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Original article

Analysis of forest fire and climate variability using Geospatial Technology for the State of Telangana, India

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ABSTRACT

The dynamic changes in the regimes of forest fires are due to the severity of climate and weather factors. The aim of the study was to examine the trend of forest fires and to evaluate their relationship with climate parameters for the state of Telangana in India. The climate and forest fire data were used and uploaded to the GIS platform in a specified vector grid (spacing: 0.3° x 0.3°). The data were evaluated spatially and statistical methods were applied to examine any relationships. The study revealed that there was a 78% incidence of forest fires in the months of February and March. The overall forest fire hotspot analysis (January to June) of grids revealed that the seven highest forest fire grids retain fire events greater than 600 were found in the north east of Warangal, east of Khammam and south east of Mahbubnagar districts. The forest fire analysis significantly followed the month wise pattern in grid format. Ten grids (in count) showed a fire frequency greater than 240 in the month of March and of these, three grids (in count) were found to be common where the forest fire frequency was highest in the preceding month. Rapid seasonal climate/weather changes were observed which significantly enhanced the forest fire events in the month of February onwards. The solar radiation increased to 159% in the month of March when compared with the preceding month whereas the relative humidity decreased to 47% in the same month. Furthermore, the wind velocity was found to be highest (3.5 meter/sec.) in the month of February and precipitation was found to be lowest (2.9 mm) in the same month. The analysis of Cramer V coefficient (CVC) values for wind velocity, maximum temperature, solar radiation, relative humidity and precipitation with respect to fire incidence were found to be in increasing order and were in the range of 0.280 to 0.715. The CVC value for precipitation was found to be highest and equivalent to 0.715 and showed its strongest association/relationship with fire events. The significant increase in precipitation not only enhances the moisture in the soil but also in the dry fuel load lying on the forest floor which greatly reduces the fuel burning capacity of the forest. The predicted (2050) temperature anomalies data (RCP-6) for the month of February and March also showed a significant increase in temperature over those areas where forest fire events are found to be notably high in the present scenario which will certainly impact adversely on the future forest fire regime. Findings from this study have their own significance because such analyses/relationships have never be examined at the state level, therefore, it can help to fulfill the knowledge gap for the scientific community and the state forest department, and support fire prevention and control activities. There is a need to replicate this study in future by taking more climate variables which will certainly give a better understanding of forest fire events and their relationships with various parameters. The satellite remote sensing data and GIS have a strong potential to analyze various thematic datasets and in the visualization of spatial/temporal paradigms and thus significantly support the policy making framework.

KEY WORDS: forest fire, grid analysis, climate parameters, Cramer's V coefficient, climate anomalies

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1. Introduction

Remote sensing and GIS have the ability to detect and monitor fires (AGER ET AL., 2017; AHMAD & GOPARAJU, 2017a) and have increased our comprehension of risk and hazard mapping from fire (CHUVIECO & CONGALTON, 1989) and have overcome the limitations of traditional fire records systems (CSISZAR ET AL., 2005; EVA & LAMBIN, 1998; FLANNIGAN & VONDER HAAR, 1986; KORONTZI ET AL., 2006).

Climate change will increase the risk of fire activity and will threaten many forest ecosystem functions (Ahmad & Goparaju, 2017b), will impact on human society (Bowman et al., 2009; Flannigan et al., 2009; Whitlock et al., 2010) and will change the structure and function of forest landscapes (Florent et al., 2002; Donald et al., 2004). The climate regulates forest fire regimes (Harrison et al., 2010) and has an important role in the distribution, structure, composition and ecology of forests (Kirschbaum et al., 1996).

Climate variability at both intra-monthly (weather) and inter-annual (climate) time scales is a major factor of fire behavior. Weather severity plays a key role during the summer season which moderates fire behavior through winds/ temperature/moisture (Flannigan et al., 2009; Bradstock, 2010).

Fire activity, movement and its spread mostly depend on the amount of fuel lying on the forest floor, local climate/weather conditions, the source of ignition and human activity (Bond & van Wilgen, 1996; Flannigan et al., 2005; Moritz et al., 2005). The amount of fuel loads and its distribution pattern in the forest affect fire activity (Finney, 2001). The moisture in the fuel by and large determines whether fuels can sustain the fire (Littell et al., 2009) and these parameters have been found to be an important deciding factor in the size of the area burned (Flannigan et al., 2005) and its spread (Blackmarr, 1972; Wotton et al., 2010).

A few forest fire studies have been carried out such as Reddy et al. (2017), who quantified the extent of the total burnt area and CO_2 emissions covering the whole natural vegetation types and all the Protected Areas of India; also Giriraj et al. (2010) identified high fire prone zones using ATSR satellite data; Vadrevu et al. (2008) analyzed the spatial patterns in fire events across diversified geographical, vegetation and topographic gradients and concluded that the maximum number of fire events are found in low and medium elevation gradients; Vadrevu et al. (2013) analyzed the various fire regimes; Ahmad & Goparaju (2017a) identified forest fire hotspot districts and further analyzed the fire events in a grid and identified grids of high fire frequency; Ahmad et al. (2017) studied the fire trends to understand the various spatial and temporal perspectives of forest fire events and identified forest fire hotspots. They further evaluated the climate/weather data and established their relationships to forest fire events using statistical methods.

A large part of the Telangana state is dominated by deciduous forests which are more vulnerable to fire (FAO, 2001) and climate/weather induced forest fires are one of the major reasons for forest degradation. The forest fire events and their relationship to various climatic/weather parameters have been widely studied in developed countries (Wotton et al., 2010; Tian et al., 2012) but very few studies address the issue in Indian regions which creates a knowledge gap in these research studies. The present study has used the forest fire and climate data sets for the whole state of Telangana and evaluated these using a grid (https://www.giscourse.com/creating-a-fishnet-grid-using-arcgis-10/). A grid is a network of evenly spaced horizontal and vertical lines which was later converted into a polygon for systematically reviewing a large dataset in GIS to enable a visualization of the spatial/ temporal pattern and then analyzed their interaction.

The aims of this study were as follows:

1. Identification of forest fire hotspot grids.
2. Analysis of trends of spatial seasonal (month wise) forest fire grids.
3. Analysis of climatic/weather datasets and establishment of the association/relationship with the incidence of forest fires using Cramer V coefficient statistical analysis (Liebetrau, 1983).
4. Evaluation of predicted (2050) temperature anomalies (RCP-6 Scenario) data for the months of February and March.

2. Materials and methods

2.1. The study area

The Telangana is one of states of India (Fig. 1) and has latitudes of 15º 49' N to 19º 54'N and longitudes of 77°15'E to 81°47'E and is spread over a geographical area of 112,077 km^2. It is bordered by the states of Maharashtra to the north and north-west, Chhattisgarh to the north, Karnataka to the west, and Andhra Pradesh to the east and south. Telangana has a hot and dry climate and is recognized as a semi-arid area and retains forest largely of dry deciduous type. The summer season starts in the month of March and lasts up to the month of May and the monsoon arrives in the month of June.

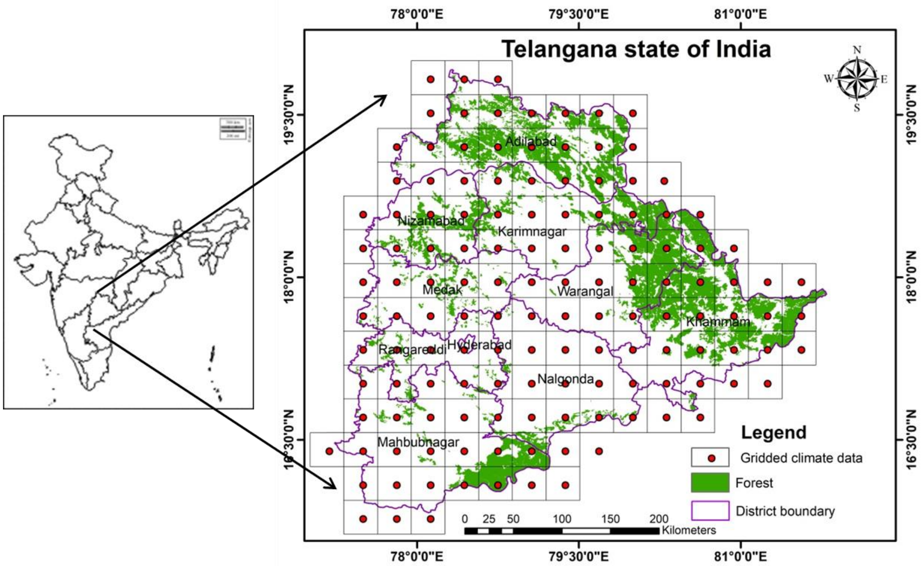

Fig. 1. The location of the study area

2.2. Data preprocessing and analysis

To achieve our aims we used various data sources such as long term forest fire events, climate, precipitation and datasets of temperature anomalies. The study utilized the forest fire points datasets (2008 to 2016) downloaded from the Forest Survey of India (FSI) website (http://fsi.nic.in/forest-fire.php). FSI has been continuously monitoring the forest fire events over the Indian territory from the year 2005 onwards using the Moderate Resolution Imaging Spectro-radiometer (MODIS) based active fire points provided by NASA and the Geography Department of the University of Maryland (http://nidm.gov.in/pdf/pubs/forest%20fire.pdf). All the fire points were first masked by FSI with the latest forest cover to eliminate the non-forest fire points. The climate decadal data (wind velocity, maximum temperature, solar radiation, relative humidity) from the date 1-8-2004 to 31-7-2014 were downloaded from the website globalweather.tamu.edu. These climate data retain the daily climate point values with the grid spacing 0.3° x 0.3°. These data were brought into the GIS domain. The vector grids (evenly spaced horizontal and vertical lines) with a spacing 0.3° x 0.3° were created using the GIS softwareover the state of Telangana in such a way that each grid polygon retains the climate data onto the centre to closely analyze the map and their relationships/associations. The forest fire points (overall and monthly) were evaluated over the grids to understand their spatial extent and grid trend. Here the hotspot grids were those grids which exhibited high numbers of forest fire events. In this analysis, four parameters (maximum temperature, relative humidity, solar radiation and wind velocity) were analyzed separately month wise (February to July) and its swing (increase/decrease) was evaluated with respect to the base month (January). We utilized the kriging interpolation technique to generate a month wise climate data map which was further utilized to produce various final maps showing the climate parameter variability (+ increase, - decrease) with respect to the base month January.

Additionally, we also downloaded district wise monthly (January to June) decadal precipitation data (1993 to 2002) from the Indian Water Portal (http://www.indiawaterportal.org/met_data/). The average monthly precipitation data from January to June was used in this study. The Cramer's V coefficient (CVC) statistical method was used to understand the relationship of the climatic/weather parameter trend with forest fire incidence. We downloaded the predicted point grid monthly (February and March) temperature anomalies (climate change scenario RCP-6) data for the year 2050 (NCAR GIS Program, 2012). These data were used to generate the temperature surface for the year 2050. The ARCGIS and Erdas Imagine Software were extensively used to analyze various data sets to achieve our above mentioned aims.

3. Results and discussion

3.1. Overall forest fire assessment

We have used the generated grids equal to the spacing of the climatic point data onto the state of Telangana and analyzed the forest fire events. The forest fire hot spot grid map over the state of

Telangana is given in Figure 2. The forest fire events were depicted by dots. The bigger dots mean higher forest fire occurrence. The total forest fire events (January to June) over Telangana state equalled 14118 for the period 2008 to 2016. The highest seven forest fire grids (in count) retain fire events greater than 600 were found to be in the north east of Warangal, east of Khammam and south east of Mahbubnagar districts. We also evaluated the forest fire percentage for each district considering the total forest fire percentage for the state of Telangana as 100%. The percentage of forest fires per district were found to be significantly high in Khammam (36.3%) followed by Warangal (24.0%), Adilabad (19.1%), Mahbubnagar (10.5%), Karimnagar (7.7%) and Nizamabad (1.6%). The rest of the districts have significantly low percentages (less than 1%) of forest fire. Asimilar spatial pattern of forest fires was studied in Canada by PARISIEN ET AL. (2006).

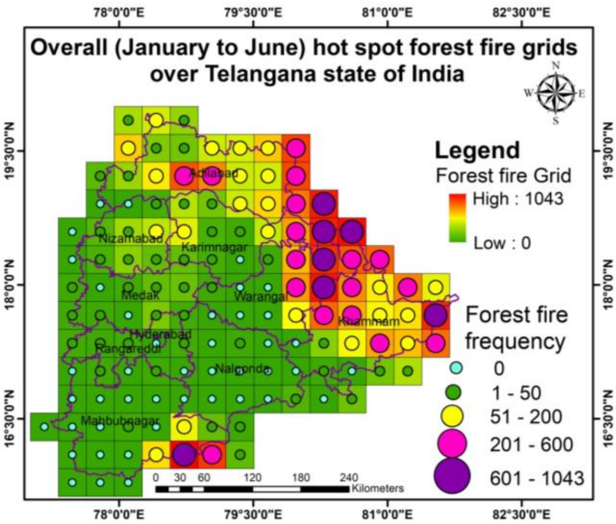

Fig. 2. The overall (January to June) grid for the forest fire hotspots for the state of Telangana (2008 to 2016)

3.2. Forest fire trend

The grid for forest fires based on their distribution pattern over the months of January, February, March, April, May and June are given in Figures 3, 4, 5, 6, 7 and 8 respectively. Table 1 shows the monthly forest fire occurrence (January to June) for the state of Telangana in order to understand the seasonal forest fire trend. The percentage of forest fires events in the month of January, February, March, April, May and June were found to be 2.2%, 25.9%, 52.2%, 14.2%, 5.2% and 0.3% respectively considering the total forest fire frequency to be 100% between these period.

Around 78% of the forest fires occurred in the months of February and March, whereas 52.2% of forest fire events were in the month of March alone (Table 1). The evaluation of forest fires events from the grid in the month of January was the lowest and equal to 317 and only two grid (in count) showed forest fire events greater than 30 (Fig. 3a).The evaluation of forest fire events from the grid in the month of February revealed that the forest fire frequency was higher in the eastern and southern sides of the state. The forest fire frequency in the month of February was found highest in four grids (in count) with forest fire events greater than 180 (Fig. 3b).

The forest fire events were significantly high in the month of March. The total ten grids (in count) showed a fire frequency greater than 240 in the month of March and out of this, three grids (in count) were found to be common where the forest fire frequency was highest in the month of February (Fig. 3b). The frequency of fires showed a decreasing trend from March onwards. In the month of April fire events were found to be highest in one grid (in count) with a fire frequency greater than 120 (Fig. 3d). Similarly, in the month of May fire events were further reduced and only one grid (in count) was found with a fire frequency greater than 90 (Fig. 3e). Furthermore, in the month of June the forest fire events were found to be at a minimum for all months because of the active pre-monsoon weather phenomenon which significantly increases the moisture content in dead wood and dying leaves lying on the forest floor. Similar monthly trends for forest fires have been observed by GIGLIO ET AL. (2013), AHMAD ET AL. (2017), AHMAD & GOPARAJU (2018).

Table 1. Forest fire events for each month for Telangana

Month	January	February	March	April	May	June
Forest fire events (frequency)	317	3657	7372	2004	729	39
Forest fire %	2.2	25.9	52.2	14.2	5.2	0.3

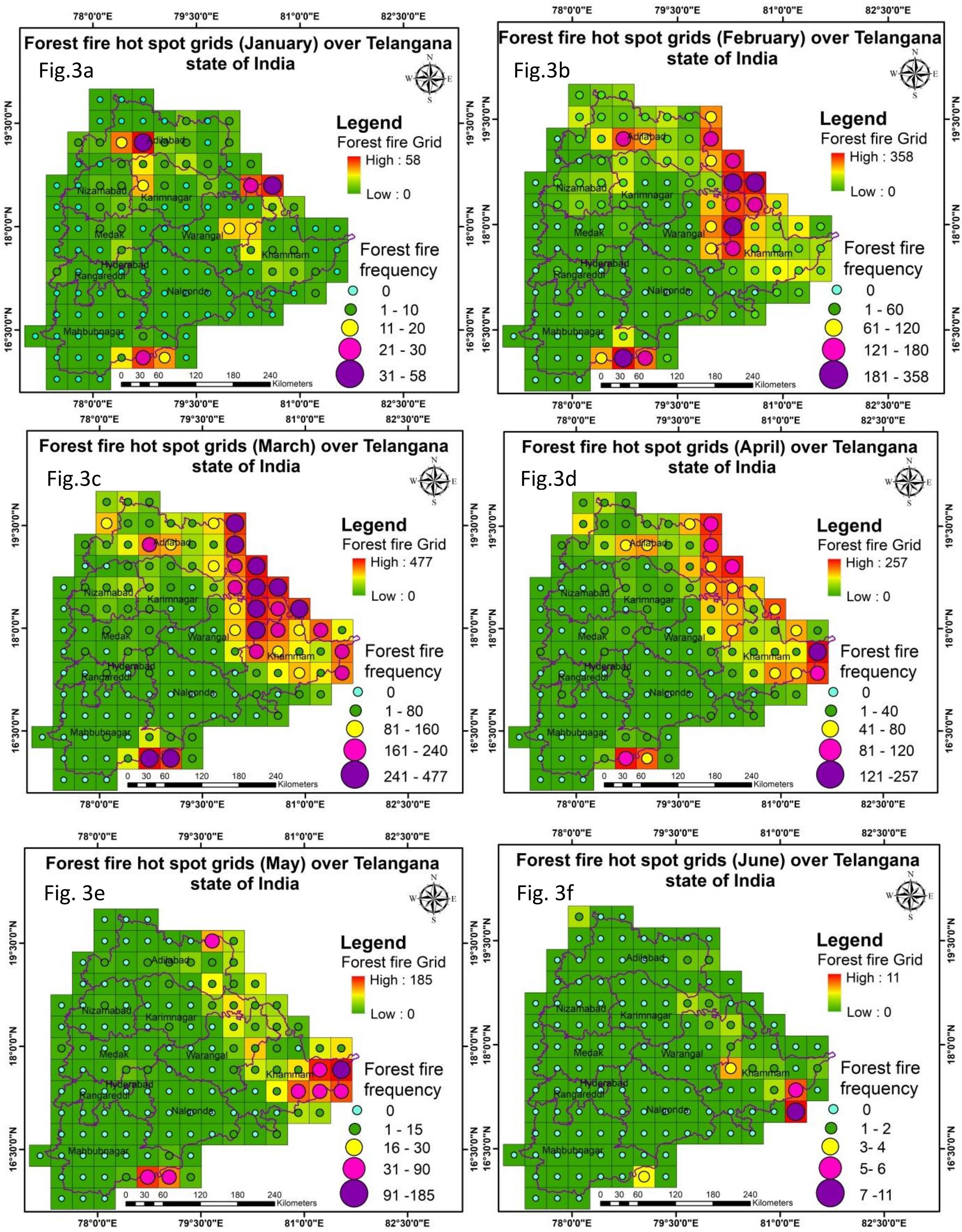

Fig. 3. Long term monthly (2008 to 2016) forest fire spatial trend (a, b, c, d, e, f is January, February, March, April, May and June respectively)

3.3. Grid based climatic data evaluation

The average of four climate parameters (maximum temperature, relative humidity, solar radiation and wind velocity) were evaluated monthly (February to July) and the variability (+ increase, - decrease) was compared with respect to the base month (January) and shown in Figures 4, 5, 6 and 7. In the month of January the forest fire incidents were significantly low. The weather severity starts in the month of February onwards and leads to a change in forest fire events until June (the start of the pre-monsoon showers).

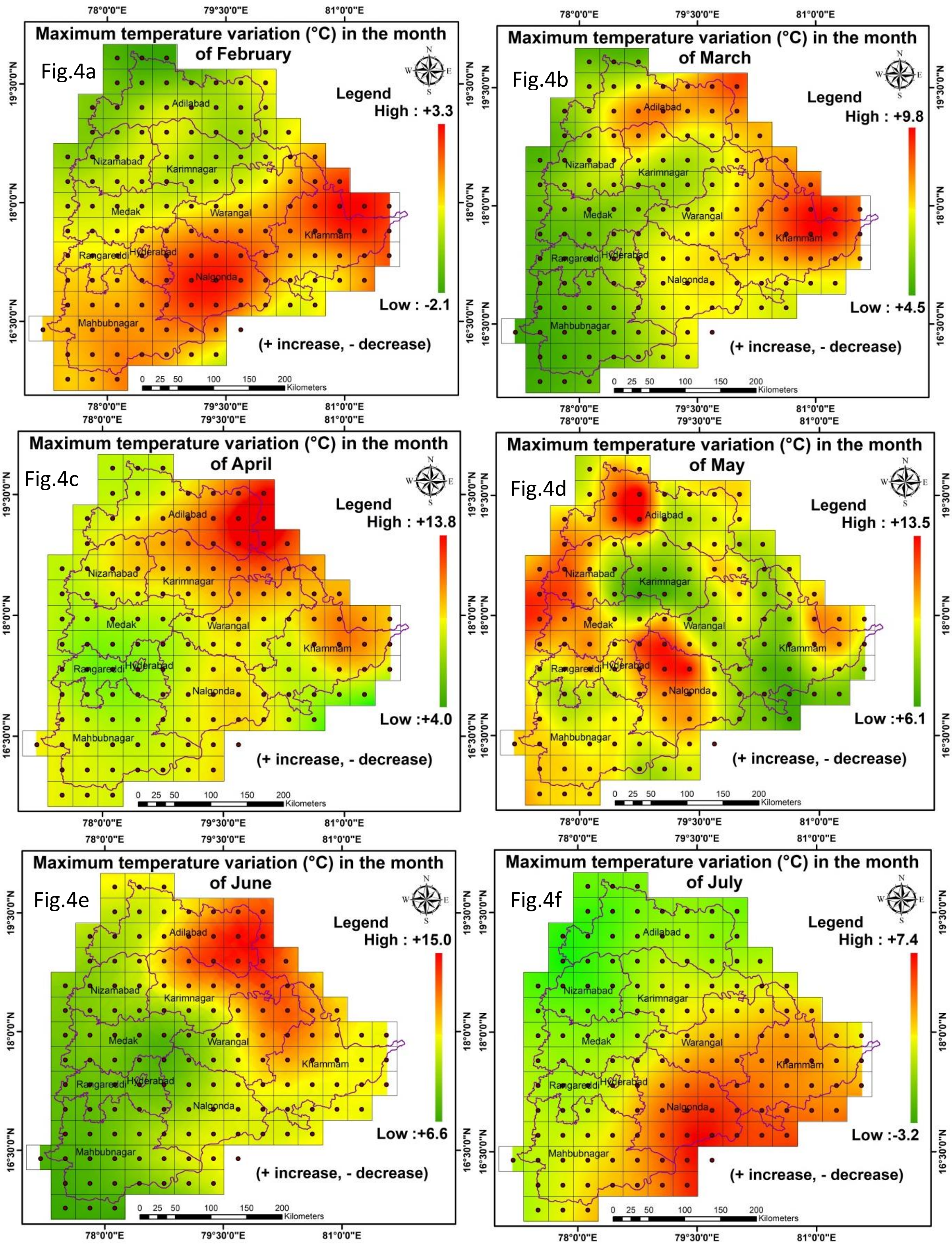

Fig. 4. Monthly maximum temperature variation when compared with the base month of January (a, b, c, d, e, f are February, March, April, May, June and July respectively)

The evaluation of the maximum temperature (°C) revealed that the temperature in the month of February was roughly between 19 to 31 whereas the maximum increase (3.3°C) was observed in the southern portion of the grids when compared with the preceding month January (Fig. 4a). The rapid increase in temperature was observed in the month of March and ranged from 28°C to 41°C. The highest increase of 9.8°C was observed on the eastern portion of the grids (in the Khammam and Adilabad districts which retain significantly high forest fire events in this month) when compared with the base month (January) (Fig. 4b). The temperature further showed an increasing trend in the month of April, which was found to range between 29°C to 46°C whereas the highest increase was observed in the grids of the north eastern region (Fig. 4c). In the months March, April, May and June the variation of temperature was found to be an increasing trend (because both the lowest and highest values were found to be positive) when compared with the base month (January) (Figures 4b, 4c, 4d, and 4e).

Analysis of the relative humidities (fraction) over the state of Telangana in the months of January, February, March, April, May, June and July were found to be in the ranges of (0.34 to 0.76), (0.52 to 0.91), (0.22 to 0.82), (0.11 to 0.84), (0.16 to 0.82), (0.20 to 0.82) and (0.34 to 0.76) respectively.

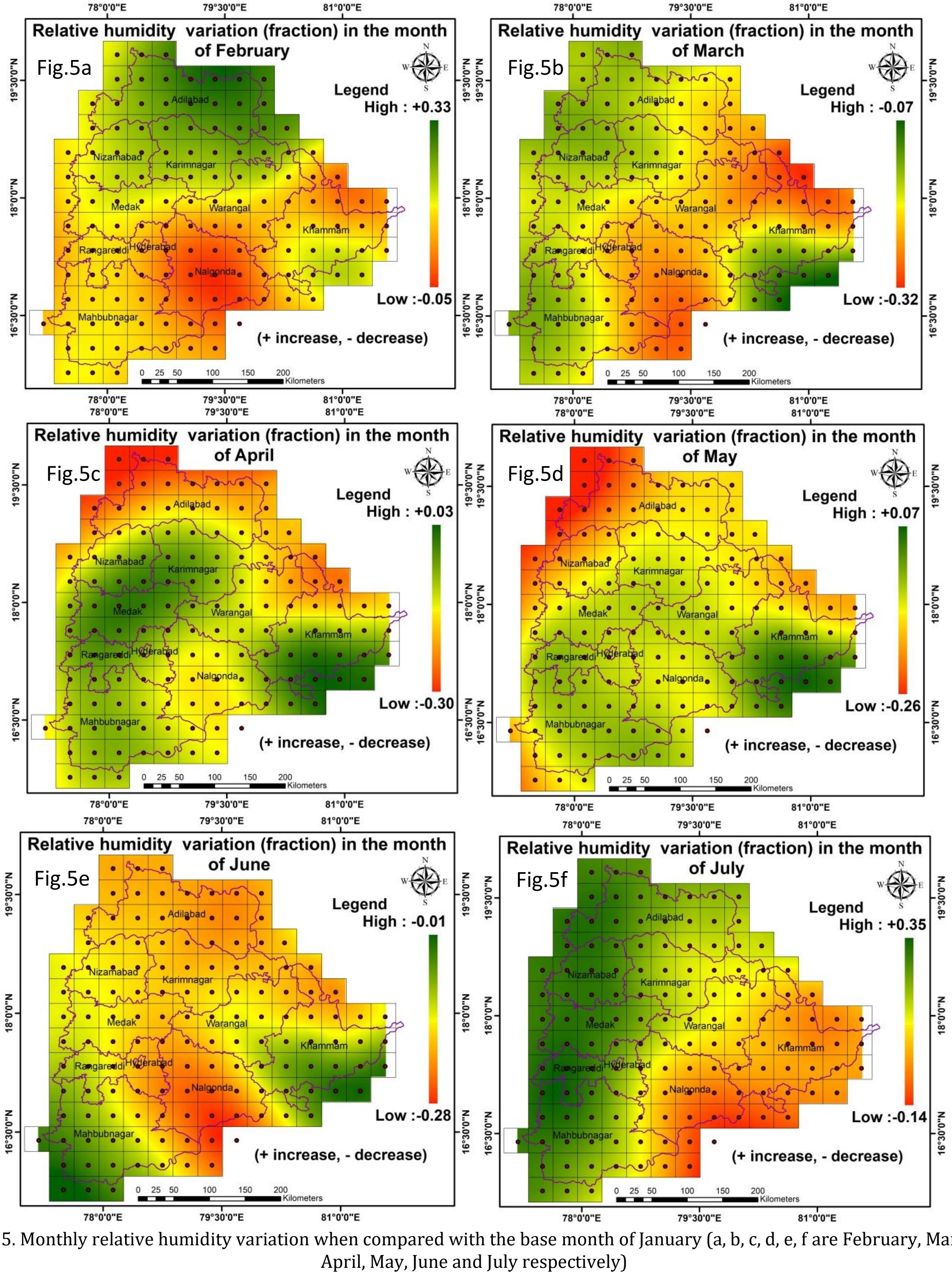

Fig. 5. Monthly relative humidity variation when compared with the base month of January (a, b, c, d, e, f are February, March, April, May, June and July respectively)

The swing (+ increase, - decrease) of the relative humidities in the months of February, March, April, May, June and July, when compared with the base month of January, were found to be in the range of (-0.05 to +0.33), (-0.32 to -0.07), (-0.30 to +0.03), (-0.26 to +0.07), (-0.28 to -0.01) and (-0.14 to +0.35) (Figures 5a, 5b, 5c, 5d, 5e and 5f).The relative humidity was found to be significantly low in all locations in the month of March when compared with base month January (both the highest and lowest values were found to be negative; Fig. 5b) whereas it was notably low over the forest fire areas (Fig. 3c).

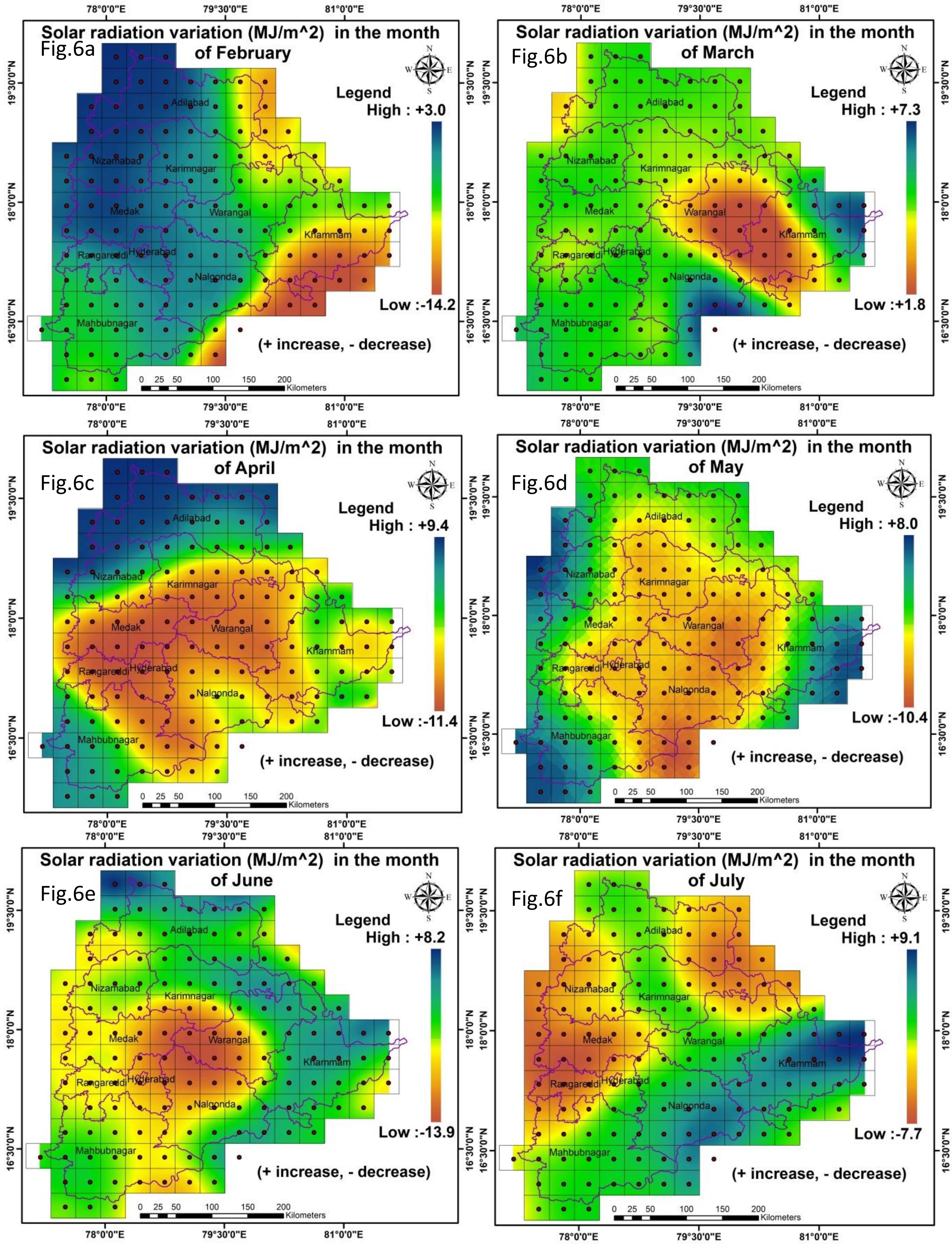

Fig. 6. Monthly solar radiation variation when compared with the base month of January (a, b, c, d, e, f are February, March, April, May, June and July respectively)

Analysis of solar radiation (MJ/m^2) over the state of Telangana for the months of January, February, March, April, May, June and July were found to be in the range of (12.2 to 19.3), (2.0 to 20.3), (13.6 to 24.6), (3.8 to 26.7), (7.7 to 25.9), (4.2 to 25.9) and (10.4 to 25.3) respectively. The lowest value for the solar radiation range was found to be highest in March equivalent of 13.6 (MJ/m^2) among all months. In the month of March the variation of the solar radiation was found to be in the range of (+1.8 to +7.3), and showed an increasing trend (because both the lowest and highest value were found to be positive) when compared with the base month of January (Fig. 6b).

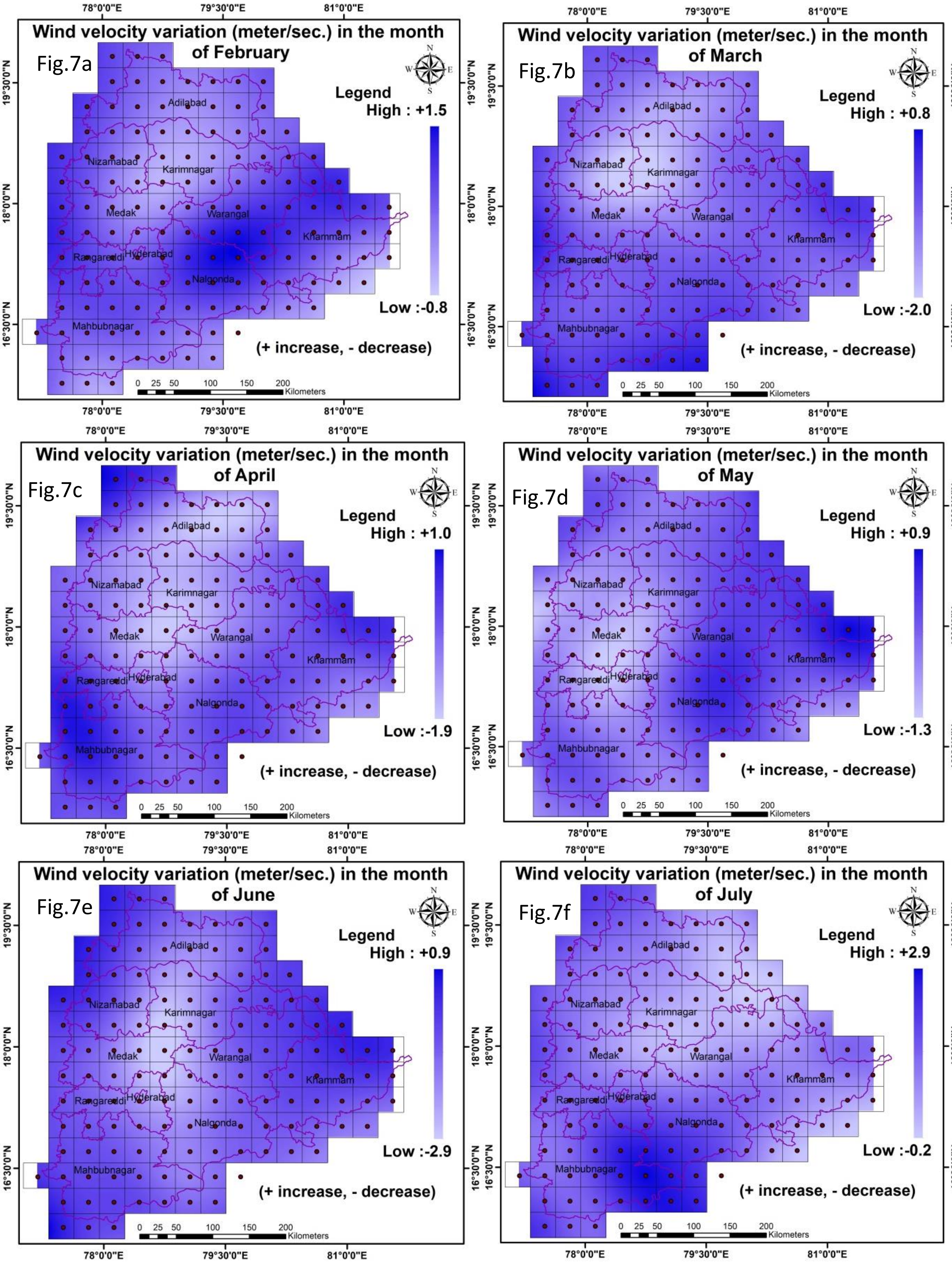

Fig. 7. Monthly wind velocity variation when compared with the base month of January (a, b, c, d, e, f are February, March, April, May, June and July respectively)

Analysis of wind velocity (meter/sec.) over the state of Telangana for the months of January, February, March, April, May, June and July were found to be in the range of (1.2 to 5.3), (2.0 to 5.1), (1.5 to 4.4), (0.9 to 6.3), (1.5 to 7.4), (1.5 to 8.6) and (2.5 to 9.1) respectively. The wind velocity swing was found to be significantly high in the months of March, April and May and roughly over the area where the forest fire events were found to be high over the same period (Figures 7b, 7c and 7d). Similar climate induced variations on forest fires have been analyzed by JOLLY ET AL. (2015) and AHMAD ET AL. (2018).

The district decadal average monthly precipitation for the state of Telangana from January to July is given in Fig. 8. The Khamam district which showed a notably high forest fire incidence (36.3%) showed significantly low precipitation from January to March (less than 5mm) and the same district had the lowest March precipitation for all districts. Furthermore, the average monthly precipitation trend at the state level (Table 2) showed that February had the lowest precipitation (2.9 mm) followed by March (7.9 mm). The average monthly precipitation for June and July were found to be significantly high (> 100 mm) due to the pre and post monsoonal activity which enhanced the moisture content in the fuel loads (dry leaves/brash/ wood) lying on the forest floor and thus greatly reduced the chances of forest fire. A similar observation of seasonal precipitation variability and fire occurrences was analyzed by CARCAILLET & RICHARD (2000) and PAUSAS (2004).

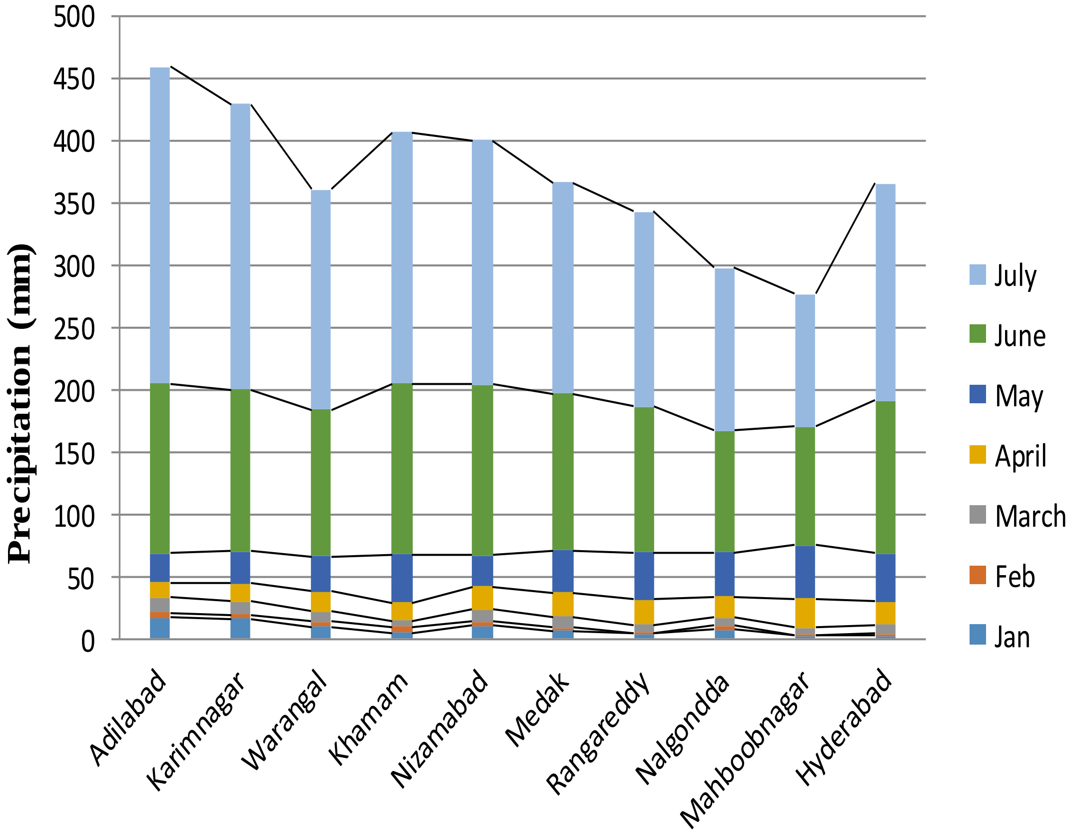

Fig. 8. Decadal average precipitation (mm) for the state of Telangana from January to July

3.4. Statistical analysis

Here the objective was to examine the monthly climate data using statistical analysis (Crammer's V coefficient, CVC) and to investigate the relationship between parameters and forest fire incidence. The climatic/weather datasets of maximum temperature, relative humidity, solar radiation, wind velocity and precipitation were analyzed monthly and average values were calculated. The average monthly observations from January to June are recorded in Table 2. The maximum temperature, relative humidity, solar radiation, wind velocity and precipitation were found to be in the range of (25.1 to 41.2), (0.330 to 0.709), (14.5 to 23.0), (2.7 to 3.5) and (2.9 to 121.7) respectively. The maximum temperature shows an increasing trend from January to June whereas the highest increase in temperature was observed in the month of March (also the month for the highest forest fire incidence) with a value of 9.3°C when compared with the preceding month. Rapid climate/weather changes were observed which significantly enhanced the forest fire events in the months of February onwards. The solar radiation increased to 159% in the month of March when compared with the preceding month whereas relative humidity decreased to 47% in the same month. Furthermore, wind velocity was found to be highest (3.5 m/s) in the month of February and precipitation was found to be lowest (2.9 mm) in the same month.

Table 2. Climate/weather monthly data (January to June)

Average climate data	January	February	March	April	May	June
Maximum temperature (°C)	25.1	28.3	37.6	39.2	40.0	41.2
Relative humidity (fraction)	0.520	0.709	0.330	0.406	0.452	0.372
Solar radiation (MJ/m^2)	17.8	14.5	23.0	17.5	17.7	16.1
Wind velocity (meter/sec.)	3.2	3.5	2.8	2.8	3.2	2.7
Precipitation (mm)	8.2	2.9	7.9	17.5	32.8	121.7

Here the CVC values for wind velocity, maximum temperature, solar radiation, relative humidity and precipitation were in increasing order and in the range of 0.280 to 0.715 (Table 3). All climate/weather parameters show a strong association with forest fire events except wind velocity. The CVC value for precipitation was found to be the highest 0.715 and showed the strongest association with fire events. The significant increase in precipitation not only enhances the moisture in soil but also in the dry fuel lying on the forest floor which greatly reduces the fuel burning capacity of the forest. Similar findings for forest fire events and their strong relationship with precipitation was observed by PARISIEN ET AL. (2006).

Table 3. Crammer's V coefficient (CVC) values for factors driving forest fires

Meteorological variable (Driving factors)	Forest fire frequency Crammer's V coefficient (CVC)
Maximum temperature	0.346
Solar radiation	0.405
Relative humidity	0.446
Wind velocity	0.280
Precipitation	0.715

3.5. Climate anomalies and their impact

Forest fire events are increasing every year in India (http://www.downtoearth.org.in/news/indian-forests-are-on-fire-a-little-more-every-day-59871) due to climate/weather severity (AHMAD ET AL., 2017). Fires and the climate have a crucial relationship (SWETNAM & BETANCOURT, 1990; MARLON ET AL., 2008; ALDERSLEY ET AL., 2011). Climate change is significantly maneuvering weather parameters severity to extremes whereas climate/weather induced interference and its impact on forest fire activity (FLANNIGAN ET AL., 2000; FRIED ET AL., 2004) contributing significantly in term of forest fire incidence (STEPHENS, 2005; WESTERLING ET AL., 2006). A study based on fire modeling predictions revealed that the incidence of forest fires will be more intense and severe in the future (PINOL ET AL., 1998; WOTTON ET AL., 2010; TIAN ET AL., 2012). Some of the studies on climate change have also shown a rise in temperature (BETTS, 2017; GIANNAKOPOULOS ET AL., 2009), reduction of rainfall pattern (GIORGI & LIONELLO, 2008), decrease in the number of rainy days (KUMAR & JAIN, 2010) and an increase in drought (SHEFFIELD & WOOD, 2008; DAI, 2011) will together influence many features of the forest fire regime (WELLS ET AL., 2004) including an increase in the span of the fire season (VOROBYOV, 2004; FLANNIGAN ET AL., 2005).

The predicted (2050) temperature anomalies data (RCP-6) and their spatial distribution pattern for the months of February and March are given in Fig. 9 for a better understanding of the likely future climate impact on forest fires. Furthermore, a significantly high number (78%) of forest fire events were observed in these months in the present scenario.

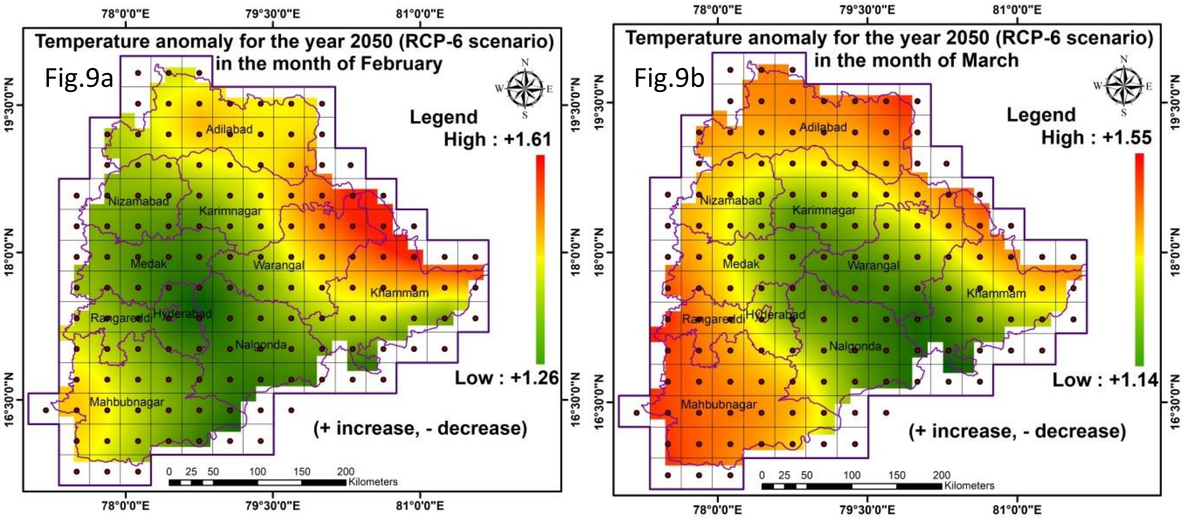

Fig. 9. Temperature anomalies (°C) for the year 2050 over the state of Telangana (for a: February, b: March)

The increase in temperature for the months of February and March (2050) was found to be in the range of (1.26 to 1.61°C) and (1.14 to 1.55°C) respectively. The significant increases in temperature in the months of February and March were found over those areas where forest fire events are notably high (in the present situation: Figures 3b, 3c) and will certainly impact adversely on the future forest fire regime. Such analyses are a matter for serious concern for policymakers as far as future fire prevention and control is concerned.

5. Conclusion

This study manifested the forest fire events in a spatial grid format and analyzed the monthly trend. The grids for the north eastern part retain a significantly high incidence of forest fire events. The seasonal forest fire trends are high in the months of February and March and were concentrated over the grids for the Khammam and Warangal districts. The evaluation of forest fire events with climate parameters showed some significant relationships. This study has its own significance because these interactions were evaluated for the first time at state level. Our study crucially fills the knowledge gap which is widely prevalent in the Asian subcontinent countries, including India, in the present climate change scenario whereas it is adequately covered by several research studies in developed countries. There is a need to implement the weather forecast and alarm system urgently especially during the forest fire period which will help to take adequate preventive steps to control the forest fires. The predicted temperature (for February and March) anomalies data for the year 2050 also reflects a significant increasing trend for temperature over those areas where forest fire events are found to be notably high in this analysis. Such evaluations are a matter for serious concern for state policymakers as far as future fire prevention and control is concerned. Therefore a new forest fire policy is urgently required to take into consideration of the likely future climate change impact.

The remote sensing and GIS techniques have enormous capability to analyze diversified spatial data sets such as climate/weather and forest fire data and therefore they should be incorporated into decision making so that appropriate forest conservation/fire prevention/control related policy/decisions are taken in time.

Future research scope: There is a need for more research in the field of forest fires, socioeconomic conditions of forest inhabitants, present climate and future climate scenarios for India which will give a better understanding/knowledge and their hidden relationships. The results of such studies will significantly promote more meaningful decision making processes.

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