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Forest Fire Locations in India, their Spatio – temporal Patterns and Impact of Climatic Variables

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Abstract

Forest fires are the most important anthropogenic and natural disasters which causes long term effects on the environment due to emissions and changes in the forest ecosystems. The fire season in India is from February – June with spatial variability depending on the cultural practices, type of forest, maximum & minimum temperature and precipitation. The paper presents spatio – temporal patterns and the influence of climate variables on the forest fires in India during 2001-2014. Fire location data obtained from MODIS fire product for 2001-2014 (except 2007) years for India during the fire season are used to isolate forest fire locations using forest mask. The daily rainfall data in 0.25^0 x 0.25^0 grid produced by Indian Meteorological Department, Pune has been used for deriving dry days, rainy days, mean dry days and rainfall for years 2001 – 2014. The forest fire locations are converted to similar grid for which meteorological data was available. Quantum GIS (QGIS), an open source geospatial tool is used for the analysis. In addition, Climate Data Operators and NCO suite (open source) are used to process rainfall data. The influence of dry days, mean rainfall and mean dry days in the grids show close relationship with forest fire count and mean forest fire frequency. From the result, it is evident that one of the dominant factors which affect fire frequency and occurrence of fires is precipitation and its distribution.

Key words: *Forest fires, Fire frequency, Dry days, Rainfall, QGIS, MODIS*

1. Introduction

Fire has been a source of disturbance for thousands of years (Roy, 2003). Forest and wild land fires have been taking place historically, shaping landscape structure, pattern and ultimately the species composition of ecosystems. The ecological role of fire is to influence several factors such as plant community development, soil nutrient availability and biological diversity. Uncontrolled and misuse of fire can cause tremendous adverse impacts on the environment and human society. According to Forest survey of India 2013 report, 77.18 m. ha area of country is reported as 'Recorded Forest area' and about 53.91% of the Forest areas in the country are prone to Forest fires. In India, the forest fires takes place mostly between February to June.

Forest fires are caused due to a number of natural and anthropogenic activities such as deforestation, Slash and burn agriculture, Grazing land management, Wild land/ Residential interface fires (fires from settlements e.g. cooking, camp fires) and use of non-wood forest products.

Different types of forest fires are Ground fires, Surface fires and crown fires. Temperature, wind velocity, fuel materials in the forest support the forest fire to spread to a wide large area (Roy et.al 2003). Land cover type also influences fire susceptibility. Shrub lands are known to be more flammable than evergreen forests (Maria et.al 2005). Soil moisture and fuel moisture is influenced by rainfall. The number, frequency, size, intensity and duration of forest fires increase as the moist forests turn into drier habitats due to droughts. (FAO 2001). Decrease in annual rainfall, dry periods in winter

along with increase in mean minimum temperature lead to warmer climate, thereby making forest more fire prone (Tambe et al., 2011).

In this study it is proposed to find the relationship between forest fires and climatic variables (precipitation, wet and dry days) in India from 2001-2014 using monthly fire location data and daily rainfall data.

2. Study Area

India, a country in South Asia situated north of the equator between 8°4' and 37°6' north latitude and 68°7' and 97°25' east longitude. It is the seventh-largest country in the world, with a total geographical area of 3,166,414 km^2, measures 3,214 km from north to south and 2,933 km from east to west. It has a land frontier of 15,200 km and a coastline of 7,517 km. India's 21.3 percent geographical area is covered with forests (FSI, 2013).

3. Materials and Methodology

3.1. Data sets used

1) Indian forest mask showing forest and non-forest areas – Roy et.al, 2012
2) India fire location data for years 2001-2014(except 2007)(February-June) -Active fires and thermal anomalies are identified by MODIS sensor. 1km resolution MODIS Active Fire products are available which shows location of fire but not actual fire size. The actual fire on site can be smaller than 1km spatial resolution. The data obtained is point vector data which represent the fire locations for each year
3) IMD Daily gridded Rainfall data – 0.25 x 0.25 Lat/ Lon.
   IMD daily gridded rainfall data of Indian subcontinent at 0.25˚ x 0.25˚ is obtained for 2001 – 2014 years.

3.2. Software used`

1. Quantum GIS 2.8.1- Wien

QGIS is a user friendly Open Source Geographic Information System (QGIS) licensed under GNU General Public License. It is used to visualise, edit, manage, analyse geospatial information and compose printable maps.

2. Climate Data Operators

Climate Data Operators (CDO) is a collection of command line operators to manipulate and analyse Climate data.

3. NCO Suite

The netCDF Operators, or NCO, are a set of operators which facilitate manipulation and analysis of data stored in the self-describing netCDF format.

3.3. Methodology

3.3.1. Analysis of Indian fire location data

From the Indian fire locating data, fires inside & outside the forest are to be obtained. The methodology in shown in the flowchart (Fig. 1).In order to get each state forest mask, the forest mask of India (Fig. 2) is clipped using shape file of Indian state boundary. The obtained state forest mask is converted into vector polygon and saved as forest and non-forest polygons separately. Indian fire location data (Fig. 2) is clipped with state boundary to obtain fire locations for each state yearly.

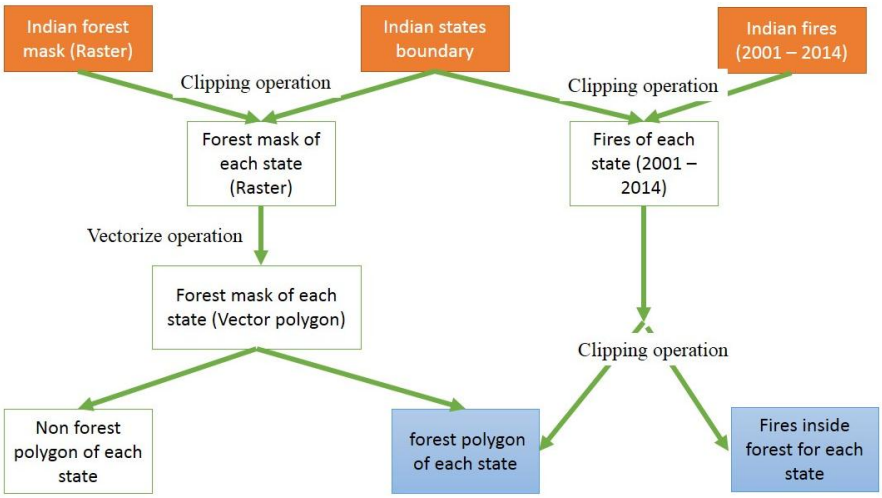


Fig 1: Forest Fire Data processing

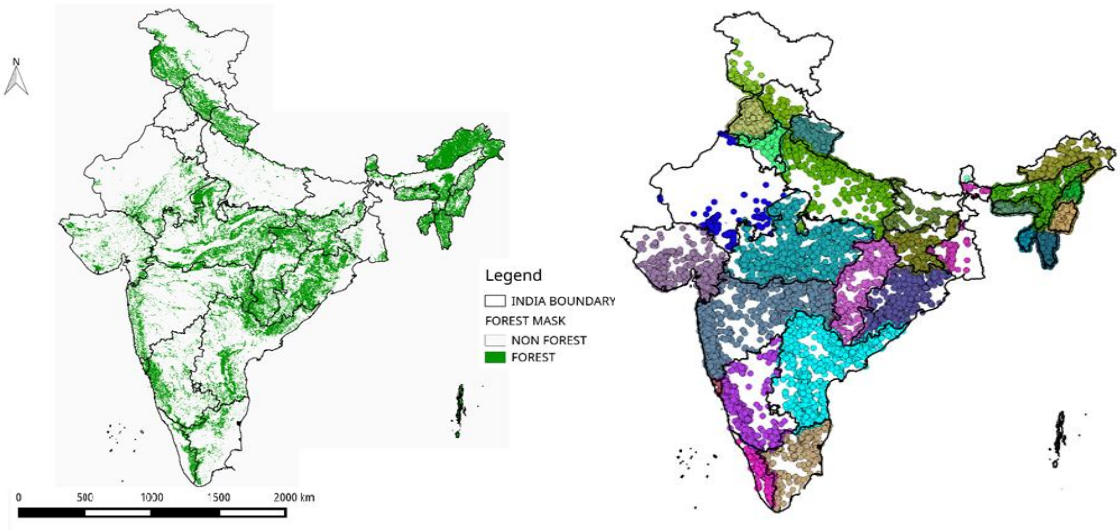


Fig 2: Map of India showing area of intact forest 2005 and location of forest fires 2004

In order to find the forest fire, the forest fire location points are clipped with forest layer. The resultant points represent the fire location inside the forest and the remaining are the fire locations outside the forest (Fig 3).

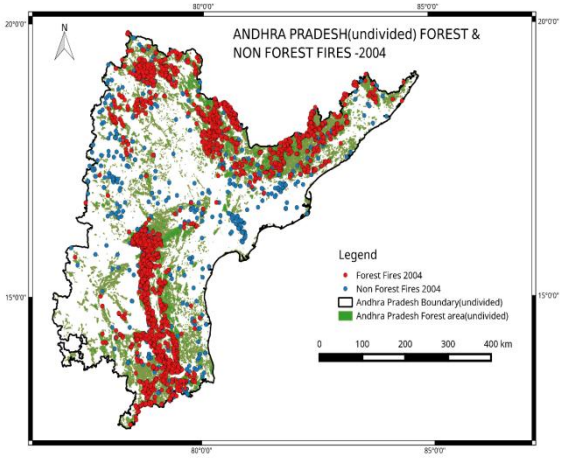


Fig 3: Forest & Non Forest fires– Andhra Pradesh (undivided) - 2004

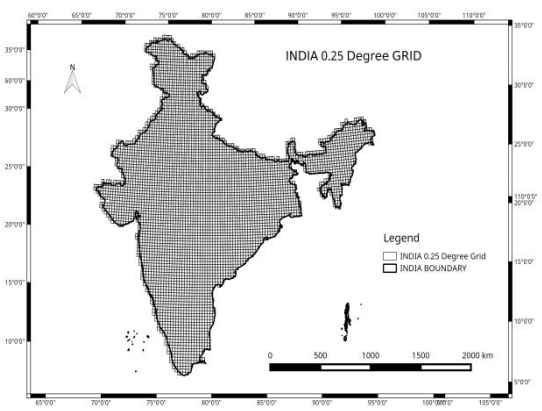
3.3.2. Analysis of Rainfall data

Climate Data Operators is used for processing the daily girdded - rainfall data. The rainfall data obtained is in .nc (NetCdf format). From this compound data, each day rainfall data is extracted. The operators used for obtaining the daily rainfall data are
cdosplityear<input_filename> YEAR
cdosplitmon<input_filename> MON
cdosplitday<input_filename> DAY

Rainfall data for February – June have been extracted. NCO suite is used to convert .nc to .asc format. The following command is used in terminal to change the .nc file to .asc file format.
ncks<input_filename>><output_filename>.The '>' is necessary in between input filename and output filename for conversion .asc files can be opened in excel and from each day rainfall data, monthly rainfall data is to be prepared. The month .asc file contains rainfall data of all days in a single file. Three new columns "NON rainy days", "rainy days" & "MEAN RAINFALL" are prepared in the monthly rainfall data. The excel data (monthly rainfall) is converted to .csv(Comma Separated Value) to load as input into QGIS. These .csv files are saved as .shp files which is most commonly used file format for vector data.

3.3.3. Spatial joining of Rainfall data and Forest fire data

Using MMQGIS plugin in QGIS, a vector grid with 0.25˚ interval is created. The created grids are clipped with India boundary to obtain only the vector grid of India (Fig. 4). A sample of Rainfall data is shown in Fig.5



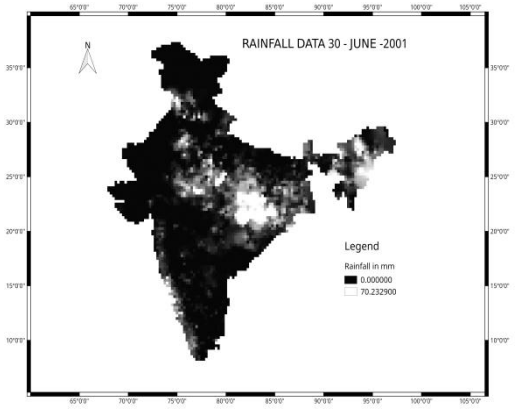


Fig 4: 0.25˚ Grid – India Boundary Fig 5: Sample Rainfall Data – 30 – June – 2001

Using vector grid for India and monthly forest fire data (all over India), Points in polygon tool is used to count number of forest fires in each grid. The resultant grid shows a column with number of forest fires in each grid.

In MMQGIS plugin, Spatial Join tool is used to Spatially Join the Grid with forest fire count and monthly rainfall data. The resultant grid contains the columns which shows number of forest fires in each grid and number of non-rainy days in the attribute table. The entire methodology of processing the rainfall data is shown in Fig 6.

Fire Frequency Analysis

Fire Frequency is calculated for each grid using the following formula

Fire Frequency = Number of Fires in a grid / Number of days in fires season
For each yearmean of fire frequency, rainfall and dry days are calculated.

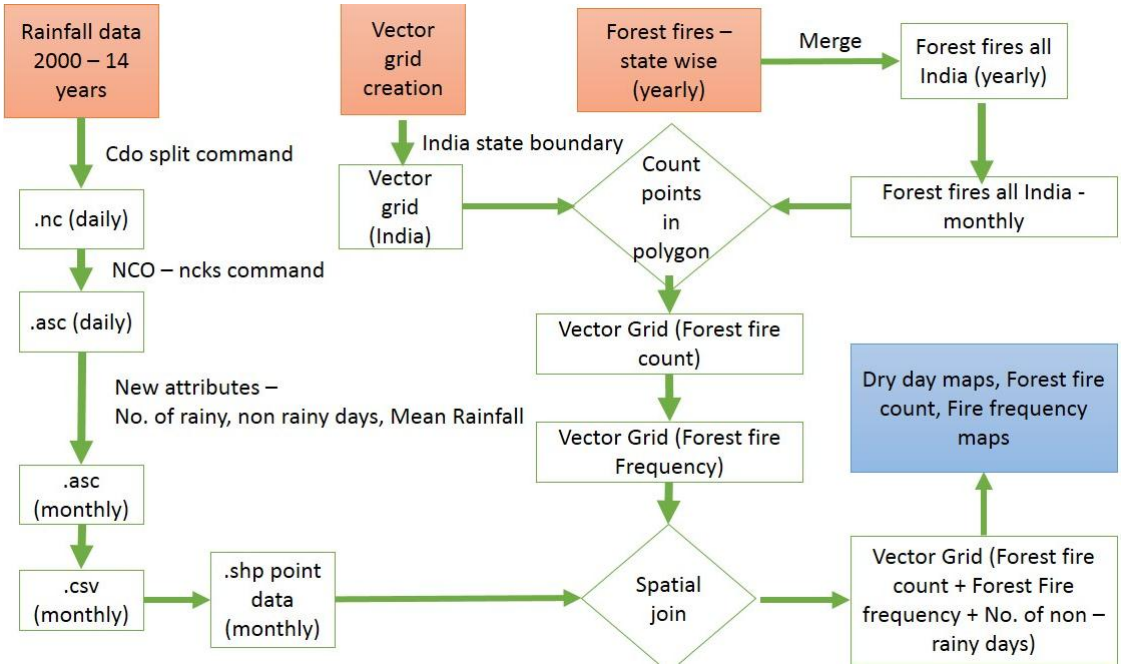


Fig 6: Methodology – Processing of Rainfall data & Maps generation

4. Results and Discussion

4.1. Occurrence of Forest Fire

The year 2009 has the highest number of forest fire, it counts around 44936 and 2002 records least number of forest fires in India(Fig 7). The figure 7 depicts the number of forest fires with year.

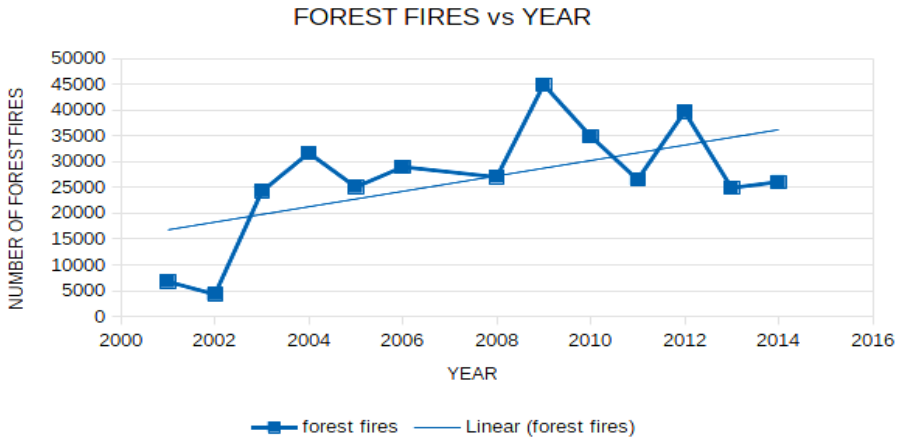


Fig 7: Forest Fires vs Year

Fig. 8 shows the variation of number of forest fires in each month (Feb – June) all the years for Chhattisgarh state. In the fire season, March month of every year has highest number of forest and total fires, June month has lowest number of forest / total fires. The highest number of Fires are recorded in March month of 2009 year with 2503 fires and 2064 forest fires. In the fire season,

number of fires recorded increases from February – March and then decreases from March to June.

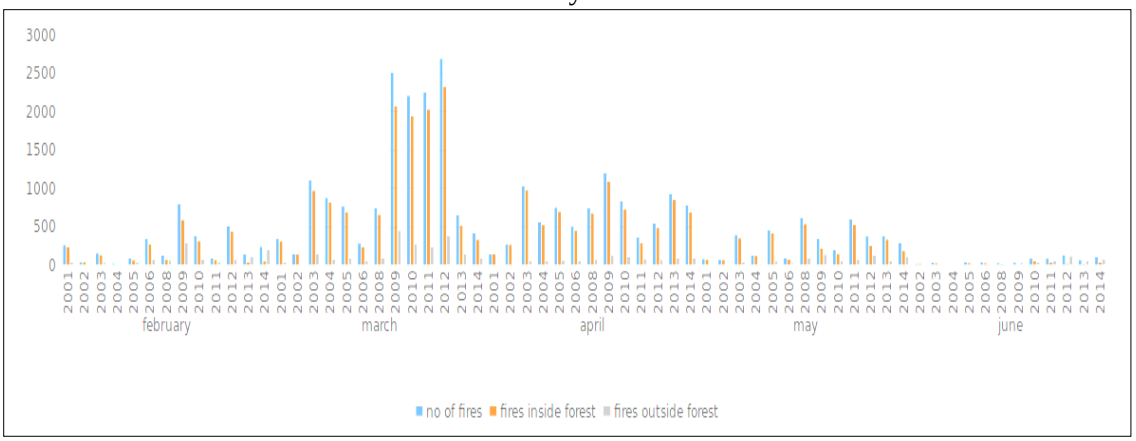


Fig 8: Chhattisgarh State Fires inside &Outside Forest 2001 – 2014

Fig 9: Shows the variation of Number of rainy days, Mean Rainfall in mm, Forest Fire count with increase in Number of dry days. The grids shown in the X – axis are arranged in the ascending order of Number of dry days. As the Number of dry days are increasing, the rainy days are decrease as they are complementary. Dry days are days with no rainfall and rainy days are days with rainfall. The least number of dry days in a grid are 506 located in Sikkim state and highest number of dry days are 1952. The least number of rainy days are 1 and highest number of rainy days are 1447. Highest number of Forest Fires occurring in a grid for all the years is 1879 and the least 0. Highest Mean rainfall occurring in a grid is 1320.15 mm located in Meghalaya state. 1879 Number of Forest Fires occurred in a grid located in Tripura State, highest of all grids. As the grids are arranged in increasing order of dry days, the trends of rainy days is decreasing. The mean rainfall shows a decreasing trend with increase in number of dry days.

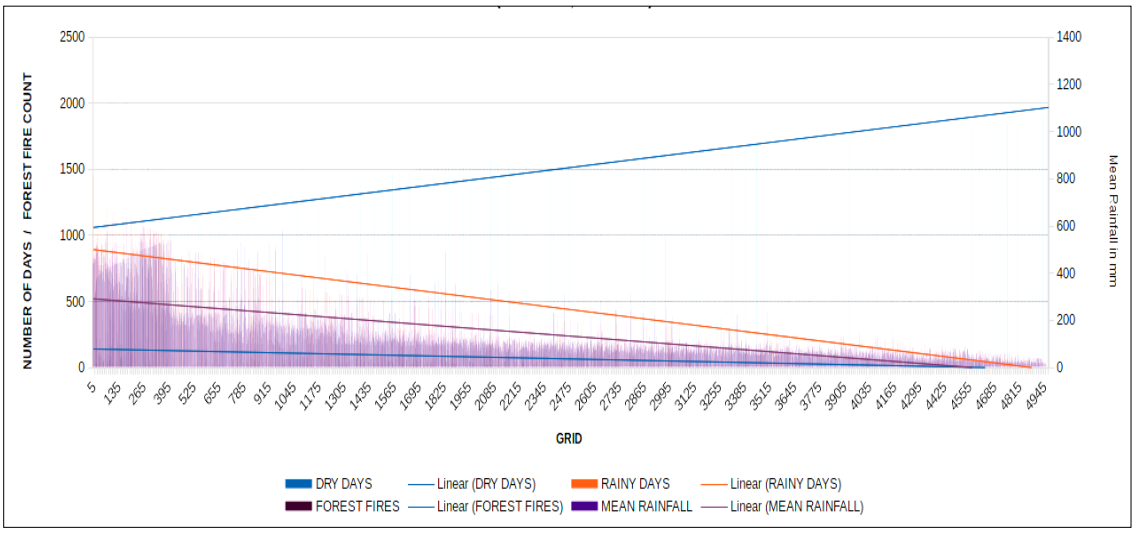


Fig 9: Dry days / rainy days / Mean Rainfall in mm / Forest Fire count vs Grid – INDIA – 2001 - 2014

Fig. 10 Maximum number of Forest Fires are occurring in the states of Andhra Pradesh, Chhattisgarh, Jharkhand, Madhya Pradesh, Mizoram, Orissa. The states Andhra Pradesh, Madhya Pradesh and Orissa are seen with consistent increase in Number of Forest Fires.

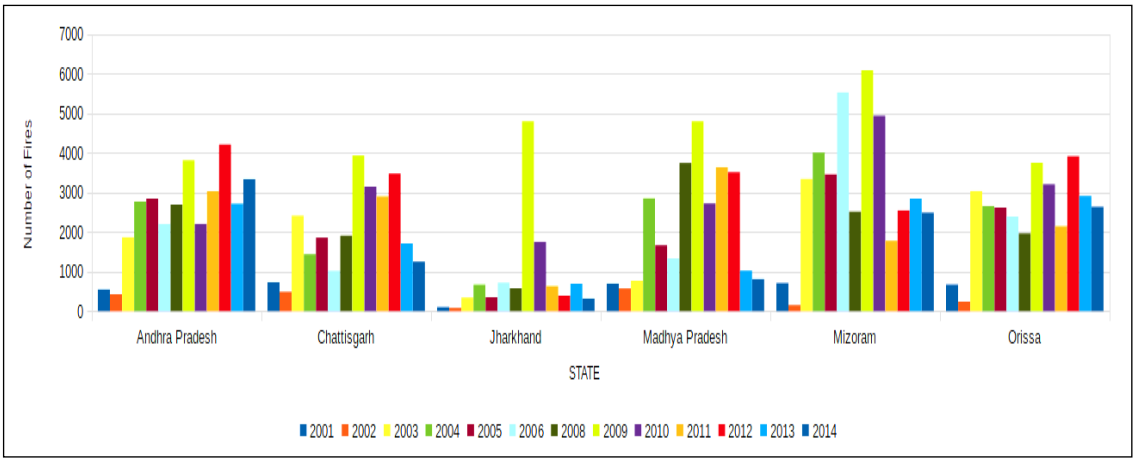


Fig 10: Forest Fires vs Year (Andhra Pradesh, Chhattisgarh, Jharkhand, Madhya Pradesh, Mizoram, Orissa)

Fig. 11shows the variation of Mean Fire Frequency, Mean dry days, Mean rainfall in cm with year. The highest mean Forest Fire Frequency is 0.1331 in the year 2012. The highest number of Mean dry days occurred in the year 2012 with a value of 121.33. Least Forest Fire Frequency of 0.0296 is observed in the year 2002. Least Mean dry days of 92.21 occurred in 2003 year. Highest Mean Rainfall of 47.74 cm occurred in year 2001 and Least Mean Rainfall of 31.90 cm in 2012 year. Trend lines show that as the Mean dry days increase, Mean Rainfall decreases and Forest Fire Frequency increases.

Table 1: Correlation values – Mean dry days, Mean Rainfall, Mean Forest Fire Frequency

Correlations (R^2)	Mean dry days	Mean Rainfall	Mean Forest Fire Frequency
Mean dry days	-	-	-
Mean Rainfall	-0.5776705227	-	-
Mean Forest Fire Frequency	0.384695527	-0.4882062128-	-

Correlation (R^2) between Mean dry days and Mean Forest Fire Frequency is 0.3846 which indicates that as the Mean dry days increase, Forest Fire Frequency increases.

Correlation (R^2) between Mean Rainfall and Mean Forest Fire Frequency is -0.4882 which indicates that as the Mean Rainfall increases the Forest Fire Frequency Decrease

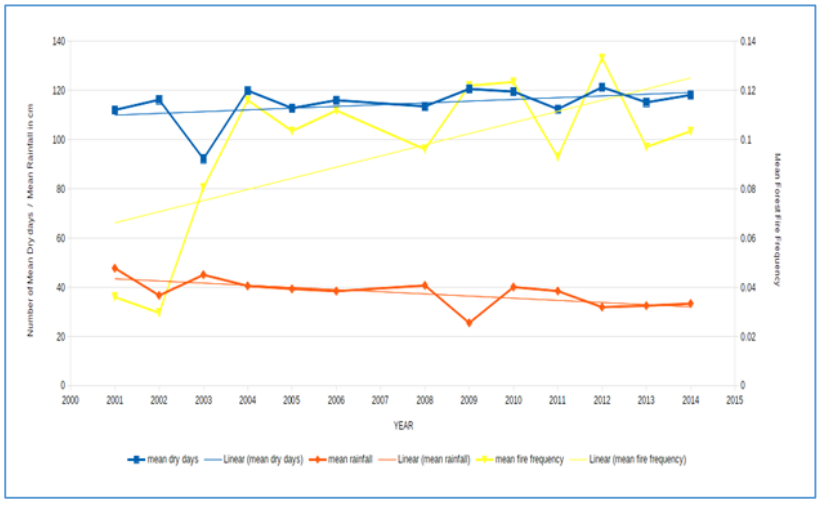


Fig 11: Mean Forest Fire Frequency / Mean Dry days/ Mean Rainfall in cm vs. Year

4.2. Calculating the dry days from 2001-2014

Dry day Maps for each year from 2001-2014(except 2007) was created. Fig 12. Shows the dry days map for 2001 year. In the fire season, Maximum number of dry days is 150 days and least number of dry days is 37 days. The maximum and minimum number of dry days for all the years are shown in table 2.

The observations made with the dry days maps for 2001-2006, 2008-2014 are

1. Places near Gujarat and some parts of Rajasthan are having high number of dry days
2. North Eastern States of India are having less number of dry days because of rainfall.
3. North – Western parts of Jammu & Kashmir are having dry days because of snowfall.
4. Sikkim state has moderate number of dry days over all years.

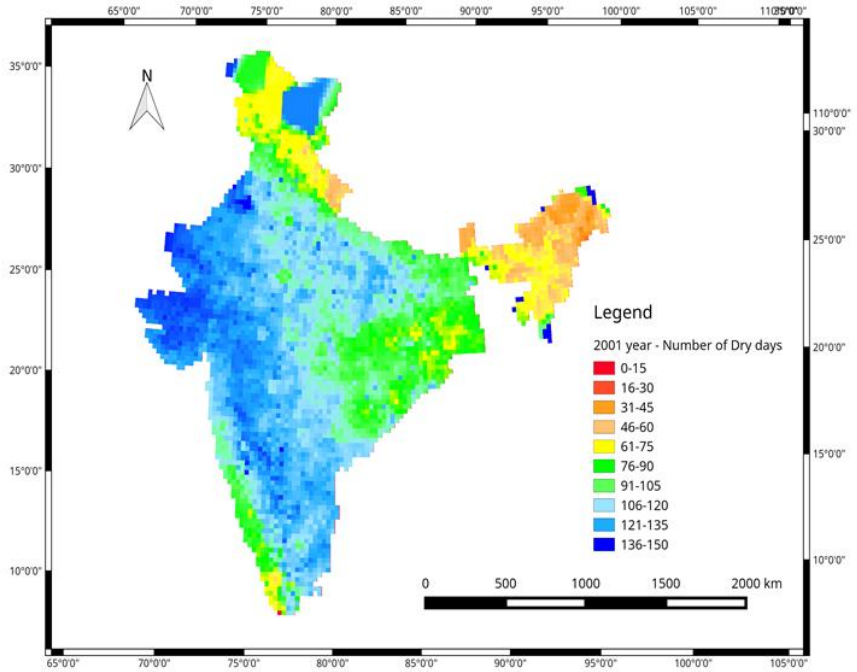


Fig 12: India – Dry days map – 2001

4.3. Forest fire count

Forest fire count in each grid was calculated using 0.25 ˚ grid of India and India forest fire points. The Maximum number of Forest fires falling in a grid are 385 fires in the year 2009, Assam state. Fig 13 shows the Forest Fire Count Map for the year 2001. The maximum number of forest fires falling in the grid is 66 (Manipur state). The maximum number of forest fires falling in a grid for each year are shown in table 2.

From the Forest Fire maps of India for 2001-2006, 2008-2014 years, North Eastern Forest states have more number of fires than other places in every year. Rajasthan and North Eastern parts of Jammu & Kashmir are very less prone to Forest fires.

4.4. Fire Frequency

The Forest Fire Frequency maps are derived using the Number of Forest fires falling in a grid. As mentioned before, Forest Fire Frequency is Fires in each grid / total number of days. Highest Fire Frequency of 2.566 is observed in the year 2009, Assam state.Fig 14. Shows the Forest Fire Frequency map for 2001 year and the highest Forest Fire Frequency is 0.4400. The highest number forest frequency occurring in a grid for all years is shown in table 2.

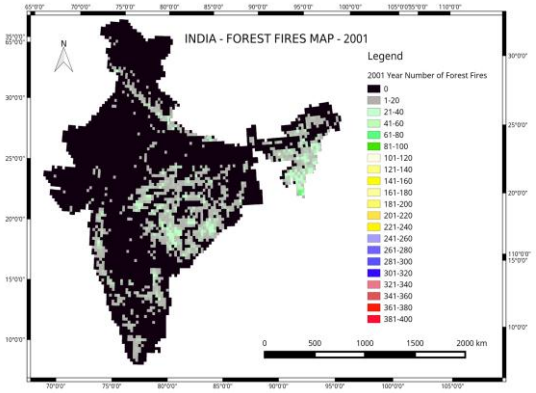


Fig 13: Forest fires map – 2001

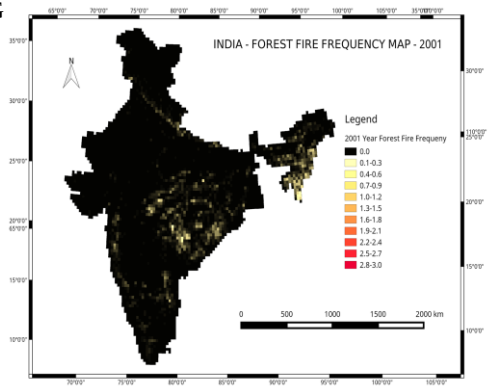


Fig 14: Forest fire frequency map -2001.

Table 2: Highest fire frequency in a grid year wise

Year	Maximum number of dry days in a grid	Minimum number of dry days in a grid	Maximum number of forest fires in a grid	Highest fire frequency in a grid
2001	150	37	66	0.44
2002	150	27	89	0.59
2003	150	28	144	0.96
2004	151	33	235	1.55
2005	149	18	218	1.45
2006	150	37	335	2.23
2008	151	29	213	1.41
2009	150	40	385	2.56
2010	150	44	362	2.41
2011	150	39	186	1.24
2012	151	38	186	1.96
2013	150	48	168	1.12
2014	150	39	233	1.55

5. Conclusion

Using QGIS, forest fire data is created from state boundary, Indian forest mask and Indian fire data using above methodology. The total number of forest fires in a month for a place (state) is necessary to build the relationship with the mean rainfall of month for the place. Using CDO, NCO Suite the Rainfall data is processed to find Daily rainfall in each grid, Mean monthly rainfall, Number of dry days, Number of rainy days. The Mean monthly rainfall data is then spatially joined with Polygon grid containing forest fire count. The resultant grid gives the Mean Monthly rainfall and Forest fire count. Using the Grid with Forest Fire count, Forest Fire Frequency is found. From this data influence of Mean dry days, Mean Annual Rainfall on Mean Forest Fire Frequency is found. From the results, it has been found that as the dry days increase the Mean Forest Fire Frequency increases.

The analysis performed for the study is useful to know the trend in forest fires over years as well as state wise, grid wise. The work can be extended by considering different other environmental variables like temperature, humidity, vegetation type etc.

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