ANALYSIS OF EXTREME TEMPERATURE EVENTS OVER CENTRAL INDIAN REGION USING SATELLITE DATA

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ABSTRACT: An analysis of Extreme Temperature events (ETE) during the months of March, April, May was conducted over the Central Indian Region for the years 2003-2016 using remotely sensed AIRS level 3 version 6 (1^0 x 1^0) Air Temperature at surface data. A high positive correlation of 0.84 was found between the AIRS and ground based IMD gridded temperature data, supporting the use of AIRS data for the study. A histogram analysis, to identify the ETE was done, which showed that the HW can be considered when the Air temperature is higher than the 99th percentile of the Daily Mean Temperature (T_{DM}).

To know about the frequency, duration and intensity of the ETE, a Heat Index (HI) was calculated using the difference between the T_{DM} and Long Term Mean (M_{LT}) i.e., the anomaly, and dividing it by the Standard Deviation of M_{LT}. The M_{LT} of the study area showed a minor rise in temperature around end of March and beginning of April which indicated possibility of ETE. The anomaly along with the HI values and intensity from sensitivity analysis were studied yearly and the days which had a HI value above 0.3 and anomaly above 0.8 were considered as ETE for that year if the duration was of two or greater than two days. Though the study area was too big and the time period too small to conclude a trend, it was inferred that the extreme events are happening early i.e. in March for some years and increasing during May along with their duration. The number of ETE of duration more than 5 days was seen to be large as well. The spatial analysis of the study area helped to visualize the region that is more affected by ETE in Central India.

1. INTRODUCTION

As per the Indian Meteorological Department (IMD), “Heat wave is a condition when departure of maximum temperature from normal is + 4ºC to + 5ºC or more for the regions where the normal maximum temperature is more than 40ºC and departure of maximum temperature from normal is + 5ºC to + 6ºC for regions where the normal maximum temperature is 40ºC or less”.

Higher daily peak temperatures and longer, more intense heat waves are becoming increasingly frequent globally due to climate change. India too is feeling the impact of climate change in terms of increased instances of heat waves which are more intense in nature with each passing year, and have severe adverse impacts on human health, increasing the number of heat wave casualties.

Northern, western, central and south central parts of India experience heat waves during summer. These conditions arise due to winds which blow from the hot and dry state of Rajasthan. Anti-cyclone which develops over this state, prevents western disturbances from entering the Indian subcontinent, leading to clear skies.

The reason for heat waves in central and south central parts of India is partially the wind originating from hot and arid regions of western India, and partially due to the rugged and barren physiography of plateau in these parts of India.

In the years when the monsoon is delayed or weak, the incidence of heat waves is higher and there is overheating because the rainfall which brings down the temperature over the heated landmass is absent or deficient.

Heat wave is a regular feature of Indian summer, especially in certain pockets of India. West India, north-west, north-central, central and south-central India are the regions which experience heat wave.

Air temperature is an essential component in microclimate and environmental research, but difficult to map in urban environments because of strong temperature gradients. Using the AIRS Air Temperature data at surface the study for the extreme temperature events has been carried out in the project.

Prolonged severe heat wave condition may cause serious problems to water supply, cause moisture stress in the soil and adversely affect agriculture. When an area is affected by severe heat wave and followed by delayed onset of monsoon, then the situation becomes more miserable for the inhabitants because of water scarcity and delay in sowing operations. There is a need to analyze the duration, frequency and intensity of the extreme events which may help in establishing proper warning systems leading to improvement in the public information campaigns on dangers of Heat Waves.

2. OBJECTIVES

- To validate the AIRS L3 Daily ($1^0 \times 1^0$) V006 satellite-derived Air temperature at surface data with the ground-based station temperature data of IMD.
- To define a Heat index and understand the characteristics of extreme events – duration, frequency and intensity using 14 years of AIRS data over Central Indian regions.

3. STUDY AREA

The study area was confined to the Central part of India extending from 78^0 E - 86^0 E, 18^0 N - 28^0 N. It comprises of Chhattisgarh, East Madhya Pradesh, East Maharashtra, Central, East and South Uttar Pradesh, Odisha, West Bihar and West Jharkhand and Part of Telangana. The area is known for recording some elevated temperatures such as Bilaspur district in Chhattisgarh recorded a highest temperature of 49.3 Degree Celsius in May 2017. Rentachintala in Guntur district of North Andhra Pradesh recorded a maximum temperature of 52 Degree Celsius in May 2012.

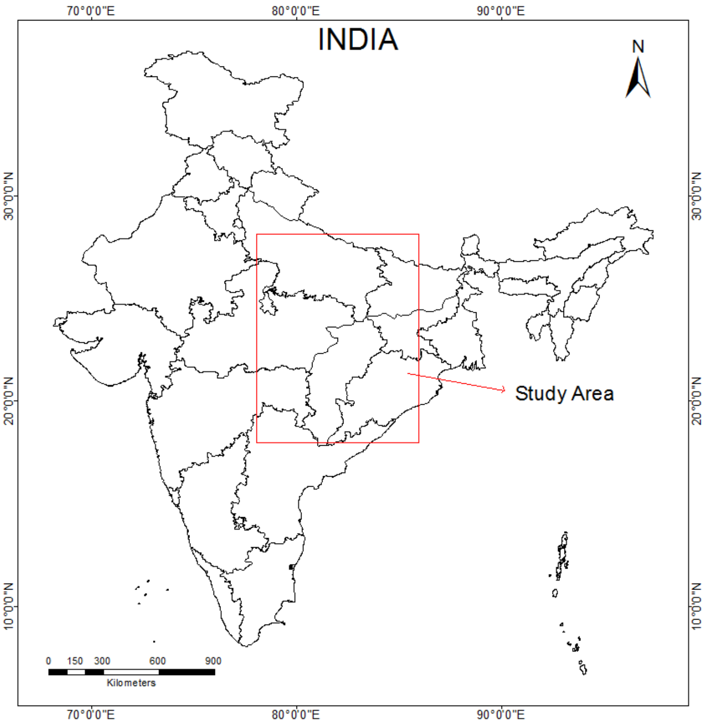

Figure 1: Location Map of Study Area

4. DATASETS

Remotely sensed data in conjunction with ground based observation data has been utilized in the present study in order to obtain more accurate temperature value.

Satellite Data Utilized

Aqua AIRS Level 3 Daily Standard Physical Retrieval (AIRS+AMSU) V006- Air Temperature at surface (AIRX3STD v006) (1^0 x 1^0) was acquired from Giovanni which is a Web interface that allows users to analyse NASA's gridded data from various satellites and surface observations. The data was downloaded in csv format and was imported in Microsoft Excel for further use.

Ground Validation Data

A high resolution daily gridded temperature data set interpolated into 1^0 x 1^0 prepared by Indian Meteorological Department for the Indian region developed using temperature data of 395 quality controlled stations for the period 1951–2013 was used to validate satellite data. The data was arranged in 31x31 grid points.

Latitude - 7.5N, 8.5N ... 36.5, 37.5 (31 Values)

Longitude - 67.5E, 68.5E ... 96.5, 97.5 (31 Values)

5. SOFTWARE USED

i) Microsoft Excel- Complete analysis of the data was done using this. DigiDB Excel add-in tool was used in sorting the data monthly and yearly as required.

ii) ArcGIS- The maps have been generated using ArcGIS software.

6. METHODOLOGY

The first component of methodology deals with the data preparation for the study which involved conversion of csv files of AIRS air temperature at surface data to excel workbooks for further analysis. The daily Air temperature data from 2003 to 2016 for the months March, April and May (MAM) was extracted and separated into different workbooks for the study area and a mean of the daytime and night time temperature was calculated to be used in further analysis as the Mean Temperature of the day.

The Gridded IMD Data was available in ascii format and it was imported into Microsoft Excel for working. The data for the study area was extracted by applying filters to remove the values outside the required extent of latitudes and longitudes. The data utilized was from 2003-2013. For each day of MAM months the mean of all the values of the grids was calculated so that daily, area averaged values would be available to validate the satellite data.

Secondly to validate the satellite air temperature data with ground station based IMD data for the research work linear Regression of both the Temperature Datasets was performed to measure to what extent there is a linear relationship between the two.

Then the Statistical Analysis of the data was carried out to understand the Extreme events and their trends with the following methods:

- Histogram Analysis: Histograms were plotted for the Air temperature data for the study areas. 95th and 99th percentile values were taken as threshold for extreme events.
- Heat Index Calculation by using Long Term Mean (M_{LT}) of each day (MAM months -92 days for 14 years) and standard deviation of the Long Term Mean.

$$\frac{Daily\ Mean\ Temp(\text{TDM}) - Long\ term\ Mean\ of\ \text{TDM}}{Standard\ Deviation\ of\ Long\ Term\ Mean}$$

Equation: 1

Long term Mean was calculated by taking the average of Daily Mean Temperature of each day for 14 years.
The Index values were plotted yearly and the variations in the values were seen.

- Duration, frequency and intensity of extreme events was calculated by taking a threshold value for index values, i.e., the values above the threshold were considered as the days on which the temperature was deviating from the normal mean temperature with respect to the long term mean and also using the anomaly in the Daily Mean Temperature (Daily Mean Temperature – Long Term Mean of Daily Temperature). Sensitivity analysis was done to analyse the intensity of the days which were found to have values above the threshold i.e. which were considered as extreme events using the Heat Index and the anomaly values.

7. RESULTS AND DISCUSSIONS

7.1 Linear Regression Analysis

The coefficient of determination was calculated between the Daily Mean Temperature derived by AIRX3STD v006 and IMD data sets using the scatter plot over the Central Indian Region. The sample size was 1004. The values of R^2 for the study area showed that the correlation between IMD and AIRS data was 0.845. Therefore the AIRS satellite data could be used for the analysis.

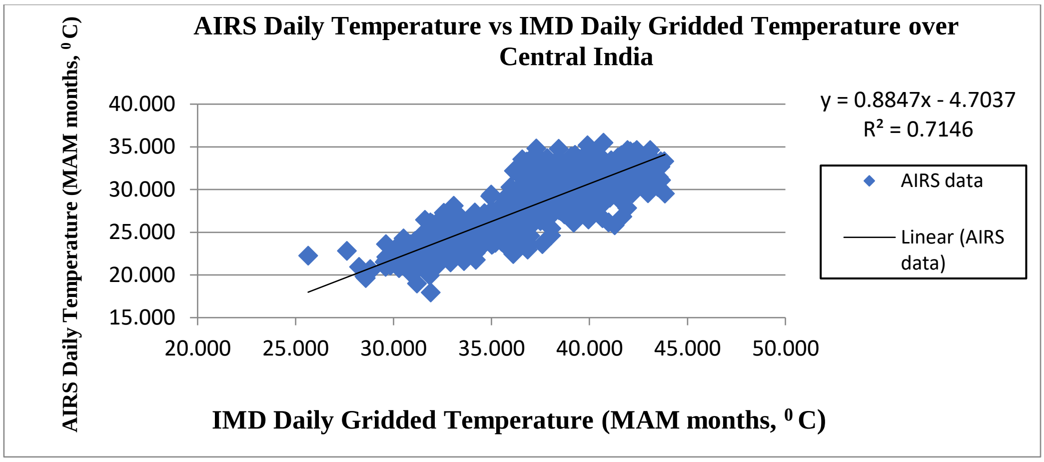

Figure 2: Linear Relationship between IMD derived average daily Temperature data (represented on x-axis) and AIRS average daily Temperature (shown on y-axis) data in Central Indian region. The black line shows the linear fitting of the data.

7.2 Identification of Heat Index

7.2.1 Histogram Analysis

The probability density functions such as histogram provide an effective way to understand the temperature characteristics. The Figure 3 depicts the distribution for daily temperature during MAM months over Central Indian Region. It has been constructed by organizing the daily mean temperature of 14 years (2003-2016) for MAM months into a frequency distribution. It has been decided on the basis of bins with 0.75°C width and conveys how frequently a particular temperature occurs.

The frequency of lower and higher temperature events was very less as can be seen in Figures 3. The extreme temperature events are at the end of the Histogram.

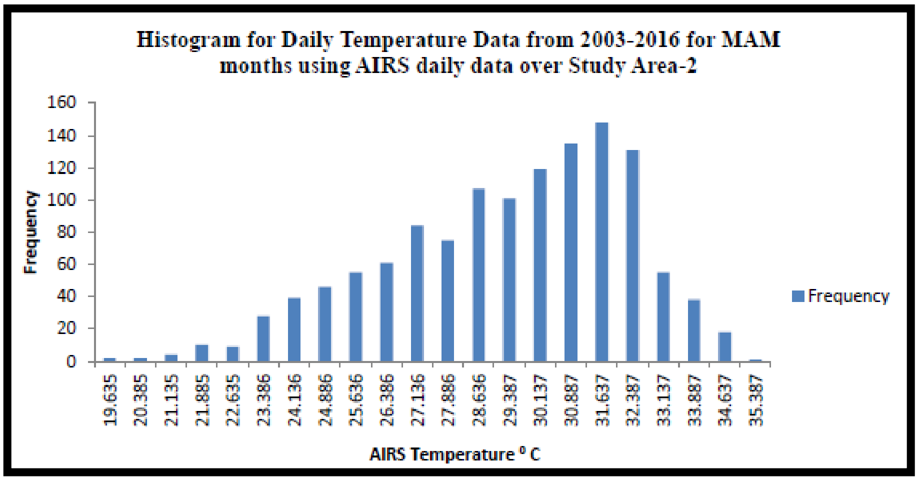

Figure 3: Histogram for Daily Temperature Data from 2003-2016 for MAM months using AIRS daily data over Central Indian Region.

To identify the threshold for the extreme temperature events, two percentiles- 95th and 99th were taken. The values were 32.970 and 34.127 for 95th and 99th percentiles respectively. The values of 99th percentile can be taken as the threshold for extreme events.

7.2.2 Calculation of Heat Index

The Heat index was calculated by using the Daily Mean Temperature of each day of MAM months for 14 years: 2003-2016 and Mean of each day for 14 years which was called Long Term Mean(M_{LT}) and standard deviation of the Long Term Means (92 values).

The formula used was (Equation 1):

$$\frac{\textit{Daily Mean Temp}(\text{TDM}) - \textit{Long term Mean of } \text{TDM}}{\textit{Standard Deviation of Long Term Mean}}$$

The standard deviation of Long Term Mean for Central India is 2.541.

The long term mean for the study area was plotted to see the rising temperature from March to May in 14 years (Figure 4).

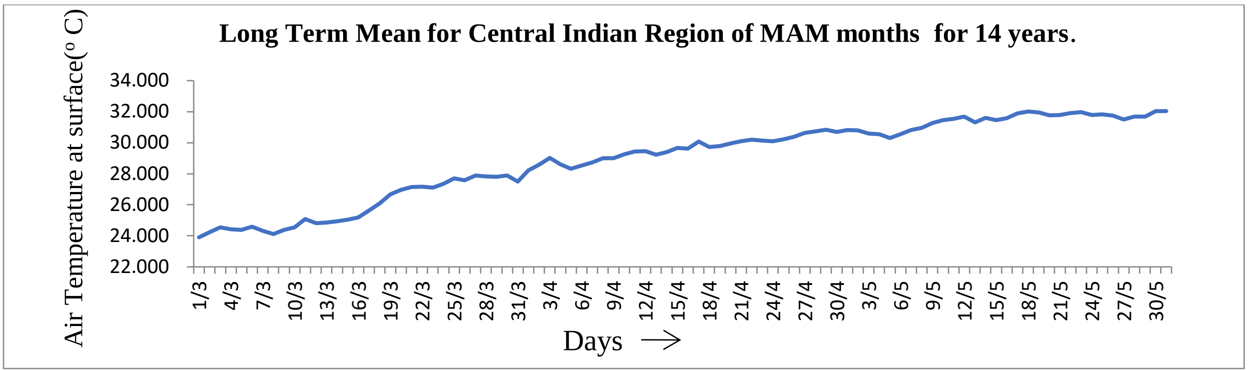

Figure 4: Long Term Mean for Central Indian Region of MAM months for 14 years

There was a normal increase in temperature throughout the MAM months with minor peaks. There was a peak seen in the First week of April which indicated a possibility of Extreme event during that period.

The index values were then plotted yearly to analyse the variations. The higher positive values of the Heat Index were the days on which there was a greater departure from the Long Term Mean and they could be considered as extreme events.

There was a lot of variation seen in the Heat Index values. The high positive values denoted possibility of extreme events. The index has been calculated using the long term mean so the extreme events identified from these values were in reference to the long term mean itself i.e. the daily mean temperatures which were deviating from the long term mean would be identified as the extreme events in spite of the actual temperature of those days. The actual temperature may be 23°C or 35°C.

7.2.3 Identification of Extreme Events, their duration, frequency and intensity

The extreme events, their duration and frequency were calculated by using the Heat Index and the anomaly values.
The anomaly values were the difference in the Long Term Mean and the Daily Mean Temperature of MAM months for 14 years. Using the sensitivity analysis the actual temperatures of the days were analysed and using the threshold values for the Heat Index as 0.3 and for the anomaly as 0.8, the days which were common for both the thresholds and extend to two or more days were considered as extreme events and their actual temperatures show the intensity.

Table 1: Highlighted Extreme Event days for Central Indian Region for year 2010 for MAM months.

Date	Heat Index	Anomaly	Intensity
01-03-2010	0.359	0.912	24.816
02-03-2010	0.684	1.737	25.979
03-03-2010	0.675	1.715	26.260

04-03-2010	0.878	2.231	26.662
05-03-2010	1.084	2.754	27.130
06-03-2010	0.736	1.871	26.457
07-03-2010	1.083	2.751	27.066

08-03-2010	0.522	1.327	25.439
09-03-2010	0.222	0.563	24.953
10-03-2010	0.015	0.037	24.580
11-03-2010	0.281	0.714	25.800
12-03-2010	0.509	1.294	26.113
13-03-2010	0.532	1.352	26.203
14-03-2010	0.904	2.296	27.241
15-03-2010	0.712	1.808	26.844
16-03-2010	0.728	1.849	27.038
17-03-2010	0.231	0.586	26.221
18-03-2010	0.574	1.459	27.552
19-03-2010	0.511	1.299	27.979
21-03-2010	0.971	2.467	29.604
22-03-2010	1.150	2.923	30.079
23-03-2010	1.281	3.255	30.358
24-03-2010	1.123	2.853	30.213
25-03-2010	1.061	2.696	30.395
26-03-2010	0.944	2.400	29.984
27-03-2010	0.937	2.380	30.275
28-03-2010	0.862	2.191	30.024
29-03-2010	0.778	1.977	29.780
31-03-2010	0.656	1.667	29.158
01-04-2010	0.630	1.601	29.812
02-04-2010	0.322	0.819	29.407
03-04-2010	0.470	1.194	30.212
04-04-2010	0.762	1.937	30.544
06-04-2010	0.926	2.352	30.871
07-04-2010	0.549	1.396	30.128
08-04-2010	0.558	1.419	30.413
09-04-2010	0.444	1.129	30.121
10-04-2010	0.860	2.184	31.437
11-04-2010	0.694	1.763	31.202
12-04-2010	1.163	2.954	32.403
13-04-2010	1.055	2.680	31.916
14-04-2010	0.877	2.229	31.622
15-04-2010	0.889	2.260	31.918
16-04-2010	0.793	2.014	31.640
17-04-2010	0.695	1.767	31.832
18-04-2010	0.727	1.847	31.576
19-04-2010	1.187	3.015	32.792

21-04-2010	0.814	2.069	32.158
22-04-2010	0.748	1.901	32.106
23-04-2010	0.747	1.897	32.036
24-04-2010	0.543	1.379	31.471
25-04-2010	0.406	1.032	31.253
26-04-2010	0.562	1.427	31.803
27-04-2010	-0.061	-0.154	30.471
29-04-2010	0.068	0.172	31.012
30-04-2010	0.133	0.337	31.025
01-05-2010	-0.355	-0.902	29.913
02-05-2010	-0.374	-0.950	29.844
03-05-2010	-0.264	-0.670	29.923
04-05-2010	-0.457	-1.162	29.394
05-05-2010	-0.003	-0.006	30.295
06-05-2010	-0.143	-0.364	30.191
07-05-2010	-0.123	-0.312	30.505
08-05-2010	-0.250	-0.635	30.333
09-05-2010	0.108	0.276	31.537
10-05-2010	0.340	0.863	32.322
11-05-2010	0.530	1.347	32.884
12-05-2010	0.855	2.174	33.865
13-05-2010	0.627	1.593	32.897
14-05-2010	0.979	2.487	34.087
15-05-2010	0.619	1.572	33.023
16-05-2010	0.813	2.067	33.645
17-05-2010	0.917	2.330	34.224
18-05-2010	0.503	1.279	33.280
19-05-2010	0.157	0.400	32.346
20-05-2010	-0.571	-1.451	30.304
21-05-2010	0.040	0.101	31.889
22-05-2010	-0.175	-0.444	31.456
23-05-2010	-0.007	-0.018	31.942
25-05-2010	0.564	1.432	33.259
26-05-2010	0.589	1.498	33.244
27-05-2010	0.253	0.642	32.135
28-05-2010	0.174	0.442	32.127
29-05-2010	-0.441	-1.120	30.556
30-05-2010	0.566	1.438	33.461
31-05-2010	0.604	1.534	33.571

The Extreme Event days were those where the duration was greater than 2 days and the values of Heat Index were greater than 0.3 and the value of Anomaly was greater than 0.8. The intensity varied from 24-35 degree Celsius.(They have been highlighted in the table in pink).

Table 2: Number and Duration of Extreme events for the Central Indian Region

Year	No of events	Duration -No. Of days								
2003	9	March	April			May				
		4	2	2	3	2	3	2	2	5
2004	4	March			April					
		2	3	18	7					
2005	7	March			April		May			
		5	3	3	2	3	3	6		
2006	6	March			April		May			
		3	3	2	9	2	3			
2007	5	March		April		May				
		2	5	3	2	2				
2008	5	March		April		May				
		6	8	4	6	8				
2009	5	March	April		May					
		10	3	9	9	2				
2010	6	March		March/ April	May					
		8	5	14/26	9	2	2			
2011	5	March			May					
		6	4	2	2	4				
2012	3	March	April	May						
		2	3	13						
2013	3	April	May							
		3	5	4						
2014	2	April	May							
		2	4							
2015	2	April	May							
		2	12							
2016	7	March		April			May			
		2	2	10	10	2	2	3		

Table 2 shows that the extreme events were higher in March and longer in duration for some years from which it was concluded that there was an early onset of rise in temperature. The trend could be figured out clearly as 14 years of data was not sufficient. The intensity of the extreme events was not very high in March for all years but there was a high deviation from long term Mean which showed that there was an increase in Air temperature. Extreme events with high intensity were seen in May for all the years which was in accordance to the rise in temperature seen in the Long Term Mean graph.(Figure: 4)

The duration of the extreme events varied from two days to 26 days, i.e. the deviation from Long Term Mean was seen for a very long period as well. The spells of heat with longer duration were the harmful ones and were declared as Extreme Temperature Events.

The days which were identified as extreme events using the above methods were verified using the annual climate summary given by IMD yearly. For the year 2010 the IMD summary stated that severe heat wave conditions prevailed over northern, north western and central parts of the country almost throughout the season from second fortnight of March to the end of May. The results obtained by the calculations also showed similar conditions from which it was inferred that the duration and frequency using the air temperature data were consistent with the ground temperature data of IMD.

7.2.4 Spatial Analysis

Spatial Analysis was done by calculating the Mean Temperature of MAM months for 14 years of the study area.

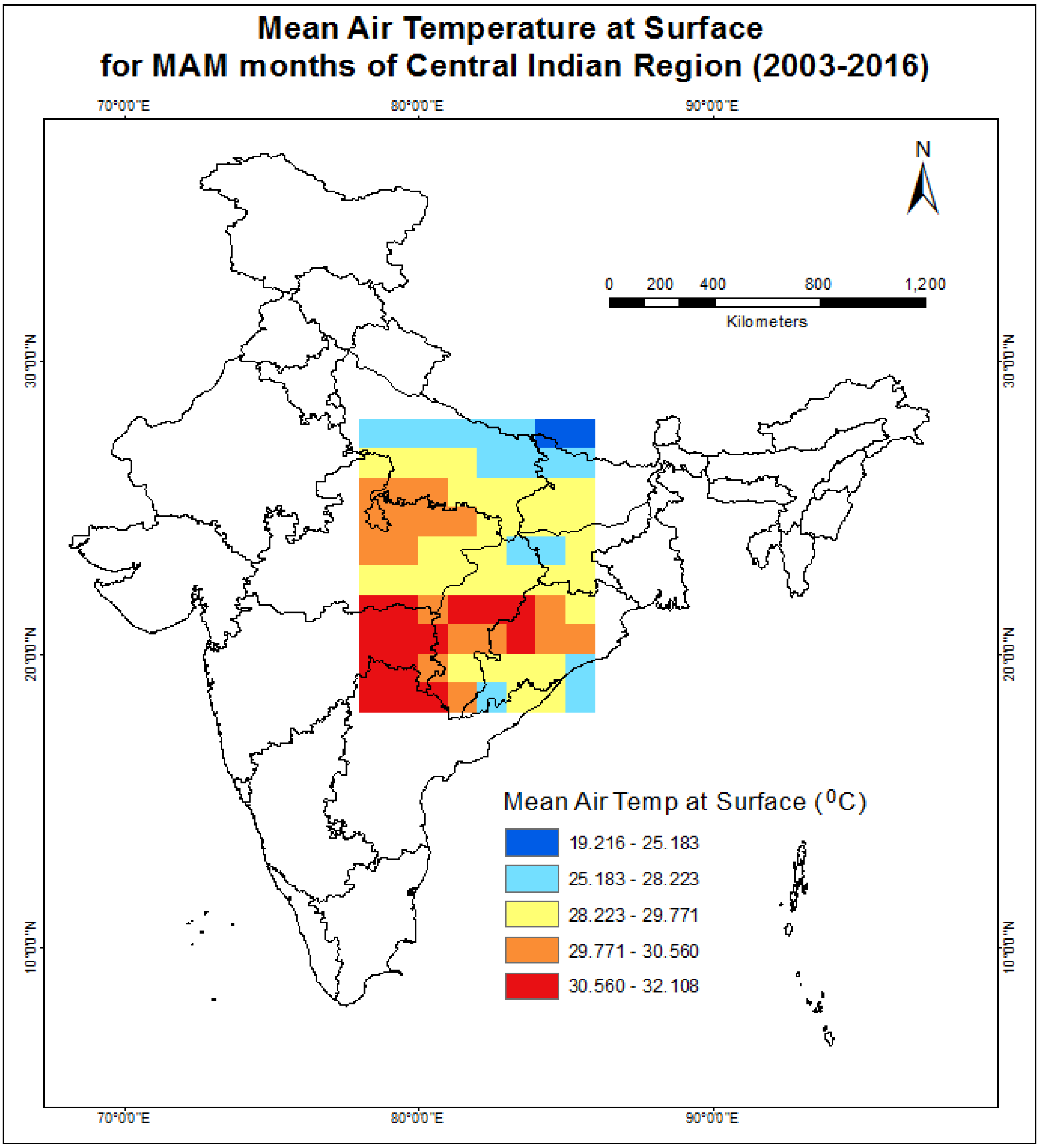

Figure 5: Mean Air Temperature at Surface for MAM months of Central Indian Region (2003-2016)

There was a Hot Spot (in bright red colour) seen in parts of Maharshtra, Madhya Pradesh, Telangana, Chhattisgarh and Odisha. There were some regions where the Mean Temperature was below 30 degree Celsius so there is no need for a detailed Heat Wave analysis there. The parts in red in Figure 5 were the regions where there is a problem of Extreme Events. For further studies on Heat Waves these regions should be considered.

8. CONCLUSION

Motivated by the recent occurrences of disastrous Heat Waves around the world as well as in India and the increasing concerns about their behaviour, this research was conducted to study the spatiotemporal variations of the extreme temperature phenomenon over the Central Indian region which is affected by the extreme temperature events during the pre-monsoon season or March, April and May months. Though the time period was too small and the study areas too big to conclude a trend, it was inferred that the extreme events are happening early i.e. in March for some years and the duration is also increasing. The number of extreme events of duration more than 5 days was found to be large.

A spatial analysis of the study area helped to narrow down the region which was more affected by the extremes in temperature that also paved a way for further Extreme temperature event studies that should be done for the region.

There was a consistent difference in the AIRS air temperature data and IMD data which showed that some modifications in temperature retrieval algorithm are suggested for Indian region. The algorithm suitable for USA may not necessarily work for this area. The reasons for such behaviour of the satellite also remain an open question for further research.

The results of this research could be of assistance in the field of disaster management. Policy-makers are expected to follow the research outcomes and create action plans for the affected regions. The spatial distribution study of the extreme temperature events might be helpful in the systematic documentation of events.

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