Chapter 4

Climatology and long- term trends of Heat Waves

In this chapter, the climatology and long-term trends of heat waves over India are discussed. For this purpose, the results based on the IMD criteria and the criteria based on the percentiles were used. As mentioned earlier, heat waves occur mainly during the period from March to June when maximum temperatures rise to very high levels, especially in the northern parts of India.

4.1 Heat wave climatology based on IMD Criteria.

In this section, long term climatology and long-term trends of Heat waves over India are discussed using the IMD station data and IMD criteria. For this purpose, the data of 1961-2020 have been used. The details of heat wave criteria followed by IMD are given in Chapter-2.

Fig 4.1a shows the average frequency of heat wave days using the data of 1961-2020. On an average more than 2 heat wave events occur over northern parts of the country and coastal Andhra Pradesh and Odisha. In some pockets, heat wave frequency even exceeds four in a season. Most of IMD stations are showing increasing trends of heat wave events during the 60-year period (1961-2020) (Fig 4.1.b) as shown by red triangles.

Fig. 4.2 shows the spatial distribution of the duration (days) of heat waves. The plot shows that heat waves last on an average 4-8 days. In some areas of central and north-western India and parts of Odisha and coastal Andhra Pradesh, the duration is more than 8 days. Over Gujarat and Chhattisgarh, heat waves last 2-4 days. Fig. 4.2 b shows the long-term trends in the duration of heat waves for the individual stations during the period 1961-2020. It clearly shows that most IMD stations show an increasing trend in the duration of heat waves during the March-June season.

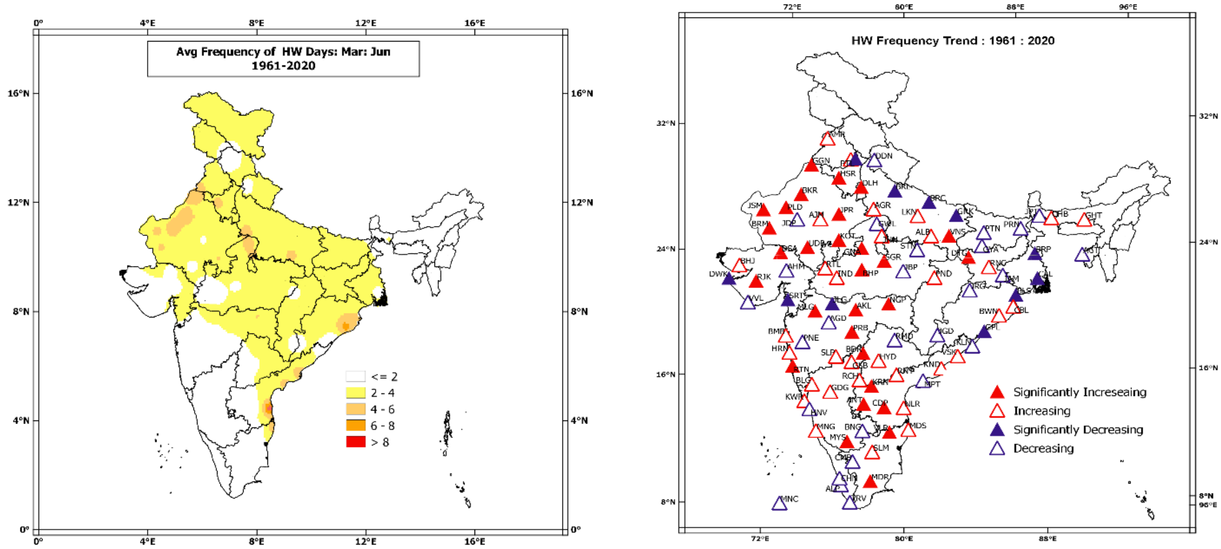

Fig 4.1 a) Heat wave average frequency during March-June for the period 1961-2020, b) HW frequency trends, station wise during the same period.

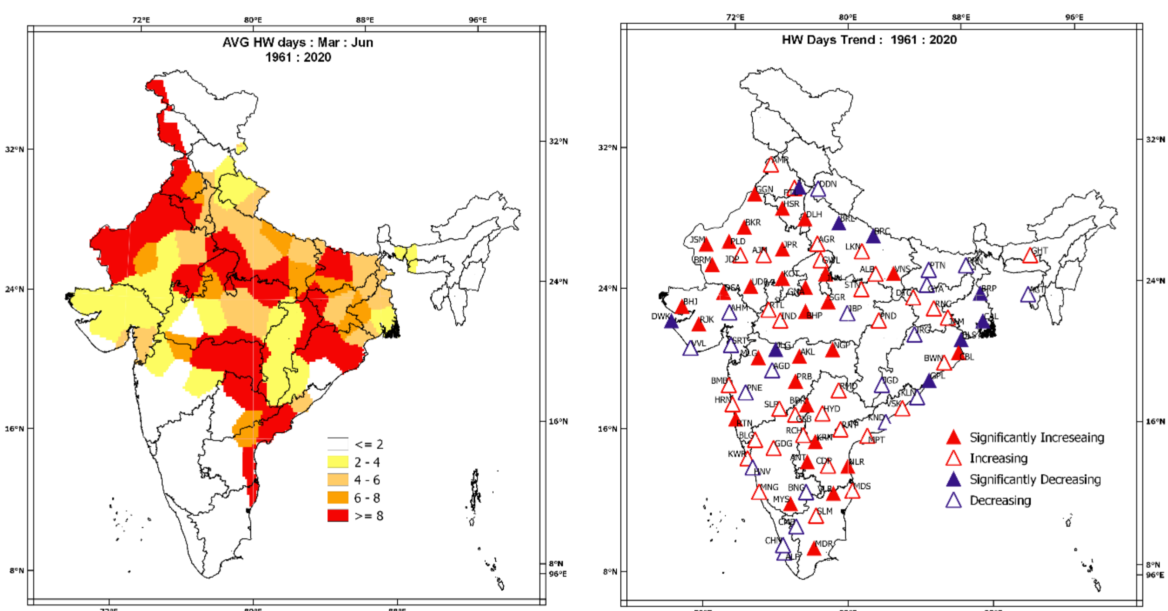

Fig 4.2 a) Heat wave average total duration (days) during March-June for the period 1961-2020, b) Station wise, HW duration trends during the same period.

Fig. 4.3 a shows the maximum duration of heat waves in March and June for the period 1961-2020. Fig. 4.3 b shows the long-term trends of maximum duration of heat waves in the same period for the individual stations. On an average, the maximum duration of the heatwave is 2-4 days. In some areas in central and north-western India, it is more than 6 days. In coastal Andhra Pradesh, the maximum duration is more than 8 days. The maximum duration of heat waves during March to June also shows an increasing trend in the northern parts of the country. The trends at some stations in the northern parts of the country are statistically significant at 95% significance level.

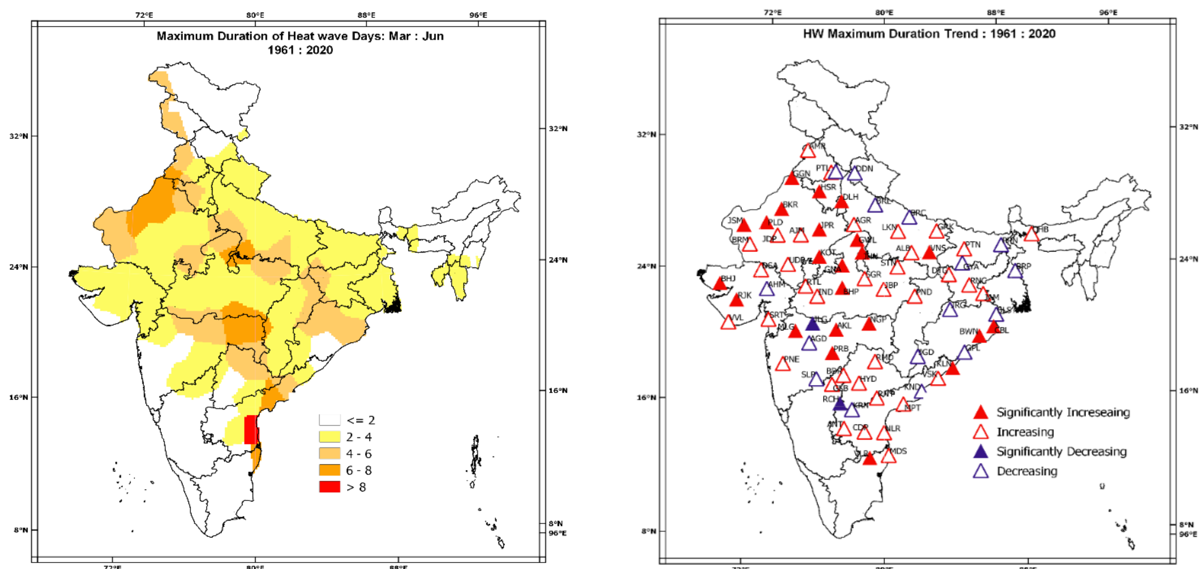

Fig 4.3 a) Maximum Duration of Heat Wave days during March-June for the period 1961-2020, b) Station wise, trends of maximum duration of heat waves during the same period.

Fig. 4.4 shows the spatial distribution of average severe heatwave (SHW) days from March to June for the period 1961-2020 based on the IMD criteria. This shows that SHW days tend to occur in the extreme northwest of India and in the eastern parts of India (Bihar, Jharkhand and surrounding areas), but 1-2 days during the hot weather season.

Earlier studies (Pai et al. 2017, Rohini et al. 2016, Ratnam et al. 2016 a) suggested a link between heat waves over India and the El Nino/Southern Oscillation (ENSO). El Nino (La Nina) is known to cause warming (cooling) around the globe, especially over the tropics. Studies have shown that the frequency and duration of heat waves increases during El Nino years.

Fig. 4.5 shows the average heat wave days during a) El Nino years and b) La Nina years, which clearly shows that heat wave days are much more during the El Nino years than La Nina years. It is interesting to note that heat wave activity over the east coast of India however remains the same or slightly enhanced during the La Nina years. Ratnam et al. (2016 a) and Rohini et al. (2016) have done some detailed analysis to show how ENSO events can influence heat waves over India. This relationship between heat waves and ENSO events is further discussed in detail in Chapter 5.

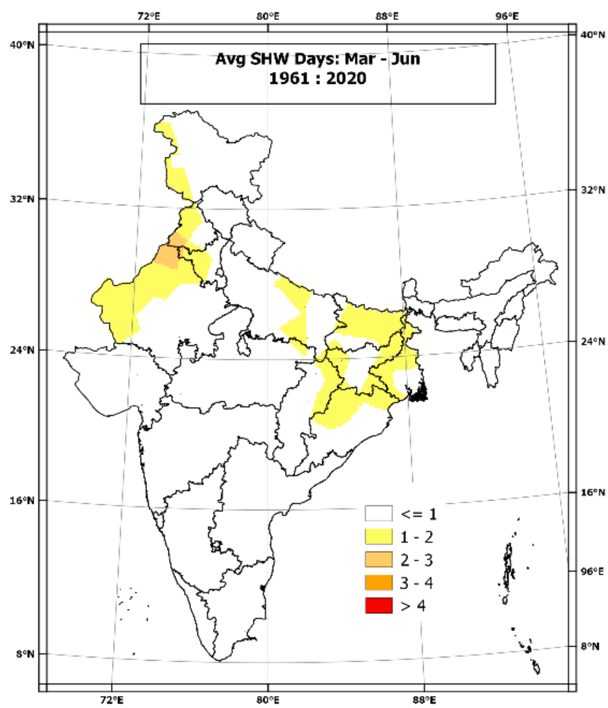

Fig 4.4. Spatial distribution of average Severe Heat Wave (SHW) days during March-June for the period 1961-2020.

Fig. 4.6 a shows the longest heat wave in days and Fig. 4.6 b shows the longest severe heat wave in days for the period 1961-2020. Over central and north-western India and coastal Andhra Pradesh, the longest heat wave days exceed 10 days at many stations. Over the far northwest of India, the longest heatwave even exceeded

15 days. The longest severe heat wave generally lasts more than 5 days in central and north-western India, while it is less than 5 days over the southern peninsula including the Andhra Pradesh coast.

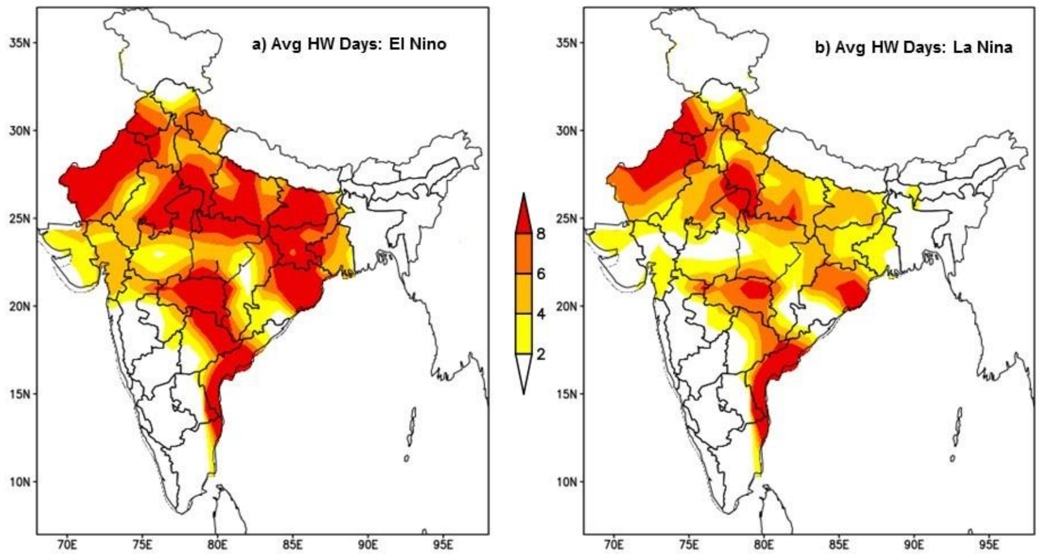

Fig 4.5. Average HW days during a) the El Nino years and b) La Nina years during the period 1961-2020.

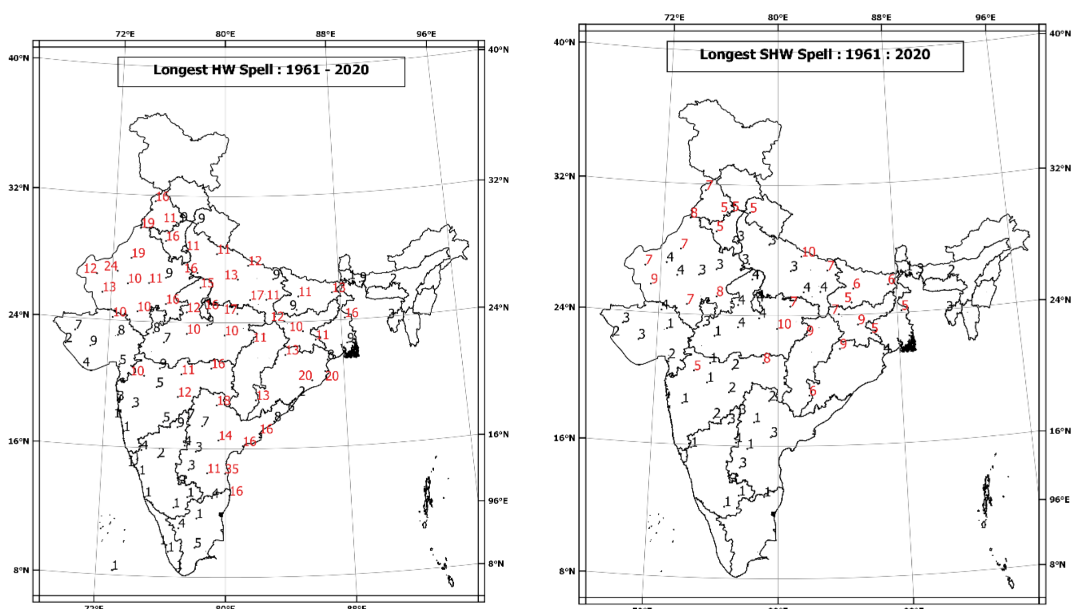

Fig. 4.6. a) Station wise longest heat wave spell during 1961-2020 b) Station wise longest Severe heat wave spell during 1961-2020.

4.2 Heat wave climatology based on area averaged temperature data

In this section, heat wave statistics based on the IMD grid data (Srivastava et al., 2009) are discussed. Based on the gridded data, two criteria can be used to define heat waves. The first is the 90th percentile and the second is the Excessive Heat Factor (EHF). These two criteria are discussed in detail in the Chapter 2. The statistics discussed below are based on the 1961-2021 data and the March-June (MAMJ) period is used to calculate the statistics. The period 1971-2000 has been considered for calculating climatology and temperature deviations.

Fig. 4.7 shows the spatial distribution of a) heat wave frequency, b) heat wave days and c) heat wave intensity in the period from March to June. Data from 1961-2021 were used for this analysis. Fig. 4.7 a shows two predominant areas for heat wave occurrence. One is over the central and north-western India. The other is the coastal area of Andhra Pradesh and Odisha. In the heat wave zone (central and north-western India), 1-2 heat waves occur on an average. Coastal Andhra Pradesh also experiences 1-2 heat waves per season. In most parts of central and north-western India, heat waves last for about 6-8 days. Heat waves also last for about a week in the coastal Andhra Pradesh. The spatial distribution of the intensity of the heat waves indicates that the maximum temperatures in the northern parts of the country exceed 44°C during the heat waves. In coastal Andhra Pradesh, the intensity of heat waves exceeds 40°C. However, due to the higher humidity in the region (because of its proximity to the sea), heat waves can have huge negative impacts on human health. For example, the 2015 heat wave on the Andhra Pradesh coast reportedly claimed 2500 lives.

Fig. 4.8 shows the spatial distribution of a) frequency of severe heat waves, b) duration (days) of severe heat waves and c) intensity of severe heat waves during the March to June.

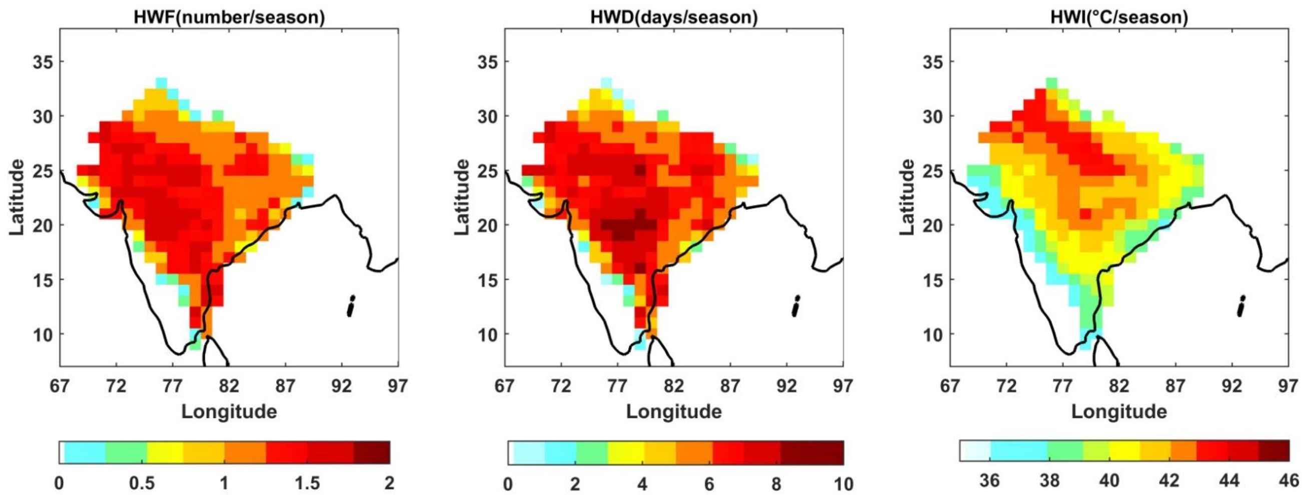

Fig 4.7. Spatial distribution of a) heat wave frequency, b) heat wave days and c) heat wave intensity during MAMJ. Period 1961-2021.

Fig. 4.8 a shows two predominant areas of severe heat waves, one over central and north-western India and another over the coastal Andhra Pradesh, where on average one severe heat wave occurs in 2 years. Severe heat waves last for about 3-4 days over central and north-western India. During severe heat waves, maximum temperatures exceed 45°C in the northern parts of the country.

Fig. 4.9 shows the long-term trends in a) HW frequency b) HW days and c) HW intensity, indicating that the frequency and duration of heat waves are increasing over central and north-western India. The frequency and duration of heat waves are also increasing in coastal Andhra Pradesh. The trend in duration is more than 1 day/decade. Most of the observed trends over central and north-western India and coastal Andhra Pradesh are statistically significant at 95% level of significance. Fig. 4.9 c shows that the intensity of heat waves (highest maximum temperatures) increased over the northern parts of the country, suggesting that higher maximum temperatures were observed during the recent heat waves. However, over the coastal Andhra Pradesh, the intensity of heat waves decreased. It is important to understand the physical causes for these observed trends.

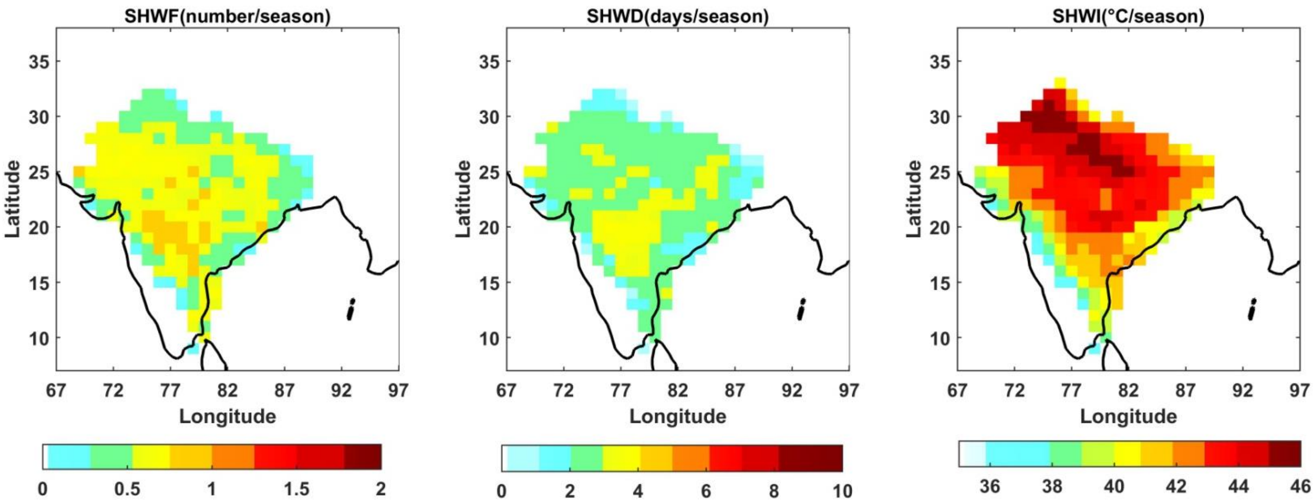

Fig 4.8. Spatial distribution of a) Severe heat wave frequency, b) severe heat wave days and c) severe heat wave intensity during MAMJ. Period 1961-2021.

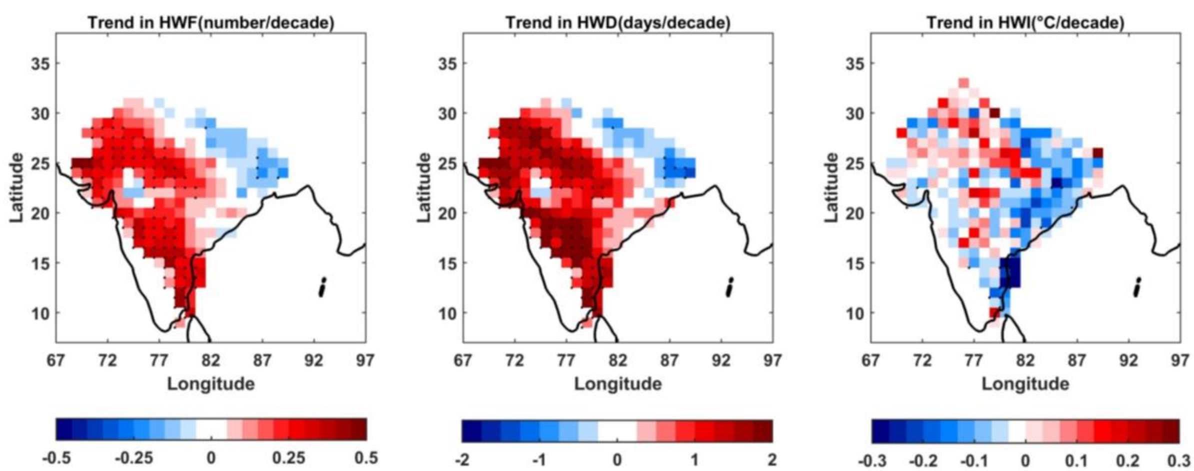

Fig 4.9. Spatial distribution of a) Trend in heat wave frequency (number/decade), severe heat wave days (days/decade) and severe heat wave intensity (°C/decade) during MAMJ. Period 1961-2021. The trends which are statistically significant are shown as dots.

Fig. 4.10 a shows the average maximum heatwave days (days/season) and Fig. 4.10 b shows the trend (days/season) of maximum heatwave days. The maximum heat wave days are more than 6 days over central India (Maharashtra and Vidarbha) and eastern parts of central India (Jharkhand, Bihar). In northwestern India, it is generally more than 5 days. Over the coastal areas of Andhra Pradesh and Odisha, it is more than

5 days. In most parts of the country, the maximum duration of the heat wave shows a statistically significant upward trend (Fig 4.10 b).

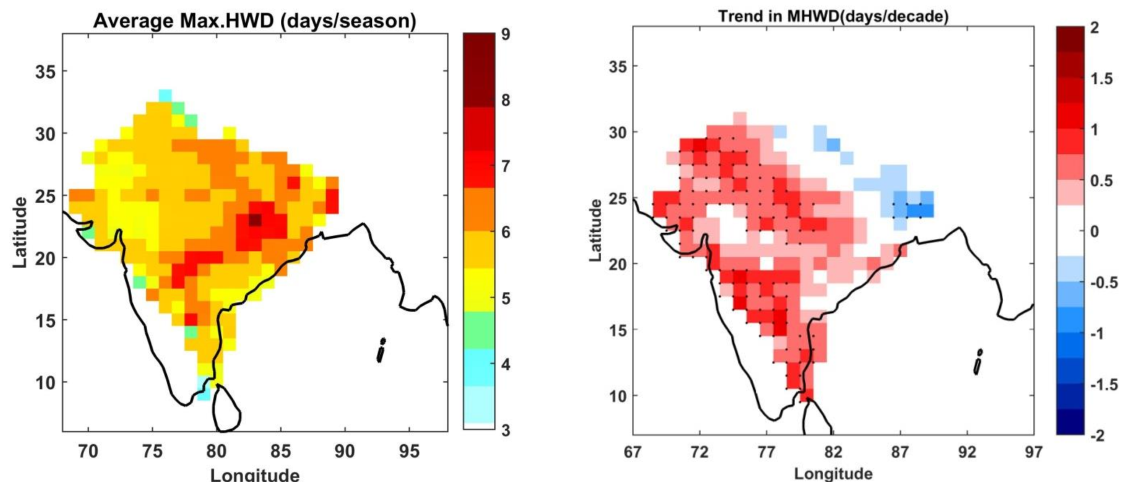

Fig 4.10. Spatial Distribution of a) average maximum HW days (days/season) and b) Long term trends. The trends which are statistically significant are shown as dots.

Fig. 4.11 shows the time series of heat wave frequency, heat wave duration and maximum heat wave duration averaged over northwest India (70^0 E-78^0 E, 22^0 N-31^0 N). The time series shows increasing trends in all three aspects of heat wave, frequency, duration and maximum duration. The observed trends are 0.16, 0.93 days and 0.31 days per decade, respectively, which are statistically significant at 95% significant level. Accordingly, the average duration of heat waves has increased by 6.5 days in seven decades (1961-20201), which is highly significant. The maximum duration has also increased by about 2 days in the same period.

Fig. 4.12 shows the time series of area-averaged heat wave frequency, heat wave duration and maximum heat wave duration averaged over the coastal region of Andhra Pradesh (12^0 – 16^0 N, 78^0 – 81^0 E) based on the 90th percentile criteria. The frequency, duration and maximum duration of heat waves are also showing increasing trends in coastal Andhra Pradesh. However, the trends (0.25/decade, 1.3 days/decade and 0.45 days/decade) are higher than the corresponding trends observed over northwest India. This is an interesting aspect to note and we need to find out the possible reasons for this.

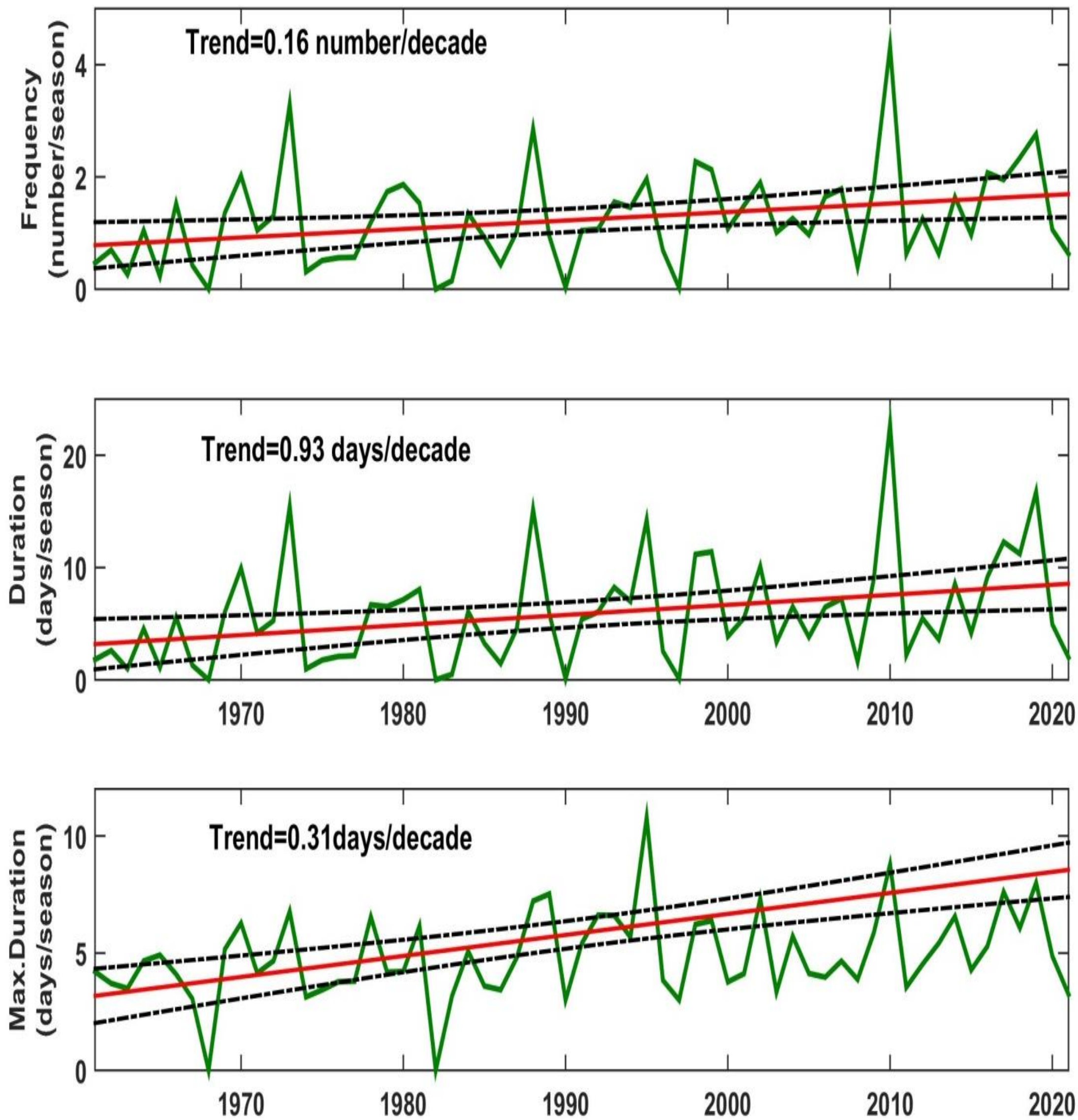

Fig 4.11. Time series of area averaged heat wave frequency, heat wave duration and heat wave maximum duration, averaged over northwest India (70E-78E, 22N-31N), based on 90^{th} percentile criteria.

Fig 4.13 shows the time series of area averaged heat wave frequency, heat wave duration and heat wave maximum duration, averaged over northwest India (70^0 E-78^0 E, 22^0 N-31^0 N) based on the EHF criteria. Based on the EHF criteria also, there are increasing trends. There are long-term increasing trends of heat wave frequency, duration and maximum duration over northwest India. However, the magnitude of the trends based on the EHF criteria is different from that based on the 90th percentile.

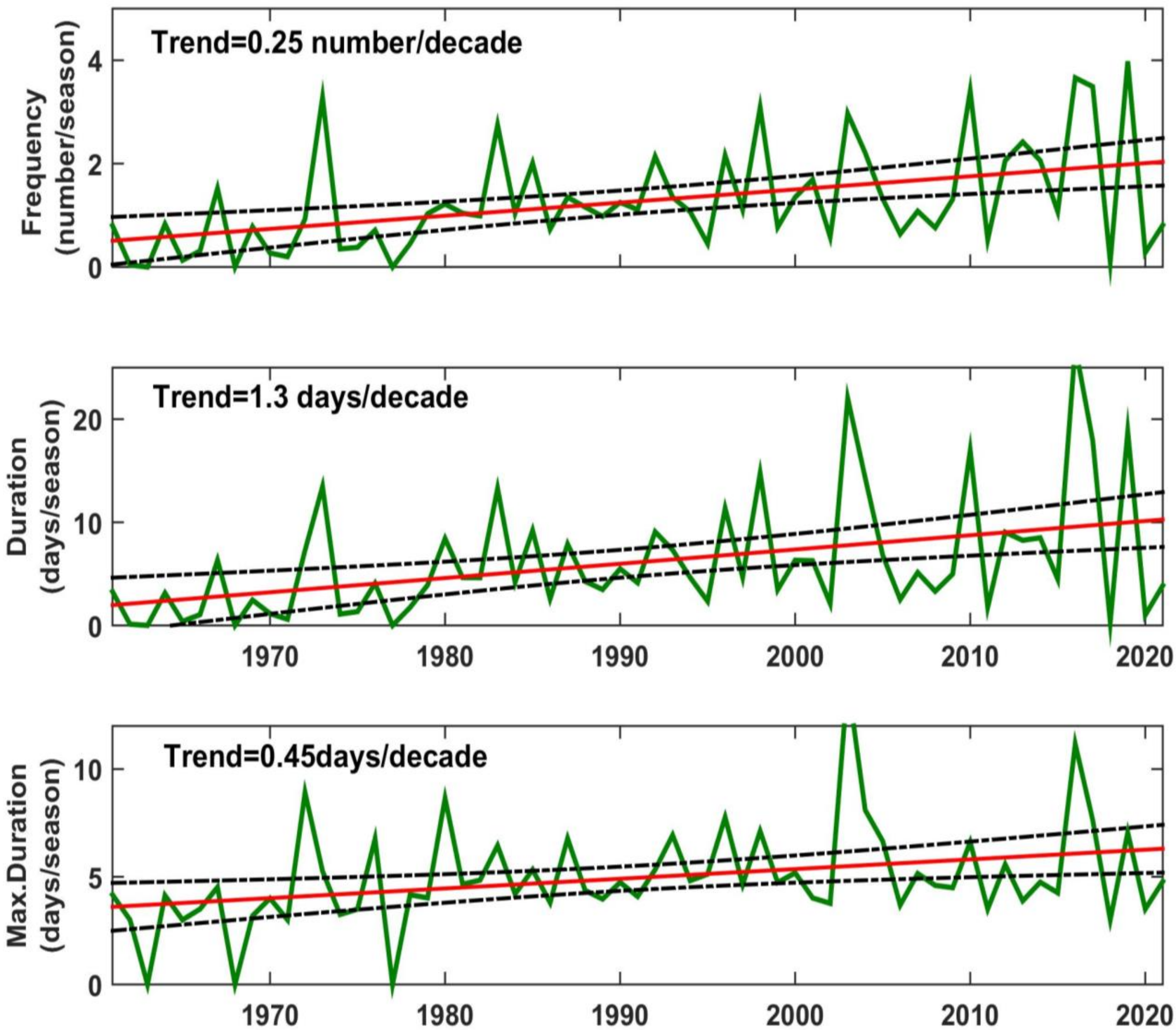

Fig 4.12. Time series of area averaged heat wave frequency, heat wave duration and heat wave maximum duration, averaged over Coastal Andhra Pradesh (12-16^{o} N, 78-81^{0} E), based on 90th percentile criteria.

Fig. 4.14 shows the time series of area-averaged heat wave frequency, heat wave duration and maximum heat wave duration averaged over the coastal region of Andhra Pradesh based on the EHF criteria. As in 90th percentile criteria, there are increasing trends in the frequency, duration and maximum duration of heat waves in coastal Andhra Pradesh, though the magnitudes are different.

Sandeep and Prasad (2018) examined heat wave episodes over the east coast of India and their inter-annual variability. The heat wave episodes exhibit a significant intra-annual variability. Intensity of heat waves averaged over the east coast of India has shown an increase of 0.06^0 C per heat wave. The geopotential height anomaly, vertical velocity, and soil moisture exhibit significant intra-annual variability between the episodes and become decisive parameters for the maintenance and variability.

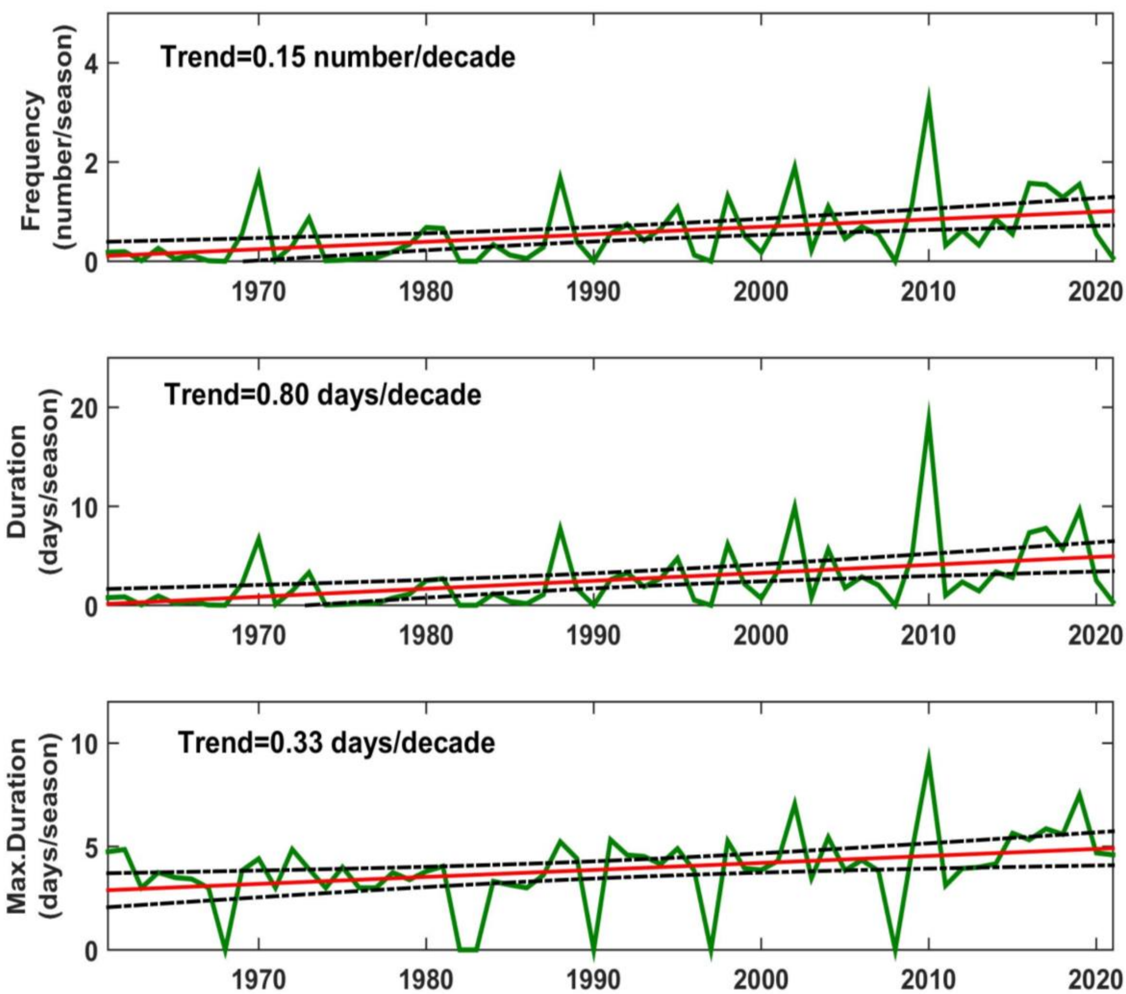

Fig 4.13. Time series of area averaged heat wave frequency, heat wave duration and heat wave maximum duration, averaged over northwest India (70^0 E-78^0 E, 22^o N-31^o N) based on the EHF criteria.

Table 4.1 shows a comparison of long-term trends of heat wave frequency, duration and maximum duration based on these two different criteria over northwest India and coastal Andhra Pradesh. In general, the trends based on EHF are lower than that based 90^{th} percentile. The trends over east coast of India are relatively larger than the trends of heat waves over central and northwest India.

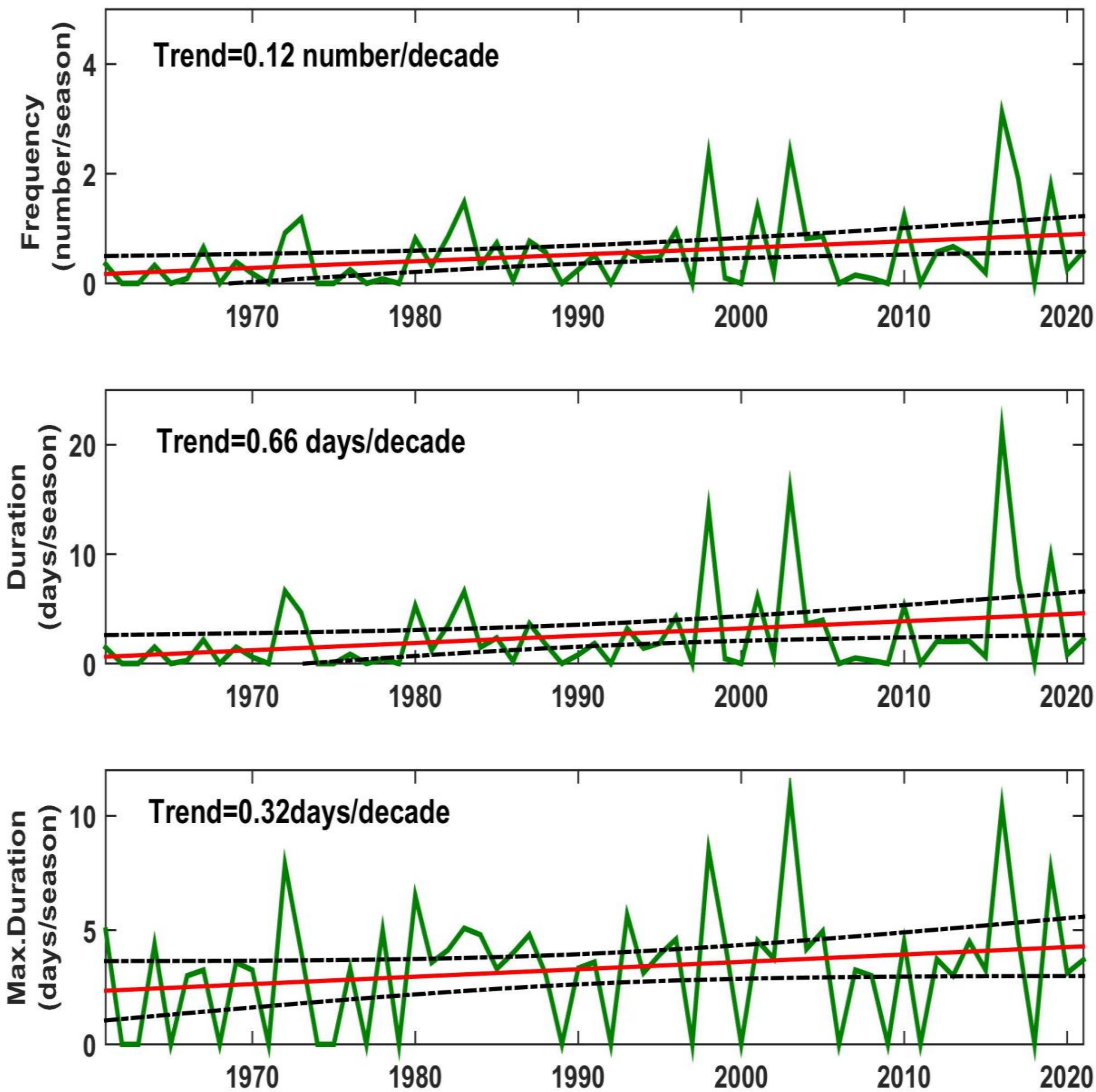

Fig 4.14. Time series of area averaged heat wave frequency, heat wave duration and heat wave maximum duration, averaged over Coastal Andhra Pradesh (12^0-16^0 N, 78^0-81^o E), based on EHF criteria.

Table 4.1

Long term trends of frequency, duration and maximum duration of heat waves over northwest India and coastal Andhra Pradesh

Area	Criteria	Frequency No/decade	Duration Days/decade	Maximum Duration Days/decade
Northwest India	90^{th} Percentile	0.16	0.93	0.31
	EHF	0.15	0.80	0.31
Coastal Andhra Pradesh	90^{th} Percentile	0.25	1.30	0.45
	EHF	0.12	0.66	0.32

Singh et al. (2021) analyzed long term trends of heat wave and severe heat wave events using IMD's gridded temperature data. The study found a spatio-temporal shift in the occurrence of heat wave events with a significantly increasing trend in three prominent heat wave prone regions that is northwestern, central, and south-central India, the highest being in West Madhya Pradesh (0.80 events/year), while a significantly decreasing trend was observed over Gangetic West Bengal (−0.13events/year). SHW events showed a southward expansion and a spatial surge during the decades of 2001–2010 and 2010–2016.

In order to obtain the relationships between the characteristics of the heat waves, the frequency (Fig.4.15 a) and intensity (Fig.4.15 b) of the heat waves are presented as a function of duration and mean areal extent. This analysis was carried out only for the heat wave prone area of northwest India, NWI (22°-31°N, 70°-77°E). Fig.4.15.a provides the probability of occurrence of heat waves per year based on the mean areal extent and duration. The most frequent heat waves (Fig.4.15.a. ~ 0.3 to 0.5 events per year, i.e. 16 to 27 events for 1961-2015) last 5 to 9 days with a mean intensity of about ~ 43°C. These heat waves have a mean areal extent of 15% to 30%. The moderately frequent heat waves (~0.2 events per year, i.e. 10 events for 1961-2015) have a duration of about 10 days with a mean intensity of 41°C and a spatial extent of 25% to 40%. The rare heat waves (less than 0.1 events per year, i.e. 5 events for the period 1961-2015) have extremely high intensities (~45°C) and a longer duration (~ 9-20 days).

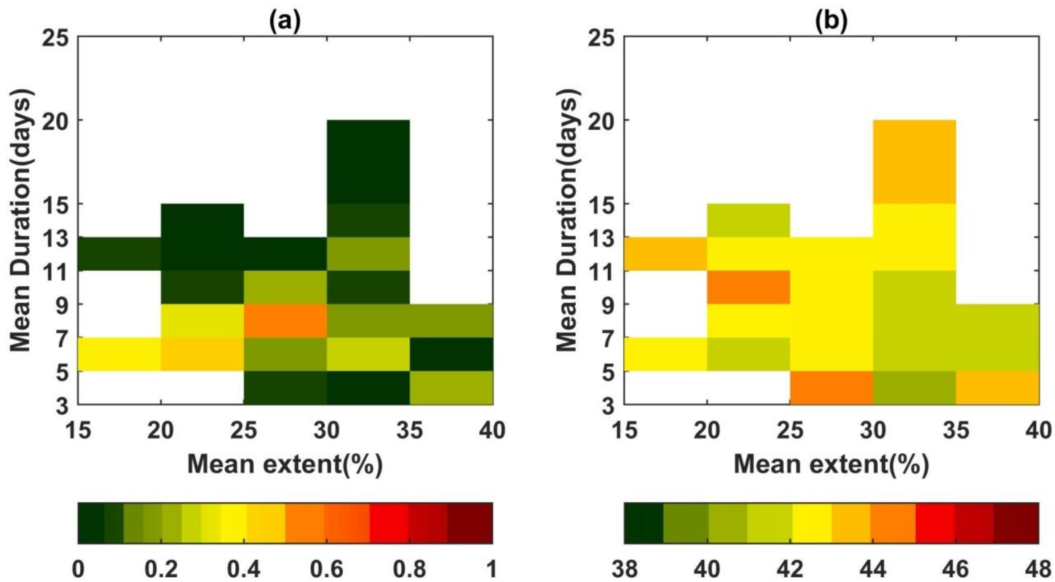

Fig. 4.15. (a) Heat wave frequency (events year^{-1}) as a function of mean areal extent and duration for AMJ season. For each bin, heat wave frequency is averaged over 1961-2015. (b) Heat wave mean intensity (°C) as a function of mean areal extent and duration. For each bin, mean intensity is computed as mean Tmax during heat wave events averaged over 1961-2015. (After Rohini 2020).

Table 4.2 shows the heat wave events over northwest India during the period 1961-2021, identified using the 90th percentile criteria and Table 4.3 shows the heat wave events over the coastal Andhra Pradesh during the period 1961-2021 based on 90th percentile criteria.

Table 4.2

Heat wave events over northwest India as per the 90th Percentile criteria during the period 1961-2021

Year	Date	Intensity(°C)	Duration (days)
1970	23Apr-27Apr	42.8	6
	11May-18May	43.5	8
1973	20Apr-2May	42.4	13
	6May-10May	43.3	5
1978	9May-13May	42.8	5
1979	6Jun-10Jun	43.4	5
1980	18Apr-22Apr	41.4	5
1981	15Jun-23Jun	43.1	9
1984	23May-28May	43.4	6
1987	19Apr-23Apr	40.8	5
	26Jun-30Jun	41.6	6
1988	10-18APr	40.8	9
	8-15May	43	8
	26-31May	43.8	6
1989	12-23May	43.3	12

1992	16-21Jun	42.3	6
1993	3-8May	42.1	6
	8-12Jun	42.5	5
1994	29May-2Jun	44	5
1995	30May-9Jun	44.3	11
1998	21-28May	43.4	8
1999	8-12Apr	40.9	5
	29Apr-5May	42.5	7
2004	9-17Apr	40.6	9
2005	19-23Jun	41.8	5
2009	27Apr-1May	42.8	5
	20-27Jun	41.2	8
2010	8-20Apr	43.1	13
	19-26May	44.5	8
	19-23Jun	43.3	5
2013	18-24May	43.3	7
2014	4-11Jun	44.4	8

2016	15-21May	44.7	7
2017	12-21Apr	41.9	10
2019	29May-11Jun	44.5	14

Table 4.3

Heat wave events over the coastal Andhra Pradesh as per the 90th Percentile criteria during the period 1961-2021

Year	Date	Intensity(^oC)	Duration (days)
1967	1-9Jun	40.7	9
1972	5-14Jun	40.7	10
1973	26-30Apr	41.6	5
1976	2-7May	41.4	6
1980	19-28May	43.1	10
1982	2-6Apr	39.8	5
1983	1-21Mar	38.5	21
1984	22-27May	41.2	6
1985	23-28Apr	40.4	6
	1-5May	41.3	5
1987	7-15Apr	40.3	9

1990	20-26Apr	40.8	7
1992	5-10Apr	39.8	6
1996	8-18May	41.8	12
1997	29May-5Jun	41.3	8
1998	19-23Apr	40.5	5
	27May-5Jun	42.3	15
1999	12-16Apr	40	5
2000	26-30Apr	41	5
2001	10-14May	41.8	5
2003	18May-13Jun	43.1	26
2004	16Mar-26Mar	38.7	11
	14-20Apr	40.5	7
2007	15-21May	40.9	7
2010	1-7Apr	39.1	7
	9-14APr	39.7	6
2012	18-24Mar	38.1	7
2014	28Mar-1Apr	39.1	5
2016	18-22Mar	39.6	5

	1-7Apr	38.8	7
	11-17Apr	40.6	7
	19-26Apr	41.9	8
2017	30Mar-3Apr	38.7	5
	16-27Apr	40.5	12
2019	28Mar-3Apr	39.3	7
2021	30Mar-3Apr	39.9	5

4.3 Future projections of Heat Waves over India

In the earlier sections of the chapter, we discussed the observed long-term trends of heat waves over India. The frequency, duration and intensity of heat waves over India have shown an increasing trend over the last 50-60 years. Greenhouse gas emissions from fossil fuels are likely the cause of this observed trend in heat waves. In the future, greenhouse gas emissions from fossil fuels are likely to increase further. Logically, the next question is what might be the heat wave scenarios over India in the future climate.

Climate and Earth system models are the best tools available to understand future climate change under increased anthropogenic activities. Previous studies (Alexander and Arblaster 2009, Meehl and Tebaldi 2004) suggest that significant trends in temperature extremes in different parts of the world will continue into the twenty-first century. For heat waves over India, Rohini et al. (2019) examined nine CMIP5 models to understand how the frequency, intensity and duration of heat waves over India will increase due to increases in greenhouse gas emissions. They have considered the pre-monsoon season (April-June) for the analysis of heat waves as the frequency of heat waves that can affect human health is much higher during this season. The IPCC RCP4.5

scenario for the period 2024-2060 was used to assess future climate change scenarios. Long-term atmospheric circulation data are also used to understand future changes. Despite moderate variations in daily temperatures, the CMIP5 models showed a modest ability to realistically simulate the observed heat waves in terms of spatial pattern and frequency. The models suggest an increase of about two heat waves and an increase in the duration of heat waves by 12-18 days over the period 2020-2064.

In the future climate change scenario, the southern parts of India and the coastal areas of India, which are not currently affected by heat waves, are likely to be affected by heat waves. The spatial trend analysis of heat wave frequency (HWF) and heat wave duration (HWD) indicates that both HWF and HWD will increase significantly in central and north-western India, by 0.5 events per decade and 4-7 days per decade, respectively. Fig. 4.16 shows the observed and future changes in the frequency and duration of heat waves over northwest India as derived from 9 CMIP5 models and the multi-model ensemble model (MME). All CMIP5 models indicate a systematic increase in both the frequency and duration of heat waves over central and northwest India. According to the MME, northwest India could experience about 4 heat waves per season with a total duration of 30 days by 2060. This is a significant increase from the present climate.

As shown in Fig. 4.17, the future increase in heat waves is supported by the strengthening of the mid-tropospheric high and the associated subsidence over central and northwest India. Land surface processes such as soil moisture depletion and increased sensible heat fluxes are also responsible for the increase in heat waves. The CMIP5 models also suggest that El Nino Modoki events (with maximum warming over the central Pacific) may be responsible for the longer and more frequent heat waves over India in the future climate.

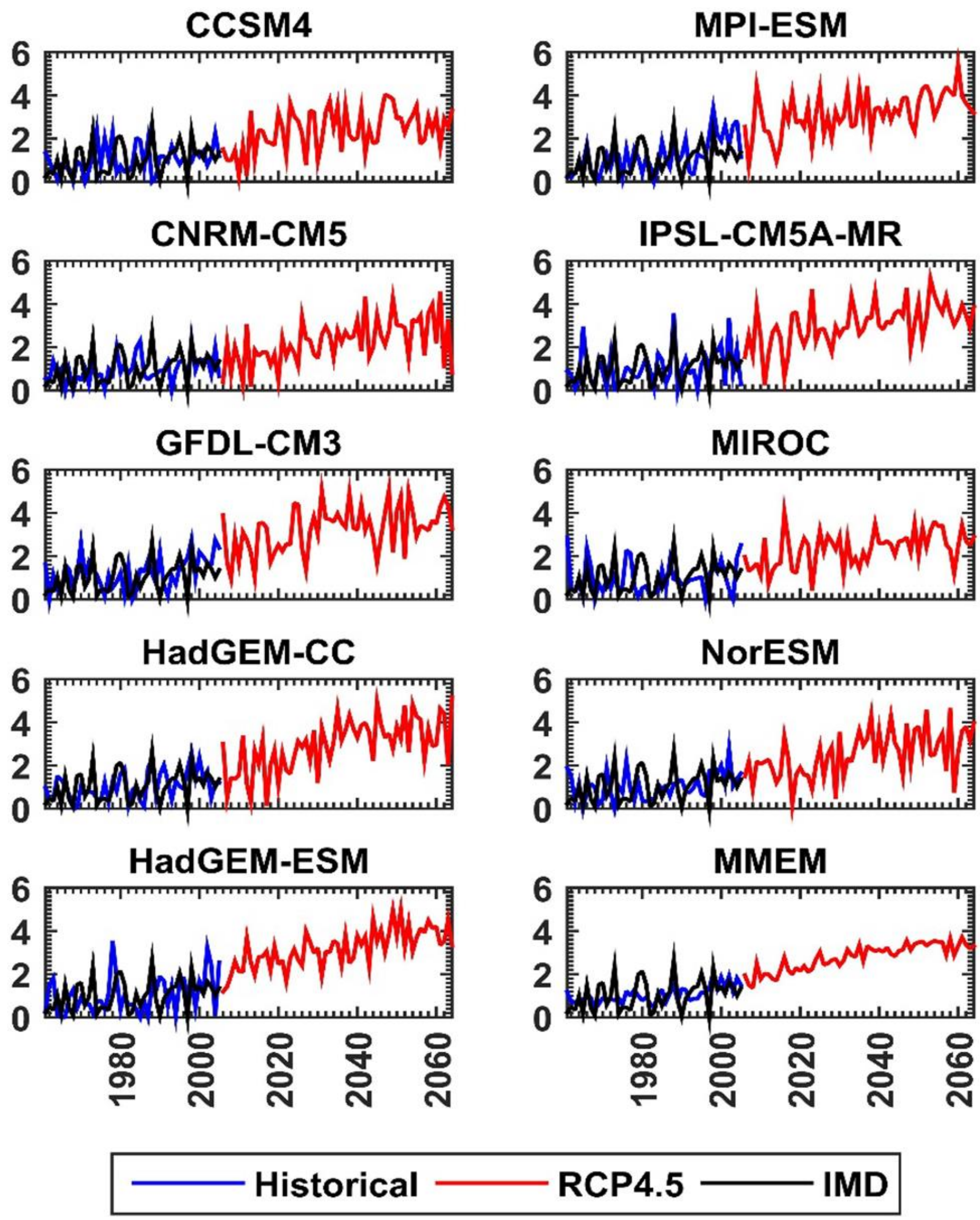

Fig 4.16 a. Time series of frequency (number/year) of heat waves averaged over the northwest Indian region 22^0-32^0 N, 70^0-78^0E as derived from observations and CMIP5 models. The IMD observations are shown in black colour. Model simulated frequency during the historical period (1961-2005) is in blue colour and future projection (2006-2064) is in red colour. (After Rohini et al. 2019).

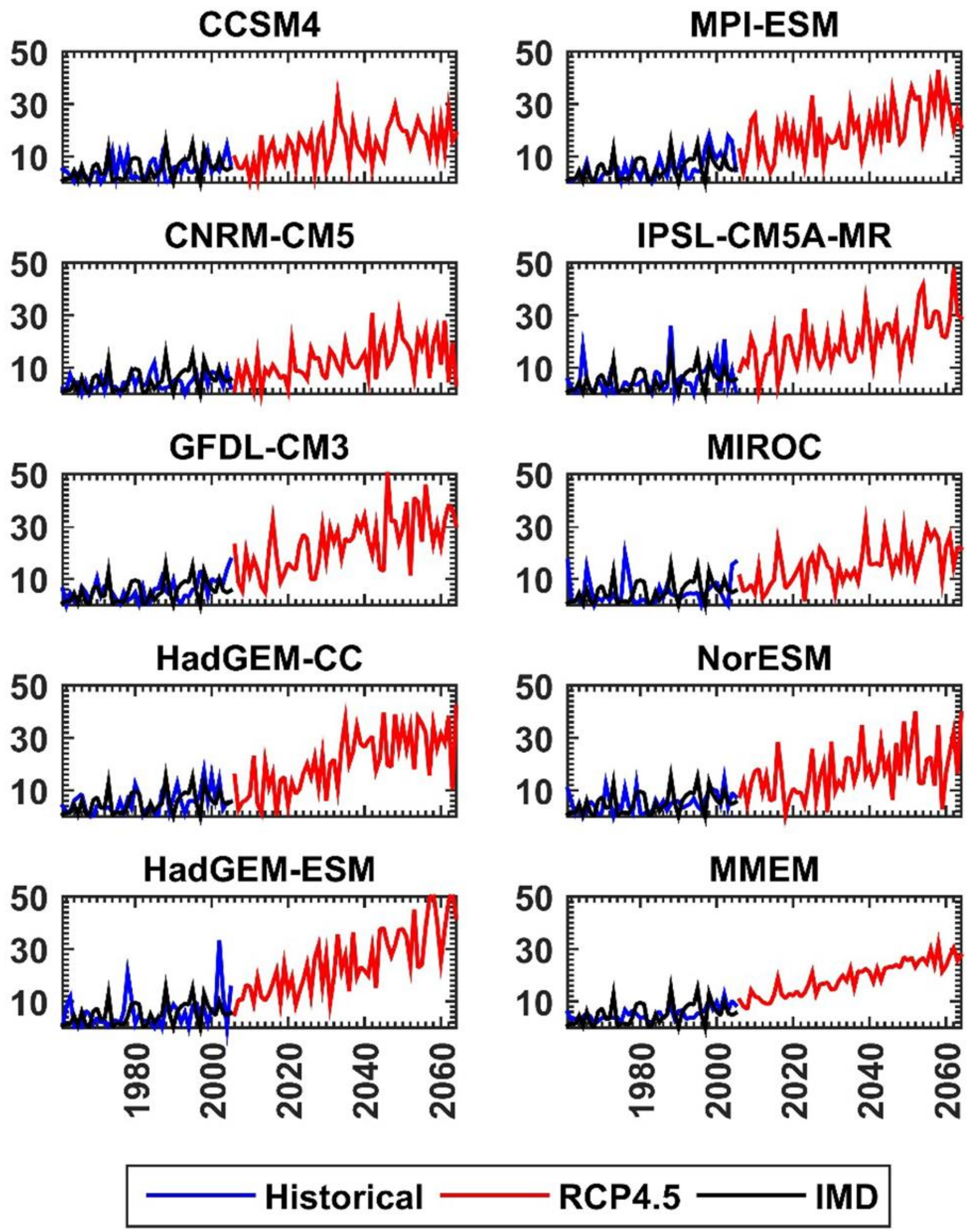

Fig 4.16 b. Time series of duration (days/year) of heat waves averaged over the region 22^0-32^0 N, 70^0-78^0E as derived from observations and CMIP5 models. The IMD observations are shown in black colour. Model simulated frequency during the historical period (1961-2005) is in blue colour and future projection (2006-2064) is in red colour. (After Rohini et al. 2019).

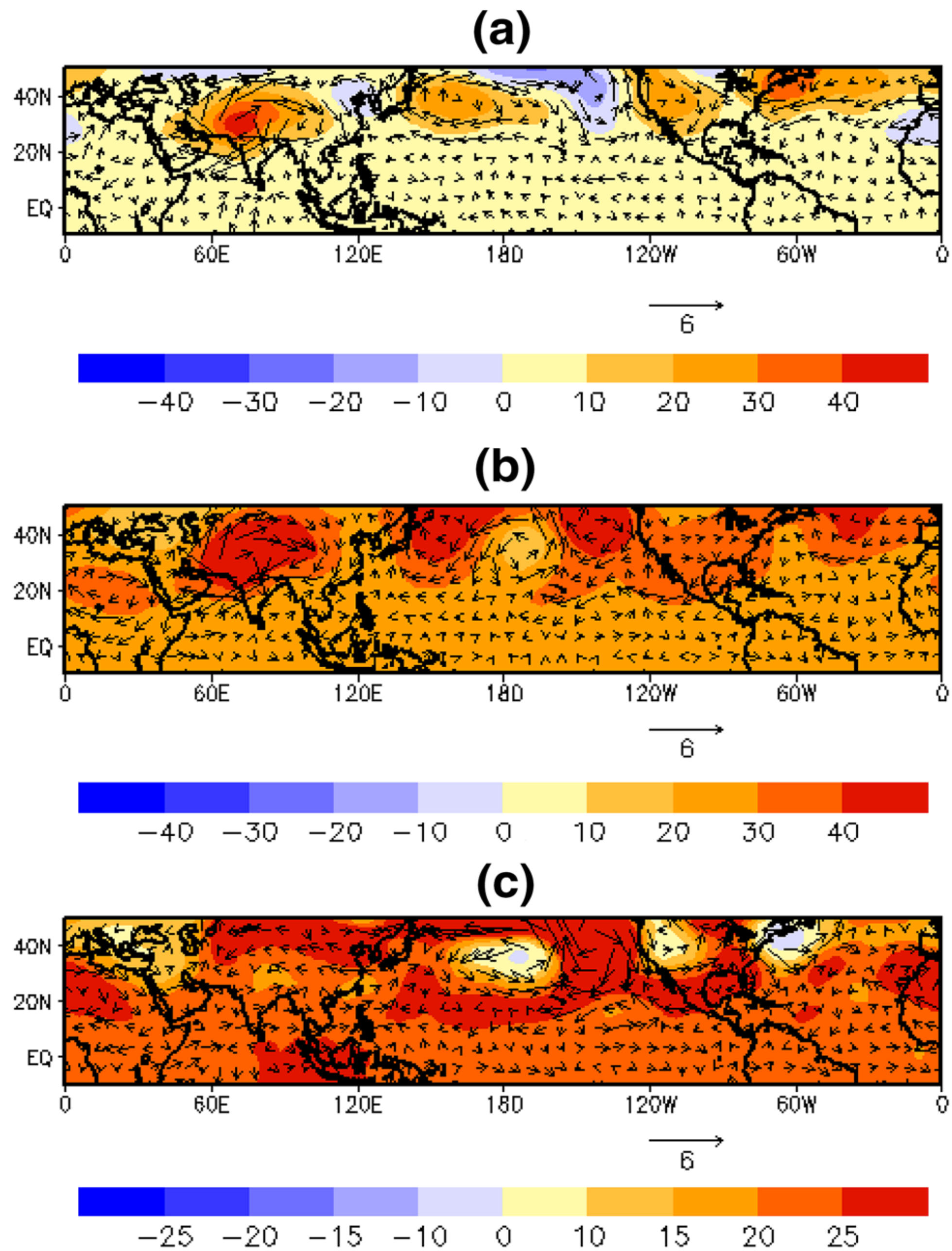

Fig 4.17. Composite anomaly of geopotential height (m) and wind vector at 500 hPa level from the CNRM-CM5 model during heat wave events a) historical period (1961-2005), b) future projection (2020-2064) and c) difference between future and present (Future-present). The period 1961-1990 was used as reference period for calculating the climatology.

Mishra et al. (2017) studied the exposure to heat waves in India in the current, 1.5^0C and 2.0^0C warming scenarios. They characterized the maximum potential exposure of people (without passive/active reduction measures) to severe heat waves in India. They showed that the frequency of severe heat waves will increase by 30 times the current climate by the end of the 21st century if the global average temperature is limited to 2.0^0 C above pre-industrial conditions. In contrast, the frequency under the RCP8.5 (business-as-usual" emissions) scenario will be about 2.5 times higher (than under the low warming scenario). Under the low warming target of 2.0^0 Celsius, population exposure to severe heat waves is projected to increase by 15 and 92 times current levels by the middle and end of the 21st century, respectively.

Mukherjee and Mishra (2018) used observations and model simulations from climate of 20th Century plus detection and attribution (D&A) and CMIP5 models to show that 1 and 3-day concurrent hot day and hot night (CHDHN) events have significantly increased. The frequency of 3-day CHDHN events is projected to increase 12-fold the current level by the end of 21st century and 4-fold by the mid-21st century under the high emission pathway of RCP 8.5. The increase in 3-day CHDHN be limited to only 2-fold by the end of 21st century under low emission scenario of RCP 2.6. Restricting global mean temperature below 1.5° from the pre-industrial level can substantially reduce the risk of 1 and 3-day CHDHN events and associated implications in India.

Ullah et al. (2022) examined projected heat stress and associated socio-economic stress in South Asia and its sub-regions using CMIP6 model data and GDP projections. They considered two common socio-economic pathways (SSP), namely SSP2-4.5 and SSP5-8.5, and three time periods: short-term, medium-term and long-term compared to the baseline period (1985-2005). The study found that the South Asian region has the potential for widespread changes in global wet bulb temperature (WBGT) of 6.50°C, which could exceed the theoretical limits of human tolerance by the mid-21st century. It is noteworthy that the climate effect is more dominant than the population effect, while the changes in the GDP effect contribute to the overall change in GDP exposure.

Das and Umamahesh (2021) examined the future projection of heat waves over India using 13 CMIP5 and 12 CMIP6 model simulation data. The Heat Wave Magnitude Index (HWMI) was used to characterize heat waves over India. The study found that maximum temperatures are likely to increase in the future, leading to more intense, frequent and prolonged heat waves over India. Large regions in the south, northeast and west of the country, which are currently unaffected, are expected to be severely affected by heat waves.

Dubey et al. (2021) and Dubey and Kumar (2022) have undertaken an analysis of future projections of heat wave characteristics and dynamics over India using a high-resolution regional earth system model (ROM). The heat wave characteristics simulated by ROM are largely consistent with observations, although some discrepancies have also been noted. The typical synoptic features associated with heatwave days for the identified regions show the presence of an elevated geopotential height with an anomalous anticyclonic structure forming an atmospheric blockade over every region except the southeast coast. The projected frequency will double and the average duration will increase by 8-12 days per season by the end of the century. Severity will also increase by 2°-3 °C. Similarly, future dynamic features will be associated with an increase in geopotential height (thickness) and a gradual decrease in potential vorticity. According to the study, the frequency of heat waves will more than double by the end of the century in most regions except the Himalayas and the northeastern hills. The duration of heatwaves is also expected to increase by 8-12 days in most parts of the country. The severity of heat waves is also likely to increase by 2-30°C in the distant future.

Murari et al. (2015) examined intensification of future severe heat waves in India and their effect on heat stress and mortality. Their study revealed that heat waves are projected to be more intense, have longer durations and occur at a higher frequency and earlier in the year. Southern India, currently not influenced by heat waves, is expected to be severely affected by the end of the twenty-first century.

There is therefore a general consensus that under future climate change, both the frequency and duration of heat waves are likely to increase significantly. Those regions where heat waves are not as frequent (such as the southern peninsula) are likely to be more affected in the future.