	416
DADRA & NAGAR HAVELI	0	0	1
DAMAN & DIU	0	0	0
DELHI	4	2	3
GOA	9	11	4
GUJARAT	572	224	202
HARYANA	43	24	39
HIMACHAL PRADESH	748	142	80
JAMMU & KASHMIR	742	62	62
JHARKHAND	666	363	101
KARNATAKA	1068	1228	538
KERALA	128	192	142
LAKSHADWEEP	0	0	0
MADHYA PRADESH	4929	2723	1383
MAHARASHTRA	3919	2516	1102
MANIPUR	1606	1752	2475
MEGHALAYA	1664	1545	1826
MIZORAM	2339	2795	2816
NAGALAND	935	1057	1248
ODISHA	3735	2123	1326
PUDUCHERRY	4	0	1
PUNJAB	487	77	52
RAJASTHAN	292	386	420
SIKKIM	1	11	5
TAMIL NADU	221	752	187
TELANGANA	1918	1246	1042
TRIPURA	861	1195	1467
UTTAR PRADESH	1165	855	396
UTTARAKHAND	1385	1578	167
WEST BENGAL	125	257	141
TOTAL	**37059**	**29547**	**22447**

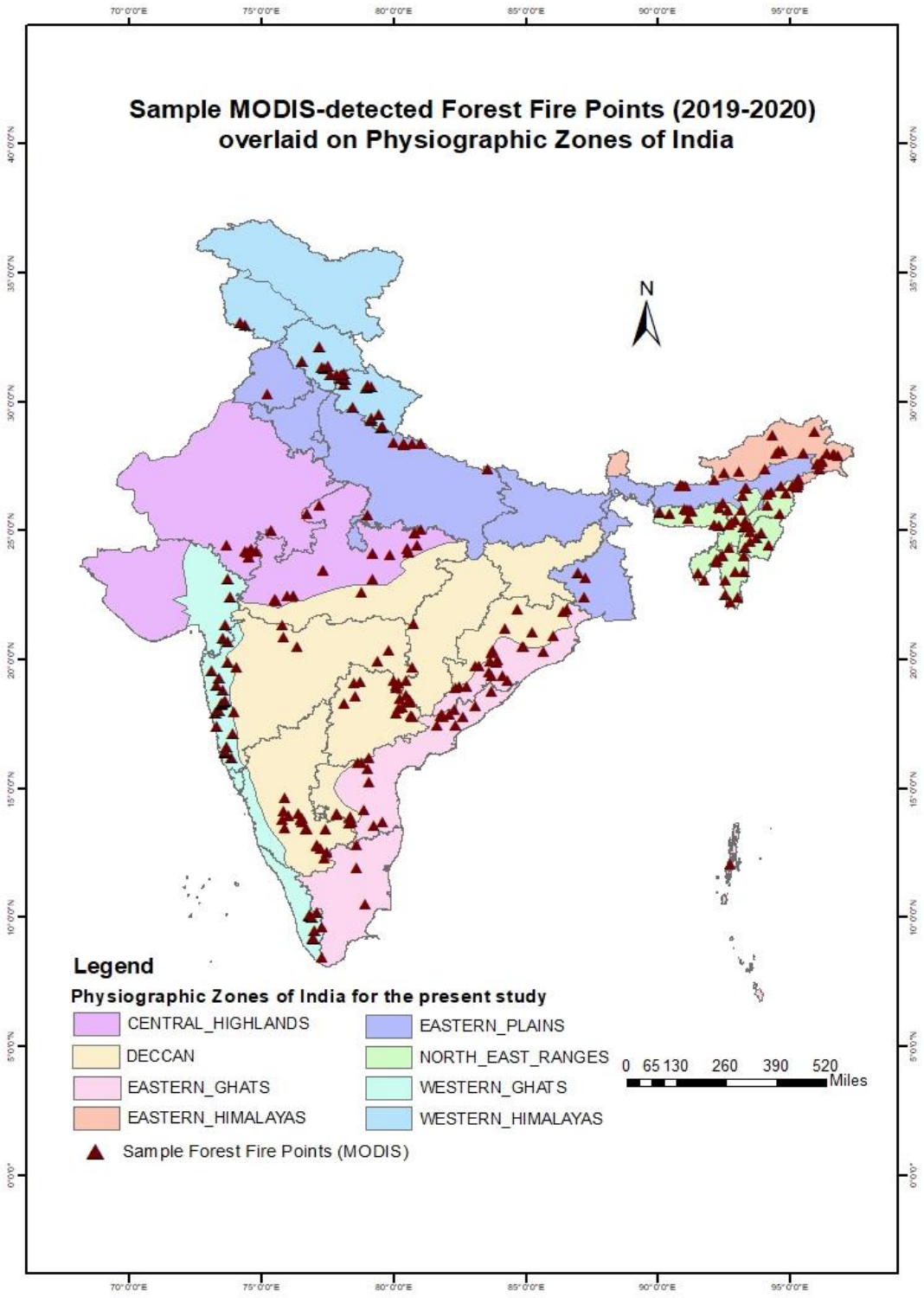
Annexure 2

Map showing distribution of total MODIS-detected forest fire points (FFPS) in the eight physiographic zones of India for the fire season 2019-2020.



Annexure 3

Map showing distribution of the sample MODIS-detected forest fire points (FFPS) in the eight physiographic zones of India.



Annexure 4

Delineation of the fire affected forest area polygons using Google Earth Engine (GEE) on pre-fire and post-fire satellite images (Sentinel-2).

Physiographic Zone- Deccan

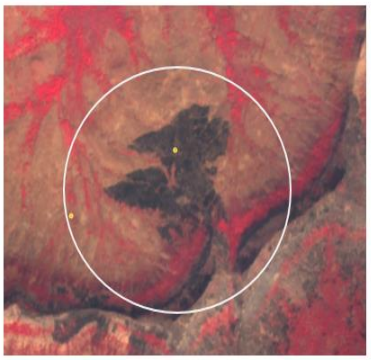
Pre-Fire Satellite Image – 24-01-2020

Post-Fire Satellite Image with burnt scar – 29-01-2020

Post-Fire Satellite Image overlaid with digitized burnt scar polygon (green)

Physiographic Zone- Western Ghats

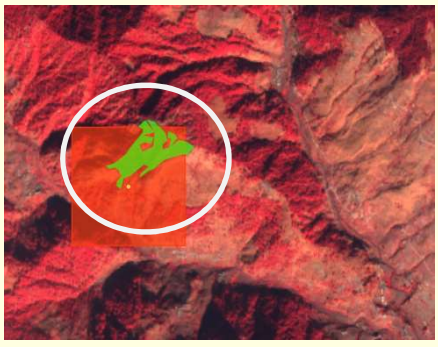
Pre-Fire Satellite Image – 06-12-2019



Post-Fire Satellite Image with burnt scar – 21-12-2019

Post-Fire Satellite Image overlaid with MODIS pixel (red) and digitized burnt scar polygon (green)





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