HEAT WAVES

Impacts and Management Strategies in Agriculture

ICAR - Central Research Institute for Dryland Agriculture
Santoshnagar, Hyderabad - 500 059, Telangana, India

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MESSAGE

The agriculture sector is vulnerable to climate change with increasing occurrences of extreme weather events like heatwaves, droughts, and unseasonal rainfall disrupting agricultural output. The years 2022 to 2024 have seen some of the most intense heatwaves, which have led to significant damage to crops, livestock, poultry, and fisheries. These climate challenges are particularly concerning for a country like India, where agriculture is a key pillar for rural livelihoods and food security.

It is crucial to develop and implement climate-smart agriculture strategies to minimize the damage caused by these climatic extremes. Accurate climate predictions, improved monitoring systems, and the integration of data from various agencies will be key to helping farmers adapt to these changes. The emphasis on strategies for different sectors, such as crops, livestock, poultry, and fisheries, shows a comprehensive approach, acknowledging that each sector requires unique adaptation methods. It is also important that this information reach not just researchers and policymakers, but also extension workers and farmers on the ground who can implement these adaptive strategies in real time.

I appreciate the initiative of ICAR-CRIDA, Hyderabad for bringing out this document. I hope this bulletin will be useful for researchers, farmers, extension specialists, policymakers, and other stakeholders in formulating strategies for minimizing the impacts of such vagaries in the future.

(Himanshu Pathak)

Dated the 21st, November, 2024
New Delhi

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FOREWORD

Extreme weather events have presented significant challenges to Indian agriculture in recent times, affecting not only farm production but also the scientific community's ability to predict these events in advance. This document aims to summarize existing information and address the issues faced by Indian agriculture due to heat waves. It explores the science behind heat wave occurrences, their impact on various agricultural sectors, and management strategies to mitigate the negative effects. According to the IPCC, the Indian sub-continent is expected to experience heat wave events with greater frequency and intensity in the future. Therefore, there is a pressing need for a comprehensive reference document for various stakeholders.

Heat waves have both direct and indirect effects on agriculture and related sectors, necessitating a coordinated scientific response to this natural disaster. The Indian Council of Agricultural Research has developed several technologies to minimize the impact of heatwaves. These promising technologies are being delivered to farmers through a participatory approach, which has been well received by the farming community. However, there is a need to integrate these proven resilient technologies into ongoing developmental programs.

I commend the efforts of the scientists from the All India Coordinated Research Project on Agrometeorology, the All India Coordinated Research Project for Dryland Agriculture, and ICAR-Central Research Institute for Dryland Agriculture for producing this timely document. I sincerely believe that this publication will be invaluable in managing future heat wave episodes.

(S.K. Chaudhari)

Dated 30th, October, 2024
New Delhi

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Acknowledgments

The consecutive events of heatwaves, both in frequency and severity during the last three years (2022, 2023 & 2024), and the extent of damage they caused to Indian agriculture have compelled us to compile this document. It includes information about the science behind the heat waves, their impact on various sectors of agriculture and allied sectors, and available adaptation strategies that may guide in prioritizing research efforts and the role of various agencies in minimizing field-level losses. In this effort;

We express our sincere gratitude to Dr. Himanshu Pathak, Secretary, DARE & Director General-ICAR, for his valuable guidance and constant encouragement in bringing out this publication.

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(Authors)

Executive Summary

Heat waves are becoming extremely intense and frequent globally, probably due to the rising average temperature of the earth. India has been experiencing unusual increases in maximum and minimum temperatures over most parts of the country continuously since 2022. Changes in large and small atmospheric processes, along with various weather and soil factors, influence the occurrence of heat waves. Therefore, forewarning and monitoring of heatwave events have much significance, especially for a large and populous country like India covering diverse agro-ecologies.

Heat waves, characterized by extended periods of extreme temperatures, exert significantly greater impact. Heat waves can negatively affect crops through withering, dehydration, and heat stress, reducing yields and diminished quality. Higher temperatures can reduce crop yields by slowing plant growth and impairing photosynthesis, disrupting the source-sink balance. Heat waves can exacerbate water stress, particularly in areas with limited water resources, leading to crop failure and financial losses for farmers. The number of fruits, fruit set percentage, and fruit weight per plant decrease with increased temperature. Reduced starch and soluble sugar concentration in the leaves of tomatoes & yield attributes *viz,* number of fruits/plants, fruit set (%), average fruit weight (g), and yield per plant are found to be reduced. An increase in body temperature of livestock and milch animals by 0.5 to 3.5 °C and a reduction in milk yield by up to 15% is reported in livestock.

Elevated temperatures during heat waves induce crop stress, reduce photosynthesis, and water uptake, and increase susceptibility to pests and diseases, consequently lowering crop yields and quality. In livestock, reduced feed intake, milk production, and heat-related illness necessitate the provision of adequate shade, ventilation, and water access. Fisheries and aquaculture suffer from altered aquatic ecosystems, affecting species distribution, abundance, and behavior, leading to financial losses. Heat waves impact horticultural crops by way of thermal stress that damages cellular structures and denatures proteins, increases transpiration leading to water stress, and reduces photosynthesis due to enzyme inactivation and chlorophyll degradation. Heat stress in animals leads to increased metabolic rates potentially leading to energy imbalances and reduced growth. Animals exhibit altered behavior to cope with heat, such as seeking shade or water which can affect feeding and reproductive performance.

Due to the efforts of the National Agricultural Research System, several technologies are currently available that can minimize the negative impacts of heat waves in various production systems. For agricultural and horticultural crops, utilizing heat-tolerant crop varieties and adjusting planting schedules to avoid peak heat periods can help mitigate heat stress. Improved soil moisture management techniques such as mulching, drip irrigation, and conservation tillage can conserve water and maintain soil moisture levels and canopy temperatures during heat waves. For livestock, providing shade and ventilated shelters, ensuring a constant supply of cool water, adjusting diets to reduce metabolic heat, and implementing ventilation and cooling systems are critical. In the case of poultry, the use of effective ventilation, applying reflective roof coatings, etc., and providing nutritional supplements through drinking water can minimize the impact.

Despite the availability of technologies, there is a need to popularize and scale these technologies by way of integrating them into the ongoing development programs. In addition, strengthening the weather forecasts and agro-advisory services can help farmers make informed decisions about the impending weather. Building capacities of farmers and large-scale awareness of climate-resilient technologies are needed to enhance their adoption. Such efforts will go a long way in enhancing the resilience of various sectors of Indian agriculture to climatic extremes, such as the recently experienced heat waves.

CONTENTS

1. Introduction

The principal source of livelihood for nearly 48% of the population in India is agriculture and the allied sectors, contributing 20% to the country's Gross Domestic Product (Economic Survey 2020-21). The recent annual economic survey of the Indian government opined that climate change-related issues could affect the farmers' income by up to 20-25% in the medium term. Climate change can profoundly impact global food production by varying intensity with changes in climatic variables (e.g., temperature, precipitation, solar radiation, etc.). In addition, the recurrent occurrence of extreme weather events also leads to higher variability in agricultural production. Over and above, Indian farmers, mostly small and marginal, are vulnerable where the social, market, and economic pressures are huge, often leading to considerable distress. Heatwaves, a form of atmospheric stress are one of the extreme events, that have been occurring frequently across various regions of the country and impacting Indian agriculture negatively (Bal and Minhas, 2017).

2. Definition and major events of heatwaves

A heatwave is a period of prolonged abnormally high surface temperatures relative to those normally expected. Heat waves may span several days to several weeks and are significant causes of weather-related mortality, affecting developed and developing countries alike. There is no standardized definition of a heat wave. To compare heatwaves in different regions of the globe, absolute temperature is not ideal as a heatwave in the tropics will always be hotter than one in the Arctic, despite communities having very different adaptive capacities. Therefore, various agencies across the globe have given different definitions for heat waves based on different purposes. Heat waves are not uniform across the globe and there is a lack of a common index to identify the heat extremes (Perkins *et al.,* 2012). The thresholds used for defining heat waves are different for different regions, depending upon the region and its geography. Some of them are given in Table 2.1.

Both cool- and warm-season heat events are principally driven by global- and synoptic-scale atmospheric patterns. Regardless of the season of occurrence or atmospheric driving mechanism, there is no consistent means of quantifying temperature extremes. Definitions or characterizations of extremes may incorporate fixed threshold values, occurrence probabilities or percentile values, temporal variations, diurnal considerations, or degree of impact on crops and ecosystems.

Table 2.1. Heatwave definition as per various organizations

Organization	Definition
WMO, Geneva	Five or more consecutive days during which the daily maximum temperature surpasses the average maximum temperature by 5 °C (9 °F) or more above the normal temperature.
National Weather Service, USA	Spell of abnormally and uncomfortably hot and unusually humid weather spanning two days or more
UK Met Office	A UK heatwave threshold is met when a location records at least three consecutive days with daily maximum temperatures meeting or exceeding the heatwave temperature threshold (25 °C (North) – 27 °C (South)
IPCC, 2021	A period of abnormally hot weather, often defined with reference to a relative temperature threshold, lasting from 2 days to months
World Health Organization	Sustained periods of uncharacteristically high temperatures that increase morbidity and mortality
India Meteorological Department, India	Heatwave is considered if the maximum temperature of a station reaches at least 40 °C or more for Plains and at least 30 °C or more for Hilly regions Based on Departure from Normal : Heat Wave: Departure from normal is 4.5 °C to 6.4 °C Severe Heat Wave: Departure from normal is > 6.4 °C Based on Actual Maximum Temperature : Heat Wave: When actual maximum temperature ≥ 45 °C Severe Heat Wave: When actual maximum temperature ≥ 47 °C If the above criteria are met at least in 2 stations in a Meteorological sub-division for at least two consecutive days, it is declared on the second day. Heatwave criteria for coastal regions : When the maximum temperature departure is 4.5 °C or more from normal, a Heat Wave may be described provided the actual maximum temperature is 37 °C or more.

Percentile temperatures

The maximum temperature percentile of a station refers to the ranking of the maximum temperature of any particular day concerning all the maximum temperatures recorded for all the days of that month in the record. For example, if there were 100 maximum temperature value records and these are arranged in ascending order, then the highest 90th value will be called 90^{th} percentile, 95^{th} value will be called 95^{th} percentile and 98^{th} value will be termed as 98th percentile. Statistically, the percentile values convey the information that the 90^{th} percentile temperature indicates that 90 percent of the time the maximum temperature will be cooler than this temperature, or in other words the maximum temperature above $90^{th}/95^{th}/98^{th}$ percentile indicates the unseasonably warm day of any month.

Major heatwave events since the year 2000

Table 2.2. Major recent heatwave events in India

Year	Duration	Max. Temp.	Deaths
2002	April-May	49.0 °C	1030
2015	May-June	49.4 °C	2500
2016	April-May	51.0 °C	160
2019	May-June	50.8 °C	184
2022	March-June	49.2 °C	90
2023	April-June	46.2 °C	111
2024	April-June	52.9 °C	411

https://en.wikipedia.org/wiki/List_of_Indian_heat_waves

Table 2.3. Major recent heatwave events worldwide

Continent	Year	Country
Asia	2002	India
	2015	India, Pakistan
	2016	India
	2017	Pakistan
	2019	India, Pakistan
	2022	India, Pakistan, China, Japan
	2023	Pakistan, China
	2024	India, Pakistan, Saudi Arab, SE Asia
Europe	2003	UK
	2006	UK
	2007	UK
	2010	UK
	2013	UK
	2014	Sweden
	2018	UK, Eurpoe
	2019	UK, Ireland
	2021	UK, Ireland
	2022	UK, Europe
N.America	2000	South US
	2001	Eastern US
	2021	Western US

https://en.wikipedia.org/wiki/List_of_Indian_heat_waves

3. Causes of heatwaves

3.1. Meteorology

An increase in the mean ($\bar{x}$) or the coefficient of variation (CV) of temperatures increases the probability of extreme temperature events (Fig.3.1). This can also lead to an increase in the frequency of heat waves. Heatwaves are most common in summer when high pressure develops across an area. High-pressure systems are slow-moving and can persist over an area for a prolonged period, such as days or weeks.

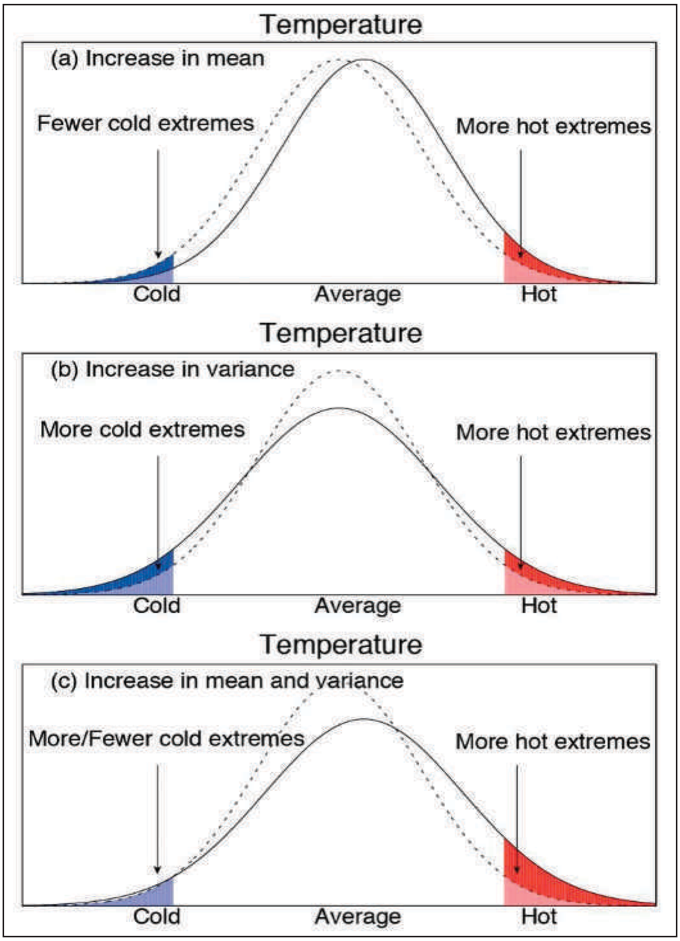


Fig. 3.1. Schematic representations of the probability density function of daily temperatures.
Dashed lines represent a previous distribution and solid lines a chaanged distribution.
The probability of occurrence, or frequency, of extremes, is denoted by the shaded areas.
In the case of temperature, changes in the frequencies of extremes are affected by changes (a) in the mean, (b) in the variance or shape, and (c) in both the mean and the variance (Source: IPCC, 2014).

3.2. Physical mechanisms

The development of heat waves is caused by the interaction of large- and small-scale atmospheric processes (Adams *et al.,* 2021). Heat waves are usually associated with anticyclonic flows in the middle and upper troposphere that extend into the lower troposphere and dynamically lead to strong subsidence, clear skies, warm air advection, and prolonged hot conditions at the surface. The blocking high (anticyclone) in the upper level, which blocks the passage of synoptic transients, has been responsible for many extreme heat waves (Perkin, 2015). In India, heat waves are generally associated with the following favourable factors (Bedekar *et al.,* 1974).

- Hot dry air should prevail over the concerned region
- There should be a region of warmer dry air and an appropriate flow pattern for transporting the air over the region
- There should be little or no moisture present in the upper air over the area
- Sky should be practically cloudless to allow maximum insolation over the region.
- The lapse rate should approach dry adiabatic in the airmass to allow warming to a considerable depth
- There should be a large amplitude anticyclonic flow or thickness values should be considerably above normal in all layers.

3.3. Weather and soil factors

Rain events

While heatwaves are common in the season preceding the monsoon, the very high temperatures so early in the year and much less than average rain normally lead to extreme heat conditions with devastating consequences for agriculture and public health. When a heatwave is accompanied by much below-average rainfall and humidity, it constitutes a dry heatwave, resulting in a severe one. A classic example is, rain events due to western disturbances were almost absent during Jan-Apr 2022, making the heatwave in 2022 severe. There is a substantial increase in the frequency of concurrent meteorological droughts and heat waves across India. Statistically significant trends in the spatial extent of droughts are observed in Central northeast India and west central India. However, the spatial extent affected by concurrent droughts and heat waves is increasing across India (Sharma and Mujumdar, 2017).

Humidity

The high values of Relative Humidity aggravate the impact of Heat Waves. They compromise the body's response to heating through perspiration by reducing the evaporation rate. High relative humidity leads to a slower evaporation rate of sweat thereby reducing the efficiency of the cooling mechanism of the human/animal body. Oppressively hot and humid air masses lingering over populated areas can produce many deaths, especially in the middle latitudes, where the chance of high-pressure build-up is higher.

Wind

The high values of wind speed aggravate the impact of Heat Waves. During high-temperature days, the surface wind gets heated up in contact with the land surface. When the hot surface wind blows and comes in contact with the human body, it tends to increase the temperature of the human/animal body thereby increasing the impact of hot temperatures.

Minimum temperature

The minimum temperatures are generally seen during the night times. If the minimum temperature at night is warmer than normal then they also give a cascading effect on the next day's maximum temperatures. The maximum temperatures may be attained the following day earlier and may also last for a longer duration. When the high daytime and night-time temperatures are seen together then they tend to increase the heat stress on humans/animals as the human/animal body finds it difficult to recover from the heat of the day during night hours.

Maximum temperature

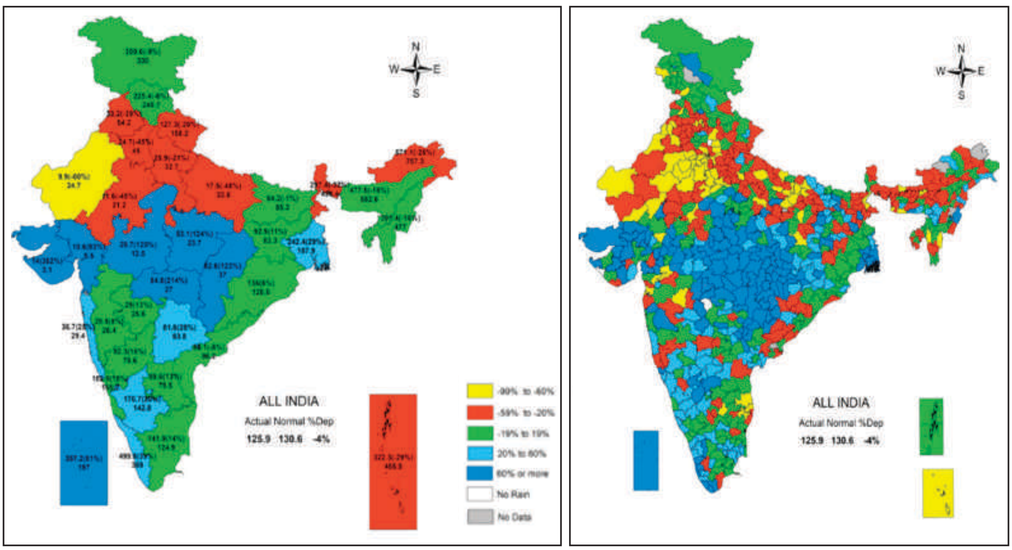
Nageswara Rao *et al.* (2020) examined the heat waves occurring over the east coast of India (Odisha, Andhra Pradesh and Telangana). The study revealed the continued increase in maximum temperature and its variability as the hot weather season progresses. A notable increase in the weekly Tmax and its variability has been observed in the recent period.

Soil moisture

The average soil moisture content appears to be a key factor in the correlation between the amount of rainfall and extreme hot temperatures. It acts as a control factor for the impact of the precipitation deficit on hot extremes. As the soil gets drier, there is an accompanying change in the rate of decrease in latent heat flux and increase in sensible heat flux leading to a strong positive feedback of increased air temperature near the surface, which further dries out the soil. Dry soil leads to stronger sensible heat and reduced latent heat flux, which leads to a deeper boundary layer that enhances the feedback loop and leads to heat-wave persistence (Dirmeyer *et al.,* 2014). Land surface moisture deficits and land-atmosphere (L-A) feedback have been connected to the onset and maintenance of heat waves in many regions (Ford and Schoof, 2017). Thus, reduced precipitation and progressive drying could consequently lead to more intense and prolonged heat-wave events.

Case study 2024

During the post-monsoon season from October to December 2023, 11 subdivisions are under deficit condition. During winter months from January to February 2024, 23 met subdivisions are under deficient and large deficient conditions. From March to May 2024, during summer deficient to large deficient conditions prevailed in 8 meteorological sub-divisions (Fig.3.2). The common factor observed in these three seasons was the subdivisions viz. Punjab, Haryana, Chandigarh, Uttarakhand, West Uttar Pradesh, East Rajasthan, and West Rajasthan were continuously under deficient or large deficient conditions. Under this situation, warm winds, dry soils, and clear skies with high temperatures might have triggered the heatwave from mild to severe conditions in these subdivisions in 2024 summer. Similar conditions also aggravated the heatwave conditions 2022 (Bal *et al.,* 2022).



01-Jan to 29-Feb 2024 | 01-Mar to 31-May 2024

Fig. 3.2. All India sub-division-wise rainfall

3.4. Sea Surface Temperature (SST) and El-Nino

A climate model experiment study by Vittal *et al.* (2020) shows that Indian heat waves during the period 1961-2010 period were strongly driven by the Sea Surface Temperature (SST) anomaly of the Atlantic Ocean compared to that of the Indian Ocean. Pai and Smitha (2022) examined the impact of extreme phases (El Nino and La Nina) of El Nino-Southern Oscillation (ENSO) on the frequency, duration, magnitude, and spatial coverage of heat waves (HWs). It was observed that there is an appreciable increase (decrease) in the number of HW days during El Nino (La Nina) events. Severe heat waves were more prominent (longest and hottest) in El Nino years. Hari *et al.* (2022) studied the inter-annual variability of the summer heatwave intensities (°C; corresponding to the climatological mean) over

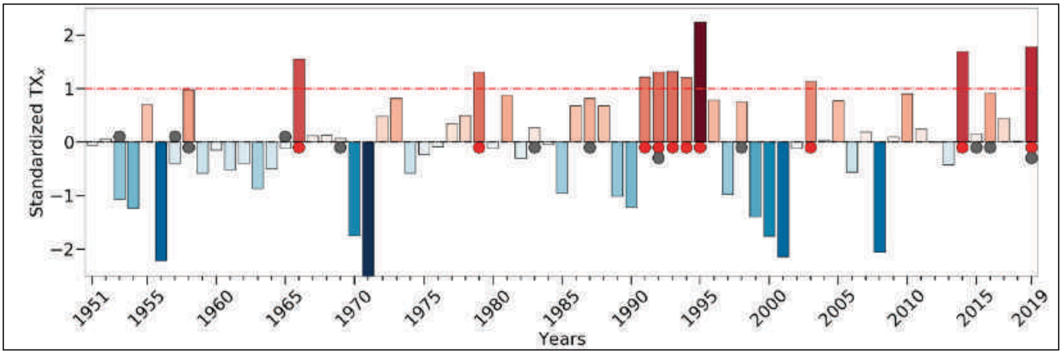


Fig.3.3. Inter-annual variability of the summer heatwave intensities (°C) over the North Central India region (red dots - major heat wave years; black dots - strong El Nino years) (Hari *et al.,* 2022)

the North Central India region (depicted by a black rectangular region in the panel). They have concluded that El Nino years are not necessarily when the risk for heat waves is the highest in India.

3.5. Climate Change

The increase in greenhouse gas emissions in the atmosphere has led to global warming with a rise of about 1.1°C since 1880. Similarly, annual surface temperatures over India have also recorded a similar increase over the period 1901-2022 (Rajeevan *et al.,* 2023). In recent years, minimum (night-time) temperatures have increased more than daytime temperatures, suggesting the possible role of moisture and greenhouse gases. Globally, the increasing frequency and intensity of heat waves observed since the 1950s have been associated with climate change. Heatwaves are extreme weather events, but research shows that climate change is making these events more likely. It is also being experienced that, extreme weather events have become increasingly common globally in recent decades (IPCC 2012; IPCC 2014). Heatwaves that occurred once every 10 years without human-caused warming are now likely to occur 2.8 times more often (or once every 3.6 years) and are 1.5ºC warmer because of climate change. The continuous increase in the duration, intensity, and frequency of heat-wave events is attributed to a response to anthropogenic climate forcing (Jia *et al.,* 2019).

3.6. Human influence

Anthropogenic factors have increased the probability of the occurrence of severe heat waves in central and central-southern India by two times during the twentieth century (Kishore *et al.,* 2022). Recently, extreme heat in South Asia during the pre-monsoon season is becoming more frequent. Two previous World Weather Attribution studies focused on extreme heat events in the region: the 2022 India and Pakistan heatwave and the 2023 humid heatwave that hit India, Bangladesh, Lao PDR, and Thailand. Despite differences in the nature and impact of the events (drier heat in 2022 leading to widespread loss of harvest, and humid heat in 2023 with greater impacts on people), both studies found that human-induced climate change influenced the events, making them around 30 times more likely and much hotter (WWA, 2024).

4. Heatwave Characteristics

4.1. Heatwave hotspots/ risk-prone regions

World

Thompson *et al.* (2022) delineated the heatwave hotspots of the world. Their study indicates that the occurrence and impacts of the heatwaves vary with regions. In a region with lower natural variability, such as the tropics, a heatwave of lesser absolute magnitude may have a bigger impact because the area may be less adapted for such unusual conditions. As per the study, high pressure and dry conditions contribute to the extreme heat conditions.

They have reported that extremes appear to increase in line with changes to the mean state of the distribution of the climate, and the projected increase in extremes aligns with projected warming.

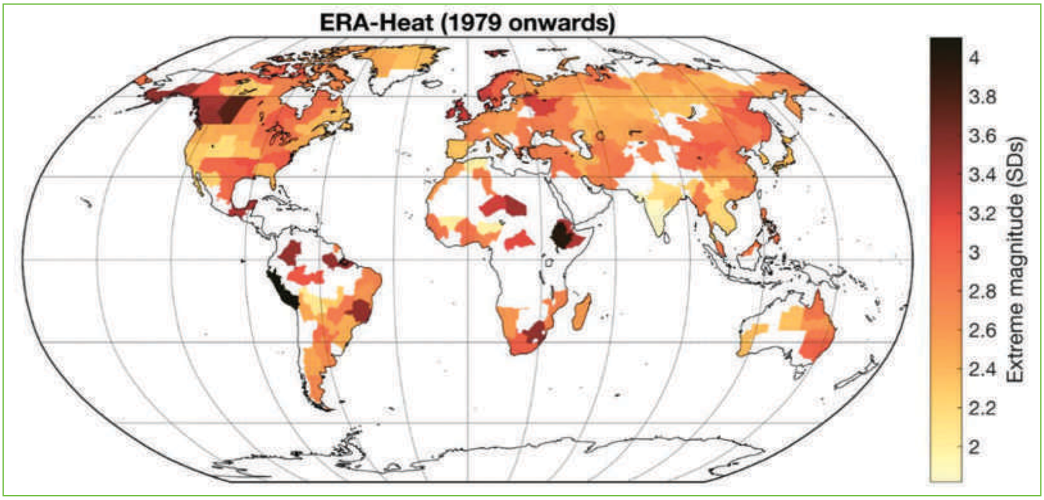


Fig.4.1. The magnitude of the greatest extremes since 1950 in each region, expressed in standard deviations from the average with climate change trend removed. (Thompson *et al.,* 2022).

India

In India, heat waves (HW) usually occur in the pre-monsoon months from March to June. There are two areas in India where heat waves are prevalent. One is central and north-western India, called the heat wave zone, and the other is on the east coast of India (Andhra Pradesh and Odisha). The frequency of heat waves is higher in the heat wave zone than on the east coast of India. Different physical mechanisms are responsible for the heat waves in the heat wave zone and on the east coast of India.

Hari *et al.* (2022) estimated the risk based on the definition following the IPCC-AR5 framework (Risk = Hazard × vulnerability), with the exposure component included in the vulnerability section. In the case of heatwave hazard, they estimated the trend in TXX intensities from 1951–2019 based on gridded daily maximum temperature data from the Indian Meteorological Department. The vulnerability, on the other hand, is estimated based on demographic data procured from the Census of India for the decade 2011, which provides decadal information on different categories of population. A total of 35 relevant indicators are selected to reflect an impact on the socio-economic system across India. The analysis indicated that northwest and central India are highly prone to heat wave risk (Fig. 4.2). Roxy *et al.* (2024) studied the trends in maximum temperatures during 1981-2020 across India and found that maximum temperature has increased diagonally across the country, with a maximum increase in the northwest (Fig. 4.3).

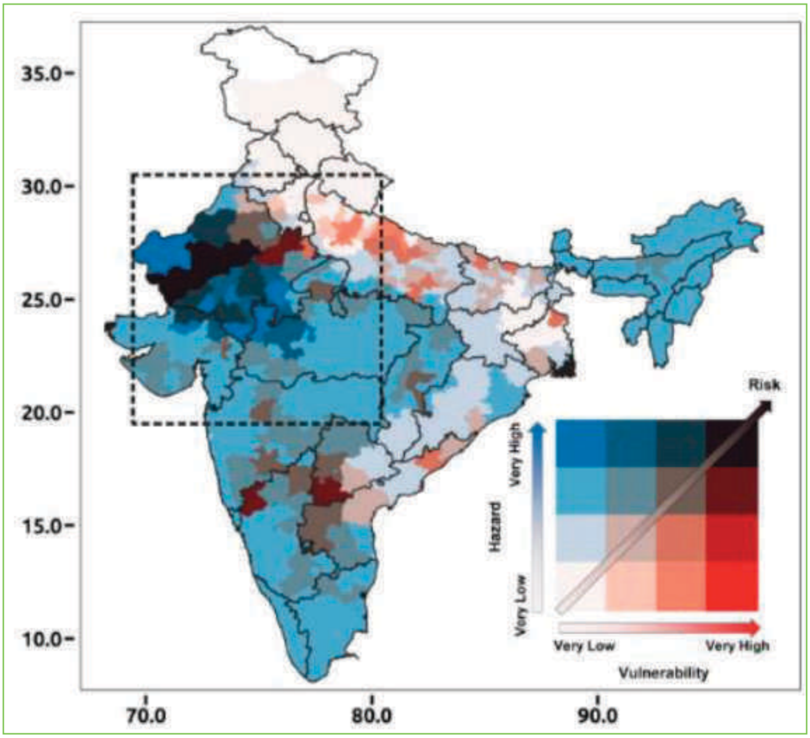


Fig.4.2. Risk-prone areas to heat waves in India (Hari *et al.,* 2022)

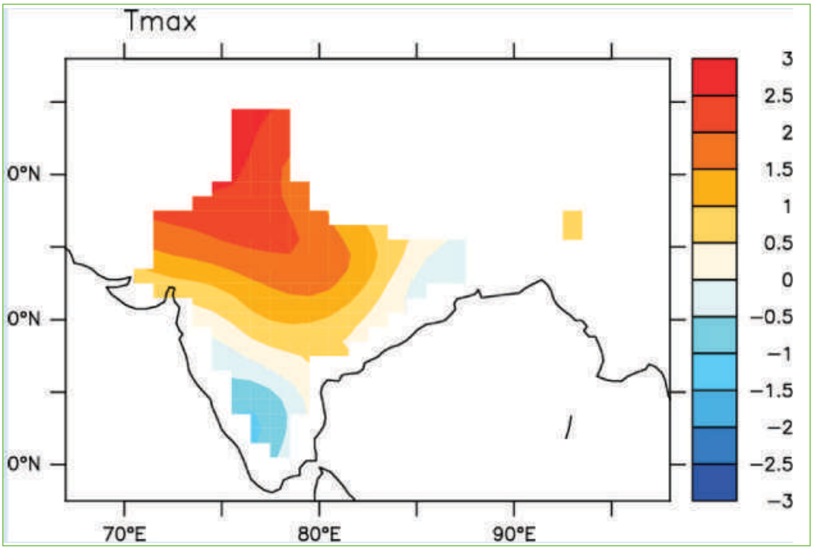


Fig.4.3. Trends in maximum temperatures in India (1981-2020) (Roxy *et al.,* 2024)

4.2. Frequency and trends of heatwave days in India

On 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 IMD stations are showing increasing trends of heat wave events during the 60 years (1961-2020) as shown by red triangles (IMD, 2023 – Met monograph) (Fig. 4.4 a&b).

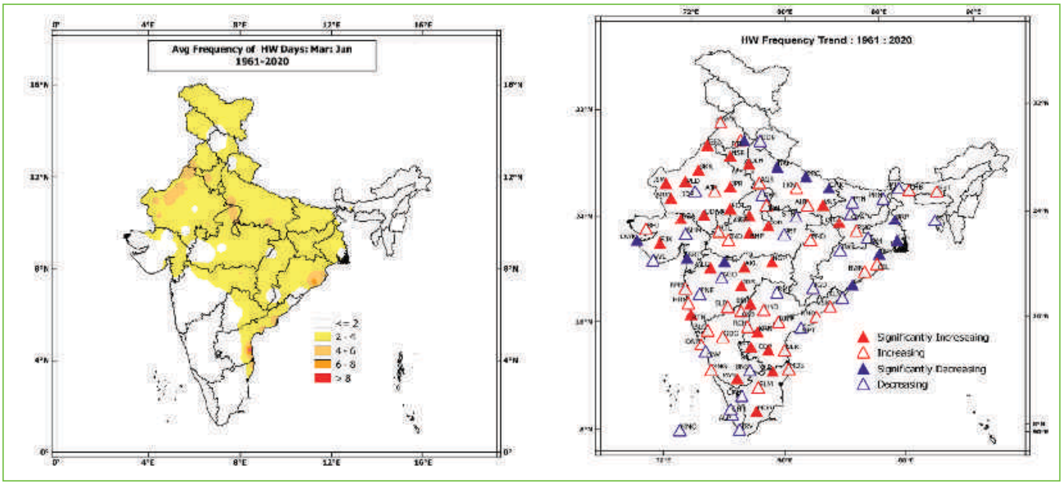


Fig.4.4. a) Average heatwave frequency during March-June for the period 1961-2020, b) HW frequency trends, station-wise during the same period (IMD, 2023 – Met monograph).

Most recent observational studies suggested an increasing trend in heat waves in India (Pai *et al.,* 2017; Rohini *et al.,* 2016). The trends of heat waves are significant both over the northwestern parts of India and the south-eastern coast of India (Ratnam *et al.,* 2016a; Rohini *et al.,* 2016). These studies suggested that the occurrence of heat waves over the north-western part of India is associated with anomalous persistent high pressure along with depleted soil moisture (Bal *et al.,* 2022) and its variability is strongly influenced by tropical ocean SST anomalies. The frequency, duration, and spatial extent of heat waves over India are found to be higher in the succeeding year of El Nino (Pai *et al.,* 2013; De and Mukhopadhyay 1998; Rohini *et al.,* 2016). Pai *et al.* (2013) examined the occurrence of heat waves in India in detail using the temperature data from 1961-2010. It was observed that many areas of the country (north, northwest, central, and northeast peninsula) have experienced HW days of more than 8 days on average per season. The severe heat waves were mainly experienced over the north, northwest, and central parts of the country.

Significant long-term increasing trends in HW days were also observed over India during the analysis period. In general, the frequency, persistency, and area coverage of the HW/SHW days were found to be more than average during the years succeeding El Nino (El Nino +1) years. Recently, Pai *et al.* (2017), have summarized the results related to heat waves over India. During the hot weather season (AMJ), stations from the north, northwest, central, east India, and north-east Peninsulas (together called Core Heatwave Zone) are most prone for HW/SHW days with relatively highest frequency experienced during May.

4.3. Heatwave Monitoring in India

IMD network of surface observatories covers the entire country to measure various meteorological parameters like temperature, relative humidity, atmospheric pressure, wind speed & direction, etc. Based on the daily maximum temperature of station data, climatology of maximum temperature is prepared for a long period (e.g. 1991-2020) to find out the normal maximum temperature of the day for a particular station. Thereafter, IMD declared heat waves over the region as per its definition.

Forecast of heat-waves

It is important to predict these events to mitigate the harmful impacts on agriculture and sustainability. As the importance of accurate prediction cannot be understated, the nature of heat waves and the mechanisms that drive them must be fully understood for an adequate representation of the phenomenon in forecast models. Short-range weather predictions with Advanced Weather Research and Forecasting model at 3-km resolution, up to 72-h lead time, have been found accurate with statistical metrics of small mean absolute error and root-mean-square error and high index of agreement confirming the predictability of the heat wave evolution (Dodla *et al.,* 2017). IMD predicts heat waves based on synoptic analysis of various meteorological parameters and from the consensus guidance from various regional & global numerical prediction models like WRF, GFS, GEFS, NCUM, UMEPS, UM Regional, etc. run in the Ministry of Earth Sciences (MoES) and other international models available under the bilateral multi-institutional arrangement. The objective consensus is derived from the models utilising MME concepts which are further bias-corrected by comparing it with initial observations. Thereafter, a subjective consensus is developed among forecasters through the exchange of knowledge, experience, and expertise in video conferencing daily to modulate the above objective consensus forecast by taking into consideration regional and local variations and other features. In this way, an operational forecast is prepared by IMD. There has been a significant improvement in POD (probability of detection) during recent years, more than 95% during recent years (2020-2023) Fig.4.5.

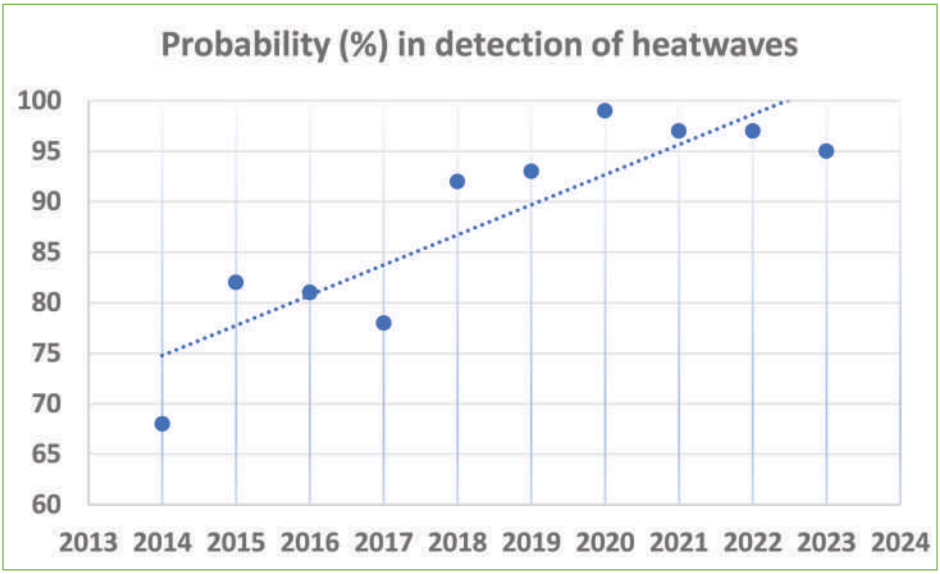


Fig. 4.5. Accuracy of heatwave warning by IMD

4.4. Heatwaves in future climate

Mazdiyasni *et al.* (2017) suggested that future climate warming will lead to a significant increase in heat-related mortality, especially in lower-latitude developing countries like India, where heat waves will be more frequent and the population is particularly vulnerable to these extreme temperatures. The study also shows that even a moderate increase in average temperatures can lead to a sharp rise in heat-related mortality and supports the efforts of governments and international organizations.

The study by Murari *et al.* (2015) using CMIP data suggests 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 21st century. Projections indicate that a sizable part of India will experience heat stress conditions in the future.

4.5. Indices for heatwave impact assessment

Index	Definition	HW attribute	Category	Areas of application	Reference
TXx	Monthly maximum of TX	Intensity	Extreme index (absolute, TX)	Agriculture and Energy	Alexander *et al.* (2006)
TR (tropical nights)	Annual count of days with TN > 20°C	Frequency	Extreme index (absolute, TN)	Health and agriculture	
SU (Summer days)	Annual count of days with TX > 25°C	Frequency	Extreme index (absolute, TX)	Health	
CDD (Cooling Degree Days)	Cumulative sum of cooling degree days (Temperature exceedances above certain base temperatures)	Accumulated intensity	Extreme index (absolute, TX, TN, TM)	Health and energy	Spinoni *et al.* (2015)
TX90P	Percentage of days with TX > 90th percentile	Frequency	Extreme index (percentile, TX)	Energy	Peterson *et al.*, (2001)
WSDI (Warm Spell Duration Index)	Annual count of days with at least six consecutive days with TX > 90th percentile	Frequency/ Duration	Extreme index (percentile, TX)	Health, Agriculture, Water and Energy	Alexander *et al.*, (2006)
HWMId (HW Magnitude Index daily)	Annual maximum HW magnitude, defined as cumulative normalized TX exceedances	Accumulated intensity	Event Index (TX)	Health	Russo *et al.* (2015)
EHT (heat excess factor)	Cumulative TM threshold exceedances weighted by an acclimatization factor	Accumulated intensity	Event Index (TM)	Health, Agriculture, Water and Energy	Perkins and Alexander (2013)
HI (Heat Index)	A measure of thermal discomfort	Intensity	Multivariate index	Health	Steadman (1979)
UTCI (Universal Thermal Climate Index)	An equivalent temperature of the human physiological response to the thermal environment	Intensity	Multivariate index	Health	Fiala *et al.* (2012)
Climatological Heatwave Days Index	A period of at least three consecutive days exceeding the 99th percentile of the daily maximum temperatures of the May to September season during a reference period				

5. Heatwave impacts: Agriculture and allied sectors

Temperature is a critical factor affecting plant growth. Each plant species has a suitable temperature range. Within this range, higher temperatures generally promote shoot growth, including leaf expansion, stem elongation, and thickening. However, temperatures above the optimal range suppress the growth. Therefore, heat waves, characterized by extended periods of extreme temperatures, exert a significantly greater impact than isolated extreme temperature events. These heat waves cause cascading effects across various sectors, including public health, ecosystems, agriculture, and the national economy (Rohini *et al.,* 2016). In India, heat waves typically occur from March to July (Ratnam *et al.,* 2016), with the highest frequency observed between April and June (Rohini *et al.,* 2016). Several researchers have reported that these events are critical for maintaining agricultural production (Lesk *et al.,* 2016). Heat waves can negatively affect crops through withering, dehydration, and heat stress, reducing yields and diminished quality (Lipiec *et al.,* 2013). Higher temperatures can reduce agricultural yields by slowing plant growth and impairing photosynthesis (Yamori *et al.,* 2012), disrupting the source-sink relationship for photosynthate assimilation (Johkan *et al.,* 2011). Most plants are susceptible to the effects of high temperatures, low precipitation, flooding, and sudden freezes during critical growth periods. Heat waves can exacerbate agricultural water stress, particularly in areas with limited water resources, leading to crop failure and financial losses for farmers (Mishra *et al.,* 2021). Additionally, they can increase the prevalence of pests and diseases in crops, leading to lower quality and yields (Pathak *et al.,* 2012).

5.1. Arable crops

Crop	Impact of heat waves	Source
Wheat	An increase in temperature resulted in yellowing and shriveling of grains, forced maturity, and yield reduction of up to 15-25%	Singh *et al.,* 2023
	In 2022, intense heat waves along with less rain through western disturbances affected wheat yields and decreased the estimated production from 111 million tons to 105 million tons.	Bal *et al.,* 2022
Green gram	Increase in whitefly infestation, poor vegetative growth, poor pod setting, and yield reduction of up to 20%	Bal *et al.,* 2022
Maize	Retarded growth, fall armyworm attack, and yield reduction of up to 18%	Bal *et al.,* 2022

Crop	Impact of heat waves	Source
Late sown wheat	Yield reduction up to 10-15%	Bal *et al.,* 2022
Chickpea	Yield reduction up to 19%	
Wheat	Decrease in yield by 4.9%, 4.1% and 3.5% over Punjab, Haryana and Uttar Pradesh	Chakraborty *et al.,* 2019
Mustard	Heat stress during reproductive stages led to flower abortion, reduced fertility, and poor seed development thereby negatively impacting yield	Pillai and Walia, 2024
Mustard	The rise in temperature by 1°C during the winter season reduced the yield by 450 kg/ha than normal and shortened the crop duration	Jain and Sandhu, 2018
Mustard	An increase in temperature by 1 °C reduced yield to the tune of 2.01 q/ha in Haryana	Kalra *et al.,* 2008
Barley	Decreased grain yield by 5.01, 2.71, 1.94, and 1.64 q/ha per degree rise in seasonal temperature in Haryana, Punjab, Rajasthan, and UP, respectively	Kalra *et al.,* 2008
Chickpea	Decreased grain yield by 3.01, 1.81, and 1.27 q/ha per degree rise in seasonal temperature in Haryana, Punjab, and Rajasthan, respectively	Kalra *et al.,* 2008

5.2. Horticultural crops

Crop	Impact of heat waves	Source
Tomato	Reduced starch and soluble sugar concentration in the leaves of tomato & yield attributes *viz,* number of fruits/ plants, fruit set %, average fruit weight (g), and yield per plant were found to be reduced	Vijayakumar *et al.,* 2021
	The number of fruits, fruit set percentage, and fruit weight per plant decreased with increased temperature	Harel *et al.,* 2014
	Temperatures higher than 35 °C reduced the fruit set and delayed the development of normal fruit colors	Sato *et al.,* 2006
	Reduction in yield by 40 to 50% in Bathinda and Sirsa districts of Punjab and Haryana, respectively	Bal *et al.,* 2022
	Reduction in tomato yield by 40% compared to normal situation in Kathua and Bandipora districts of Jammu and Kashmir	
Potato	Predicted about 10% yield reduction for the year 2050 for Eastern Indo-Gangetic Plain using MIROC HI.3.2 A1b and B1, PRECIS A1b, A2, B2 scenarios.	Kumar *et al.,* 2015

Crop	Impact of heat waves	Source
	An increase in temperature above 21 °C causes a sharp reduction in tuber yield and at 30 °C complete inhibition of tuber formation occurs	Haris *et al.,* 2015
Brinjal	Higher temperatures of 32-45 °C caused flower drop and poor fruit set	Baswana *et al.,* 2006
Okra	Stunted plant growth, early onset of reproductive phase, high infestation of white flies, wilting and scorching.	Bal *et al.,* 2022
Onion	Reduction in bulb size by 30% in Uttar Pradesh	
Mango	Malformation, flower, and fruit drops observed in chamba, kullu and Bilaspur districts of Himachal Pradesh	
Kinnow	Reduction in yield up to 23% in Bathinda and Faridkot districts	

5.3. Livestock and fisheries

Crop	Impact of heat waves	Source
Livestock	Increase in body temperature of livestock and milch animals by 0.5 to 3.5 °C	Bal *et al.,* 2022
	Reduction in milk yield up to 15% in Godda district of Jharkhand	
	Less availability of green fodder for milch animals and thereby reduction in milk yield up to 11%	
	The annual total milk loss due to thermal stress at the all-India level was 1.8 million tonnes or approximately 2% of the total milk production of the country amounting to a whopping Rs. 2661.62 crores per year	Upadhyay *et al.,* 2009
Poultry	During the initial two days of the heat wave, egg production in layers dropped by up to 10%. In the following days, the decrease stabilized at approximately 4-7%, depending on the ambient temperature.	Bal *et al.,* 2022
	Broiler chickens experienced a body weight loss of 500-600 g per bird compared to the standard 2 kg at day 35. During summer, reduced performance was linked to a significant drop in feed intake by about 15-20% in broilers and up to 35g per bird per day in layers resulting in egg weight reduction of 3-5g.	

5.4. Insect pests

Sporadic, extreme weather events, such as heat waves, can rapidly impact all sorts of living organisms, and their communities (Gillespie *et al.,* 2012; Sentis *et al.,* 2013). Insects are cold-blooded organisms (poikilotherms), they cannot regulate their body temperature to cope with the ambient conditions. Either they alter their physiology or metabolic activities or they must move away from those harsh conditions to a suitable place for survival. Hence heat waves exhibit a serious negative effect on insect pests and their natural enemies as they exceed their thermal optima required for their necessary physiological functions, activities, fecundity, and fitness. (Kuo *et al.,* 2006; Karl *et al.,* 2011; Zhang *et al.,* 2019).

In another way, the insect pests will survive under extreme heat wave conditions by adapting themselves to thermal stress or through migration. The heat wave creates ideal conditions for insect herbivores, despite initial short-term negative effects, they survive by increasing their thermal fitness and bounce back with long-term positive effects via changes in host plant physiology that lead to weaker defence mechanisms. One such example is aphid abundance on milkweed plants, particularly in the year following heat wave treatments (Cope *et al.,* 2023). In another study, the younger rapidly growing plants are thought to be more susceptible to heat waves and biotic stresses than later stage crops slow growing plants (Jentsch *et al.,* 2007). The insect pests with strong migratory ability move to newer localities. Insects accidentally introduced through human activities (movement of planting materials) will also get the chance to survive in newer regions with favourable weather conditions. The recently introduced major invasive pests in India viz., maize fall armyworm from African countries, spiraling whiteflies in plantation crops, and chilli black thrips from Thailand fall under such category where the subtropical climatic conditions of India favoring these invasive pests' survival, establishment, and further spread to new areas and causing significant economic damage to the various crops of agriculture and horticulture importance (Timmanna *et al.,* 2022).

6. Action mechanism of heatwaves on agriculture and allied sectors

Through several mechanisms, heat waves exert multifaceted impacts on agricultural, horticultural, livestock, and fisheries production. Elevated temperatures during heat waves induce crop stress, reduce photosynthesis, and water uptake, and increase susceptibility to pests and diseases, consequently lowering crop yields and quality (Johkan *et al.,* 2011). Livestock face heat stress, resulting in reduced feed intake, milk production, and heat-related illness, necessitating the provision of adequate shade, ventilation, and water access (Das *et al.,* 2016).

6.1. Crops

Component	Mechanism of action	Source
Rice	Long exposure to high temperatures during flowering may cause sterility in rice plants by affecting dehiscence, pollination, and pollen germination	Jagadish *et al.,* 2010
	High temperatures affect rice production by shortening the grain filling duration, leading to reduced yields	Jagadish *et al.,* 2011
Wheat	High temperature at pre-anthesis retards pollen viability, seed formation, and embryo development. The post-anthesis high temperature declines the starch granules accumulation, stem reserve carbohydrates, and translocation of photosynthates into grains. High temperature above 40 °C inhibits photosynthesis by damaging the photosystem-II, the electron transport chain, and photosystem-I.	Khan *et al.,* 2021
Mustard	High temperatures disrupt physiological, morphological, and biochemical mechanisms essential for plant growth and development. Heat stress detrimentally affects various aspects of mustard physiology by altering chlorophyll content, and osmotic water potential to impair photosynthesis and reduce seed oil accumulation. Heat stress during reproductive stages leads to flower abortion, reduced fertility, and poor seed development, significantly impacting yield potential	Pillai and Walia, 2024
Chickpea	Temperatures ≥35°C affected male reproductive tissues (pollen and anther) function and pod set. Both anther and pollen showed structural abnormalities such as changes in anther locule number, anther epidermis wall thickening, and pollen sterility	Devasirvatham *et al.,* 2013

Phenological shifts caused by heat waves disrupt pollination processes in horticulture, impacting fruit sets and yields. Additionally, heat waves exacerbate pest and disease outbreaks, accelerating their reproduction and leading to higher infestation rates and crop damage (Sandra *et al.,* 2021). Fisheries and aquaculture suffer from altered aquatic ecosystems, affecting species distribution, abundance, and behavior, alongside economic and social repercussions like financial losses and food shortages (Maulu *et al.,* 2021).

6.2. Horticultural crops

Heat waves impact horticultural crops through various mechanisms, including thermal stress that damages cellular structures and denatures proteins, increased transpiration leading to water stress, and reduced photosynthesis due to enzyme inactivation and chlorophyll degradation (Mishra *et al.,* 2023). Elevated temperatures also raise respiration rates, consuming more carbohydrates and energy, thus hindering growth (Hatfield and Prueger, 2015). Phenological disruptions affect flowering and fruit sets, resulting in poor pollination and fruit quality (Roussos, 2024). Additionally, heat stress impairs nutrient uptake and alters soil microbiomes, creating nutrient imbalances (Giri *et al.,* 2017).

Crop	Mechanism of action	Source
Tomato	Higher temperature during the flowering stage leads to more transpiration thereby reduction in yield due to impaired pollen, another development, and reduced pollen viability.	Sato *et al.,* 2006
	Limits nutrient availability, hampers photosynthesis, disrupts reproduction, denatures proteins, upsets signaling pathways, and damages cell membranes thereby reducing yield.	Khan *et al.,* 2024
	Overproduction of reactive oxygen species like H_2O_2, OH, superoxide, and singlet oxygen in response to heat stress has proven to disturb cellular homeostasis in tomato plants	Suzuki *et al.,* 2012
Cucumber	Production of protochlorophyllide, an intermediate in the biosynthetic pathway of chlorophyll, was repressed by 70% at high temperatures (42 °C) compared to control (25 °C), which reduced chlorophyll manufacture to 60% in seedlings	Kumar *et al.,* 1998
Okra	Heat stress has a significant impact on the morphological, physiological, and proteomic processes of okra plants, reducing photosynthetic rate, damaging plasma membrane structure, and hastening the aging process	El-Shaieny *et al.,* 2022
Potato	Moderately elevated temperatures of 25 °C and 28 °C cause a decrease in the rate of sprout elongation	Firman *et al.,* 1992
	Temperatures ≥ 28 °C partly or entirely suppress the stolon formation	Pantelic, 2019
Lemon	An increase in temperature led to a high incidence of insect pests, sunburn, and less fruit set	Bal *et al.,* 2022

6.3. Livestock and Fisheries

Heat waves significantly affect animals, including fisheries, through various physiological, behavioral, and ecological mechanisms (Christensen *et al.,* 2021). Animals may exhibit altered behavior to cope with heat, such as seeking shade or water which can affect feeding and reproductive activities. Increased metabolic rates in response to heat stress raise energy demands, potentially leading to energy imbalances and reduced growth (Becker *et al.,* 2020). In aquatic environments, higher temperatures can decrease dissolved oxygen levels (Yanes *et al.,* 2020), causing hypoxia and stressing aquatic species, while also promoting harmful algal blooms that further degrade water quality (Ali *et al.,* 2022). Heat stress can impair immune function, increasing susceptibility to diseases and parasites. In fisheries, the altered distribution of species as they seek cooler waters can disrupt ecosystems and impact local fisheries' productivity and sustainability (Barange *et al.,* 2018). Additionally, heat waves can lead to increased water evaporation, reducing habitat availability and exacerbating competition for resources.

Crop	Mechanism of action	Source
Livestock	Reduction in productivity, illness, metabolic alterations, oxidative stress, immune suppression, and even death	Lacetera, 2018
	Heat waves can promote the reproduction and growth of disease-transmitting insects and mycotoxin-producing fungi in stored grain. Consuming such contaminated grain can weaken livestock's immune systems, making them more susceptible to infections.	Frank, 1991; Bernabucci *et al.,* 2011
	An increase in temperature leads to an increase in body surface temperature, respiration rate (RR), heart rate, and rectal temperature which in turn affects feed intake, production and reproductive efficiency of animals	Kadokawa *et al.,* 2012
	In lactating cows, feed intake starts to decline at 25-26°C and drops sharply above 30°C, with a 40% reduction at 40°C. Dairy goats' intake decreases by 22-35%, and buffalo heifers by 8-10% at 40°C. This reduction helps decrease heat production but leads to negative energy balance, resulting in weight and body condition loss.	Rhoads *et al.,* 2013; Hamzaoui *et al.,* 2012; Hooda and Singh, 2010; Kadzere *et al.,* 2002; Lacetera *et al.,* 1996
	Reduced acetate production whereas propionate and butyrate production increased as rumen function altered. As a response animal consumed less roughages, changes rumen microbial population and pH from 5.82 to 6.03.	Nonaka *et al.,* 2008 Hall, 2009

Crop	Mechanism of action	Source
Livestock	Affects health by lowering saliva production, variation in digestion patterns, and decreasing dry matter intake (DMI)	Nardone *et al.*, 2010 Soriani *et al.*, 2013
Poultry	As temperatures rise slightly, poultry reduces feed consumption, which can maintain production efficiency if nutrient intake is adequate, though egg size and shell quality may decline. With moderate heat stress, a more significant drop in feed consumption occurs, resulting in lower weight gains and deteriorating egg quality, necessitating cooling procedures. Under severe heat stress, the risk of heat prostration increases, especially in heavier and high-production birds, requiring emergency cooling measures to ensure survival, as feed consumption and egg production drastically decrease, and water intake rises significantly.	Pragya *et al.*, 2016
Fisheries	Heat stress in fish triggers a temperature compensation mechanism, leading to increased metabolic rates and energy expenditure, which depletes energy reserves like proteins, glycogen, and lipids.	Liu *et al.*, 2023

7. Adaptation strategies to minimize the impact of heat stress

Extreme heat events are a threat to human health, productivity, and food supply, so understanding their drivers is critical to adaptation and resilience. Intergovernmental Panel on Climate Change (IPCC) predicted that temperatures in India are likely to rise between 3-4 °C by the end of the 21st century. These predictions, combined with the regression estimates showing the negative impact of the rise in temperature on crops, imply that in the absence of any adaptation by farmers, farm incomes will be lower by around 12% on average in the coming years, and un-irrigated areas will be the most severely affected, with potential losses amounting to 18% of annual revenue.

To minimize the impact of heat stress on agricultural, horticultural crops, livestock, and fisheries production, several adaptation strategies can be implemented. For agricultural and horticultural crops, utilizing heat-tolerant crop varieties and adjusting planting schedules to avoid peak heat periods can help mitigate heat stress. Improved soil moisture management techniques such as mulching, drip irrigation, and conservation tillage can conserve water and maintain soil moisture levels and canopy temperatures during heat waves.

Employing shade structures, row covers or high tunnels can protect sensitive crops. Livestock management practices can include providing ample shade, ventilation, and access to clean water sources as well as adjusting feeding schedules to cooler times of the day. Installing fans, misters or evaporative cooling systems in livestock housing facilities can also help alleviate heat stress (Chauhan *et al.,* 2023). In fisheries and aquaculture, implementing sustainable management practices to maintain water quality, such as reducing nutrient runoff and managing fishing pressure, can enhance resilience to heat stress. Additionally, diversifying aquaculture species to include heat-tolerant species and implementing monitoring programs to track temperature fluctuations and anticipate heat wave impacts can help mitigate losses in fisheries and aquaculture production (Adhikari *et al.,* 2018).

7.1. Crops

7.1.1. Crop varieties tolerant to heat stress

Varieties	State	Source
Wheat		
Lok-1, Vidisha, GW-173, Arpa	Chhattisgarh	Maheswari *et al.,* 2019
RSP 561	Jammu & Kashmir	
MP 4010, RVW 4106	Madhya Pradesh	
PBW 658, PBW 590	Punjab	
RAJ 3777, RAJ 3765, RAJ 3077, RAJ 3777, RAJ 3765, RAJ 3077, RAJ 4037, RAJ 4083, RAJ-3777, Raj3765, MP-3288, HI-1500, RAJ-4037, Raj-4037, Raj4083, RAJ 3765, RAJ 3077	Rajasthan	
NIAW 34	Karnataka	
WH 1124	Punjab, Haryana, Delhi, Rajasthan, Western Uttar Pradesh and plains of Jammu and Kashmir, Himachal Pradesh, Uttarakhand	
DBW 107	Eastern Uttar Pradesh, Bihar, Jharkhand, Odisha, West Bengal, Assam and plains of North Eastern States	

Varieties	State	Source
Chhattisgarh Gehun 4 (CG 1015)	Chhattisgarh	Maheswari *et al.,* 2019
DBW 173	Punjab, Haryana, Delhi, Rajasthan Western Uttar Jammu and Kathua district of Jammu & Kashmir, Paonta Valley, Himachal Pradesh and Tarai region of Uttarakhand	
Pusa Wheat 1612 (HI 1612)	Eastern Uttar Pradesh, Bihar, Jharkhand, West Bengal (excluding hills), Odisha, Assam and plains of other North Eastern States	
Pusa Wheat 8777 (HI 8777)	Maharashtra and Karnataka	
AAI-W9 (SHIATS-W9), AAI-W10 (SHIATS-W1 0)	Uttar Pradesh	
DBW296	Punjab, Haryana, Delhi, Rajasthan (except Kota and Udaipur division) and Western Uttar Pradesh (except Jhansi division), parts of Jammu and Kashmir (Jammu and Kathua district), parts of Himachal Pradesh (Una district and Paonta valley), and Uttarakhand (Tarai region)	ICAR, Annual Report (2022-2023)
MP1358	Maharashtra, Karnataka, and Plains of Tamil Nadu	
Chickpea		
JG-14, Indira Chana, JG-315, JG-11	Chhattisgarh	
JAKI 9218, JG 6	Madhya Pradesh	
RSG 888, GNG 663	Rajasthan	
Pant G 186	Uttarakhand	
CUMS-17 (Suprava)	West Bengal	
Pigeonpea		
Bahar	Uttar Pradesh, Bihar	Boraiah *et al.,* 2021
UPAS-120	NWPZ and NEPZ	
Mustard		
Urvashi, RGN13, Pusa Mustard 25, RGN 13	Rajasthan	Maheswari *et al.,* 2019
Pant Rai 19, Pant Rai 20	Uttarakhand	
NRCDR601, RGN 229, RGN 236, RGB 298, Divya-33	Delhi, Haryana, J&K, Punjab, Rajasthan	

Varieties	State	Source
RH 0119	Haryana	Maheswari *et al.*, 2019
Pusa Mustard 25	Haryana, Punjab, Rajasthan, Delhi, Western UP, NEH Region	
Pusa Mustard 26	Haryana, Punjab, Rajasthan, Delhi, Western UP, NEH Region	Boraiah *et al.*, 2021
Pusa Mustard 27	MP, Kota Region of Rajasthan, UP, Uttrakhand, NEH Region	Maheswari *et al.*, 2019
Pusa Mustard 28	Haryana, Punjab, Rajasthan, Delhi, Western UP, NEH Region	
RGN-298	Rajasthan, Punjab, Haryana, Delhi, Jammu & Kashmir and Uttar Pradesh	
Pusa Tarak	Delhi	Boraiah *et al.*, 2021
KMR 16-2 (Surekha)	Uttar Pradesh	ICAR, Annual Report (2022-2023)

Heat stress tolerant wheat varieties developed by various ICAR institutions

Varieties	Developed by	Source
HD3059 (Pusa Pachheti), HD3271 (Pusa Wheat 3271), HD3298, HD3226, HD2967, HD2985, HD3118, HD3249, HD2967, HD3271, HD3407, HD2932, HD3090,	IARI, New Delhi	Mamrutha *et al.*, 2024
DBW71, DBW90, DBW173, DBW327 (Karan Shivani), DBW187, DBW303, DBW107, DBW316, DBW187, DBW187, DDW48, DBW168	IIWBR, Karnal	
WH1124, WH1270	CCSHAU, Hisar	Mamrutha *et al.*, 2024
PBW752, PBW771, PBW757, PBW833	PAU, Ludhiana	
DPW621-50 (PBW621 & DBW50), DBW303	IIWBR, Karnal/ PAU, Ludhiana	
JKW-261 (Birsa Gehun-4)	BAU, Ranchi	
HI1621 (Pusa Wheat 1621), HI1563, HI1621, HI1634, HI1633	IARI, RS Indore	
MP3336	JNKVV, Jabalpur	

RAJ4238	MPUAT, Durgapur	
CG1029 (Kanishka)	IGKVV, Bilaspur	
GW513 (Gujarat Wheat 513)	SDAU, Vijapur	
NIDW1149	ARS, Niphad	
AKAW4627	PDKV, Akola	

7.1.2. Adaptation strategies for crops to minimize the impact of heat waves

Component	Adaptation strategy	Source
Mustard	Agronomic strategies, such as nutrient management (balanced fertilization) with a focus on nitrogen, phosphorus and potassium based on soil tests and microbial inoculation with commercial formulations like Azospirillum and Bacillus strains can mitigate heat stress and enhance plant resilience.	Pillai and Walia, 2024
Wheat	Zero-till sowing of wheat immediately after rice harvest for timely sowing of wheat, integration of short-duration pulses or oilseeds to diversify and reduce the wheat cycle's exposure to high temperatures and application of light and frequent irrigation during the reproductive stage to maintain soil moisture and maintain heat stress, is quite effective in countering the adverse effects of higher temperature in Northern India	Singh *et al.,* 2022
Wheat	Genotypes that can maintain a higher accumulation of proline, glycine betaine, expression of heat shock proteins, stay green and antioxidant enzymes activity viz., catalase, peroxidase, superoxide dismutase, and glutathione reductase can tolerate high temperature efficiently through sustaining cellular physiology. The pre-anthesis acclimation with heat treatment, inorganic fertilizer such as nitrogen, potassium nitrate and potassium chloride, mulches with rice husk, early sowing, presoaking @ 6.6 mM solution of thiourea, foliar application of 50 ppm dithiothreitol, 10 mg per kg of silicon at heading and zinc ameliorate the crop against the high temperature	Khan *et al.,* 2021
Rice-wheat	Residue management of rice by various machines like super straw management system or happy seeder enables timely sowing of wheat. Short-duration rice varieties like PR 126 or Pusa Basmati 1509 which mature 10 days earlier, facilitating timely wheat planting.	Bal *et al.,* 2022
	Spray of KNO_3 @ 0.5% at boot leaf and anthesis stages can minimize yield loss	
Rice	Modification of agronomic practices i.e., adjusting sowing time to early June for optimal flowering periods, avoiding peak heat, or selecting early morning flowering cultivars like IR 64 to mitigate heat stress during flowering. Induction of acclimation by using growth regulators like gibberellic acid at 50 ppm during the panicle initiation stage and fertilizers like silica (10 mg kg^{-1}) and zinc as foliar sprays at the heading stage to enhance heat tolerance.	Khan *et al.,* 2019

7.2. Horticulture crops

7.2.1. Horticultural crop varieties tolerant to heat stress

Varieties	State	Source
Bottle gourd		
Thar Samridhi	Rajasthan	Boraiah *et al.,* 2021
Pusa Santushti	Delhi, Punjab, Uttarakhand, Bihar, Madhya Pradesh, Maharashtra	
Brinjal		
Kashi Sandesh, Kashi Taru	Uttar Pradesh, Bihar, Jharkhand	Maheswari *et al.,* 2019
HLB-25	Haryana	Baswana *et al.,* 2006
HLB-12	Haryana	Boraiah *et al.,* 2021
Chilli		
Kashi Abha	Uttar Pradesh	Boraiah *et al.,* 2021
Cauliflower		
Sabour Agrim	Bihar	Maheswari *et al.,* 2019
Carrot		
Pusa Meghali	Madhya Pradesh, Maharashtra	Boraiah *et al.,* 2021
Pusa Vrishti	North Indian Plains	
Clusterbean		
RGC-197, RGC-936	Rajasthan	Maheswari *et al.,* 2019
Cowpea		
Kashi Kanchan, Kashi Nidhi	UP, Bihar, Jharkhand, Odisha, M.P.	Maheswari *et al.,* 2019
Arka Garima	Madhya Pradesh, Maharashtra, Karnataka, Tamil Nadu, Kerala	Boraiah *et al.,* 2021
Okra		
Kashi Pragati, Kashi Kranti	Uttar Pradesh, Bihar, Jharkhand, Chhattisgarh	Maheswari *et al.,* 2019; Boraiah *et al.,* 2021
Onion		
NP53, Raseedpura local	Rajasthan	Maheswari *et al.,* 2019
Pea		
Matar Ageta 6	Punjab	
Azad Pea G 10	Rajasthan	

Varieties	State	Source
Tomato		
Arka Meghali, Arka Vikas	Chhattisgarh	Maheswari *et al.,* 2019
Varkha Bahar-1, Varkha Bahar-2	Punjab	
VRNTH-18283, RNTH-19095	Uttar Pradesh	ICAR, Annual Report (2022-2023)
Potato		
Kufri kiran, Kufri lima Kufri surya,	North Indian Plains and plateau regions	Gupta *et al.,* 2023
Kufri Lauvkar		Boraiah *et al.,* 2021
Water melon		
Durgapura, Madhu Durgapurakesher, & local	Rajasthan	Maheswari *et al.,* 2019
Radish		
Pusa Chetaki	All India	Boraiah *et al.,* 2021
Kashi Rituraj	Uttar Pradesh	ICAR, Annual Report (2022-2023)
Spinach		
VRPLK-2	Uttar Pradesh	ICAR, Annual Report (2022-2023)

7.2.2. Adaptation strategies to minimize the impact of heat waves on horticultural crops

	Adaptation strategy	Source
Potato	Planting of crops within 1st fortnight of November in West Bengal. Varying sprout length of seed tubers (sprout length should be kept 15 mm instead of 5 mm)	Banerjee *et al.,* 2022
	Temperature-dependent planting time is a major factor in determining growth and yield in the major potato-growing regions of the Indo-Gangetic Plains	Haris *et al.,* 2015
Tomato	Application of gibberellic acid @ 75 mg/l for reducing heat stress and to improve morphological, physiological, and biochemical characteristics	Guo *et al.,* 2022
	Pretreating seeds with low concentrations of inorganic salts such as Potassium nitrate, applying osmoprotectants and signaling molecules through foliar sprays, and subjecting plants to preconditioning measures	John and Stephen, 2024

	Adaptation strategy	Source
Okra	Application of salicylic acid (1.5 mM) through foliar spraying	Khalid *et al.*, 2023
	Make 2-3 sprays of Lambda Cyhalothrin 2.5% EC @ 1ml/lit or a mixture of Acetamiprid (0.5 g) + Pyriproxyfen (1 ml/ lit) for control of Jassids and white flies	Bal *et al.,* 2022
Cucurbits	Soil moisture management, application of organic mulch and maize as border crop. Use a shading net of 50% (1.5-2.0 m above the field surface) to reduce the intensity of solar radiation.	
Orchards	Mulching is beneficial for retaining soil moisture over extended periods. Apply mulch using paddy straw or organic/inorganic materials readily found in the local area. Additionally, employing black polythene material is crucial to curb excessive evaporation.	
	It is advised to use a foliar spray of 2-4% Kaolin, adjusting the concentration based on the severity of the condition, to minimize transpiration. Additionally, two foliar applications of Potassium nitrate at a concentration of 1-1.5% can be administered at 15-day intervals throughout April and May.	

7.3. Animal systems

To minimize the impact of heat waves on animal systems, including livestock and fisheries, a combination of adaptive strategies is essential. For livestock, providing shade and ventilated shelters, ensuring a constant supply of cool water, adjusting diets to reduce metabolic heat, and implementing ventilation and cooling systems are critical. Selective breeding for heat tolerance and scheduling activities during cooler times also help mitigate heat stress (Baidya and Sethy, 2023). In fisheries, managing habitats to create cooler microclimates, enhancing water quality through aeration and pollutant control, and selectively breeding heat-tolerant fish are effective measures. Adjusting harvest practices to avoid extreme heat and implementing real-time monitoring systems can further protect fish populations (Adhikari *et al.,*2018).

7.3.1. Animal breeds tolerant to heat stress

	Adaptation strategy	Source
Cattle	Tharparkar is the best dairy breed tolerant to heat stress adapted to the Indian states of Punjab and Haryana.	Sodhi *et al.*, 2006
	Vrindavani	Khan *et al.*, 2021
Goat	Sirohi, Jakhrana, Jamunapari, Beetal, Gohilwadi, Zalawadi, Kutchi for hot arid, and semi-arid tropical environment	Ramachandran and Sejian, 2022
Sheep	Magra, Marwari, Chokla	Singh *et al.*, 2016
Poultry	Caribo Mrityunjay for hot and dry regions of India	ICAR-CARI
	Caribo Tropicana for hot and humid regions of India	ICAR-CARI
Fish	Genetically Improved Farmed Tilapia (GIFT), Pangasius	Boraiah *et al.*, 2021

7.3.2. Adaptation strategies against heat waves to minimize the impact on livestock and fisheries

	Adaptation strategy	Source
Livestock	Modification of the microenvironment to enhance the heat dissipation mechanism to relieve heat stress is one of the most important measures to be considered in a hot environment. Cooling ponds and sprinklers can also be used to cool the environment.	Das *et al.*, 2016; Kadokawa *et al.*, 2012
	The use of foggers for misting will reduce the temperatures and contribute to Enhancing milk production.	Wolfenson, 2009
	Shading is one of the cheapest ways to modify an animal's environment during hot weather. For outdoor animals, the provision of shade (natural or artificial) is one of the simplest and most cost-effective methods to minimize heat effects.	Das *et al.*, 2016
Poultry	Use effective ventilation, apply reflective roof coatings, and ensure proper siting and construction materials. Natural ventilation works best for houses up to 12 meters wide, with adjustable side-wall curtains for airflow control.	Pragya *et al.*, 2016
	To manage heat stress, foggers should be installed to inject fine water particles into the air, cooling it as the water vaporizes. They should operate intermittently to avoid excessive humidity, have a water flow rate of 50-100 gallons per hour, and use at least 100 psi pressure for a fine mist, ensuring effective cooling without wet litter.	

	Adaptation strategy	Source
Poultry	Reduce stocking density in hot weather to provide more floor space per bird.	Pragya *et al.,* 2016
	Providing Ascorbic acid (Vit C) @ 400 mg/ L+ Electrolytes + Acetyl salicylic acid (Disprin 1 tablet/5 L) + Sodium bicarbonate 1g/Litre through drinking water	
	During the summer season, incorporating ashwagandha extract at 0.75%, turmeric extract at 0.1%, and amla powder at 1.0% into the diet enhanced bird performance by mitigating the effects of heat stress.	Bal *et al.,* 2022
Fisheries	Pumping fresh water to cool down the temperature of fish ponds. Application of oxygen tablets during higher temperature	Adhikari *et al.,* 2018
	Thinning of the growing stock should be done @ 10-15 kg/m^3 compared to 15-20 kg/ m^3 under normal conditions. Reduce the quantity of feed by 10-20% compared to normal conditions.	Bal *et al.,* 2022

8. Heatwaves and Farmers

8.1. Heatwave -farmers' health and comfort factor

Heat waves are considered silent killers because of their direct impact on human health (Heo *et al.,* 2019). Heat waves have immense impacts on human health, causing heat cramps, heat exhaustion, heat stress, and heat stroke (Oldenborgh *et al.,* 2018) and very severe heat waves even lead to death (Steffen *et al.,* 2014). Children and the elderly are particularly affected, but also people who already suffer from illnesses such as heart and respiratory diseases, kidney diseases, and psychiatric disorders (Nitschke *et al.,* 2007; Hansen et al., 2008; Wilker *et al.,* 2012; Steffen *et al.,* 2014).

8.2. Advisories for farmers to minimize the impact

Generalized forecasts have, however, limited use in farming. Weather information for agricultural operations will be a tailored production that can be effectively used in crop planning and its management. A comprehensive weather-based farm advisory is an interpretation of how the weather parameters of the present and in the future will affect crops, livestock, and farm operations and suggests actions to be taken. To make the agromet advisory services a more successful and continuous process, it should be supported with an agrometeorological database, crop conditions, real-time weather information, research results on crop-weather relationships, skilled manpower in multi-disciplinary resources, and user interface.

Heatwave is a major global health concern as positive temperature extremes increase human mortality and decrease workplace productivity (Goodman *et al.,* 2018). Many countries including India, have experienced record-breaking heatwaves in recent years, which may have a significant effect on farmers' health or health information-seeking behaviours, especially heatstroke, urological diseases, and mental health but is yet to be examined. Climate change is rapid, widespread, and irreversible, alerted the Intergovernmental Panel on Climate Change (IPCC) in its sixth assessment report. With global warming, such extreme events, especially the heatwaves, emerge stronger and more frequently over most of the world (Dong *et al.,* 2023). When extreme events including heat waves are set to increase in severity and frequency due to climate change, the poor farmers are going to suffer the most. Heat acclimatization is an important factor, but it has its limits and there is individual variability. The magnitude of acclimatization depends on the intensity, duration, and frequency of physical activity in the heat and environmental conditions.

- Avoid going out in the sun, especially between 12.00 noon and 3.00 pm
- Drink sufficient water as often as possible, even if not thirsty
- Wear lightweight, light-coloured, loose, and porous cotton clothes. Use an umbrella/hat, shoes, or chappals while going out in the sun
- Avoid strenuous activities when the outside temperature is high. Avoid working outside between 12 noon and 3 pm
- While traveling, carry water with you
- Avoid alcohol, tea, coffee, and carbonated soft drinks, which dehydrate the body
- Avoid high-protein food and do not eat stale food
- If you work outside, use a hat or an umbrella, and also use a damp cloth on your head, neck, face, and limbs
- Do not leave children or pets in parked vehicles
- If you feel faint or ill, see a doctor immediately
- Use ORS, homemade drinks like lassi, torani (rice water), lemon water, buttermilk, etc. which helps to rehydrate the body
- Keep animals in the shade and give them plenty of water to drink
- Keep your home cool, use curtains, shutters, or sunshades and open windows at night
- Use fans, and damp clothing, and take a bath in cold water frequently

(Source: https://www.ndma.gov.in/Natural-Hazards/Heat-Wave/DosDonts#:~:text=Avoid%20 alcohol%2C%20tea%2C%20coffee%20and,head%2C%20nec k%2C%20face%20and%20limbs)

9. Heatwaves: Plans, Policies & Linkages

9.1. Heatwave linked to the drought manual

The Drought Manual of Government of India (2020) describes indicators to be considered for monitoring the drought and the procedure for declaring drought. The indicators are categorized into mandatory indicators (rainfall deviation, dry spell, standardized precipitation index) and impact indicators related to agriculture, vegetation indices (remote sensing), soil moisture, and hydrology. The document also details a procedure for states to declare drought. As seen from the manual, the predominant factors for drought include rainfall, its derivate parameters, and the phenomena influenced by rainfall, including soil moisture, stream flows, reservoir levels, and groundwater recharge.

Though drought declaration was considered for Kharif season for many years, the revised provision for rabi season also considers the northeast monsoon's predominant influence in different states. The combined effect of drought, insufficient rain or lack of rain, and heat waves due to temperature increase is considered for management purposes.

Often, the dry spell coincides with an increase in temperature during both the kharif and rabi seasons. In the case of heat waves, the definition, as per IMD, considers deviation from maximum temperature to an extent of 5-6 degrees. During a dry spell i.e., a rainless period between two events of rain, temperatures can increase and are likely to affect crop growth and productivity in association with dry spells in both seasons. Further, during summer months, i.e. March to May, the horticulture systems and summer crops might get exposed to normal high temperatures and also to heat waves. The effect of high normal temperatures and heat waves is not considered in the drought manual. Similarly, the effect of concurrent long dry spells and heat waves for other associated agriculture systems including livestock, poultry, etc. are also not part of the manual.

Though the definition of a heat wave is broadly defined to caution human beings, the same definition is used for the agriculture sector with the same temperature thresholds. Heatwave continuously occurs if the deviation from the average maximum temperature persists for more than one day.

To include the heatwave in the drought manual, the following should be taken into consideration

I. Enhancing the data collection on temperature at finer resolution and to match the rainfall measuring stations. Priority is to be given to rainfed areas.

II. A system to be put in place for data collection and analysis through software that can identify the areas where heat waves are happening.

III. Heatwaves can also be considered as one of the impact indicators along with other indicators already defined

IV. Whenever the duration of a heatwave is more than 3 days, the affected area can be considered heat wave impacted areas

V. Heat wave-impacted areas are also to be considered for crop-cutting experiments for deciding the support through NDRF/SDRF.

VI. The drought manual can further include drought and heatwave effects on horticulture and summer crops.

VII. Though some information is available (Table 10.1) on temperature thresholds for different crop growth stages for various crops, data gaps need to be bridged through systematic research efforts. Till such threshold temperature data is available, a uniform threshold value for each crop including horticulture crops and each season can be specified which could be used as a reference for heatwave quantification and monitoring rather than using the IMD definition.

VIII. The heatwave definition of IMD, covering the increase in temperature over maximum temperature for heatwave quantification, falls short of heatwave impacts for the agriculture sector. An increase in minimum temperature over normal minimum temperatures, also a more probable scenario under climate change, needs to be accounted for quantification of heat waves in the agriculture sector. Knowledge gaps in this regard are to be filled up through appropriate research in NARES.

Though the density of temperature data collection centers is not as intensive as it is for rainfall measurement considering the enhanced network compared to earlier years, temperature measurements thus monitoring of heat waves can be considered.

Instead of using the definition of heat wave as given by IMD, deviation from optimal temperatures (both minimum and maximum) for different crop growth seasons for various needs to be identified. A separate manual may not be considered and heatwave management can be included in the drought manual itself as an additional chapter. This view is expressed because temperatures also increase during rainless periods or dry spells and can be best addressed by addressing both. Further, some of the adaptation measures might be the same for both drought and heatwave. It is also observed that there is a substantial increase in the frequency of concurrent meteorological droughts and heat waves across the whole of India. Statistically significant trends in the spatial extent of droughts are observed in Central northeast India and west central India. However, the spatial extent affected by concurrent droughts and heat waves is increasing across the whole of India (Sharma and Mujumdar (2017)).

Table 10.1 Temperature-related stresses for field and horticultural crops

Crop name	Stage of crop growth	Threshold temperature
Groundnut Summer	Germination	< 17 °C
	Vegetative	> 35 °C
	Pegging	> 30 °C
	Pod development	> 34 °C
Sesame summer	Germination	< 15 °C (not suitable)
	Growth and develop.	> 30 °C
	Flower dropping and pollination	> 35 °C
Pearl millet Summer	Germination	< 18 °C
	Crop growth	> 33 °C
Wheat	Germination	> 25 °C
	Anthesis	> 22 °C
	Milk	> 26 °C
	Grain filling	> 30 °C (not suitable)
	Dough stage	7-18 °C (suitable for 5 to 15 days)
Chickpea	Germination	> 24 °C
	Flowering	> 30 °C
	Pod development	> 30 °C
	Seed development	> 30 °C
Cumin	Germination	> 22 °C
Garlic	Bulb development	> 25 °C
Onion	Bulb development	> 32 °C

Crop name	Stage of crop growth	Threshold temperature
Tomato	Flowering	> 32 °C
	Fruit setting	> 35 °C
Cucurbits	Whole crop period	> 25 °C
Mango	Flowering & fruit setting	< 15 °C Night & > 25 °C Day during 5 days
	Initial fruit development	> 35 °C with higher day-night fluctuation during the week or more
	Maturity stage	35-40 °C during a week or more causing sun burning mostly on the western side of fruits

9.2. Heatwave from a contingency plan perspective

Mitigation measures for heatwaves are already covered in contingency plans for crops, livestock, poultry, and fisheries sectors, wherever applicable in each of the DACP. Indicative measures are given below. For field crops, temperature thresholds for a few crops and for their growth stages are standardized and mitigation measures are suggested in a few places. For sectors of livestock etc., measures to be taken before the event, during, and after the event are prescribed.

Contingency measures for heat stress in rabi crop in Gujarat

Crop name	Stage of crop growth	Suggested management practices
Groundnut Summer	Germination	If the temperature is below 17 °C • Delay sowing. • Use organic mulch. • Delay second irrigation after sowing. • In case of line sowing harrowing to be followed to loosen the soil surface.
	Vegetative	Sprinkler and drip irrigation
	Pegging	Sprinkler and drip irrigation
	Pod development	Sprinkler or drip irrigation an alternate day
Sesame summer	Germination	Delay sowing.
	Growth and development	Light and frequent irrigation.
	Flower dropping and pollination	Light and frequent irrigation

Crop name	Stage of crop growth	Suggested management practices
Pearl millet Summer	Germination	Delay sowing (2nd to 3rd week of Feb.)
	Crop growth	Light and frequent irrigation
Wheat	Germination	Delay sowing up to optimum temp (20-25 °C)
	Anthesis	Light and frequent irrigation
	Milk	Light and frequent irrigation
	Grain filling	Light and frequent irrigation Use early sowing variety Lok-1 and prefer early maturing variety GW-173 and GW-11 in late sowing to avoid high temp.
	Dough stage	Light and frequent irrigation, if temp. greater than 18 °C
Chickpea	Germination	Delay sowing to get optimum temp (15-20 °C)
	Flowering	Give irrigation External application of ABA* can protect plants against heat stress
	Pod development	Give irrigation immediately External application of ABA* can protect plants against heat stress
	Seed development	Give irrigation immediately External application of ABA* can protect plants against heat stress
Cumin	Germination	Light and frequent irrigation Delay sowing
Garlic	Bulb development	Drip irrigation on an alternate day Frequent light irrigation
Onion	Bulb development	Drip irrigation on an alternate day Light and frequent irrigation
Tomato	Flowering	Use of mulch and irrigate the crop with mini/micro-sprinkler
	Fruit setting	Use of mulch and irrigate the crop with sprinkler
Cucurbits	Whole crop period	Drip irrigation Use of straw/ silver plastic mulch

Crop name	Stage of crop growth	Suggested management practices
Mango	Flowering & fruit setting	Irrigation during low or high temperatures. Mulching during low or high temperatures. Shelter belts/ Windbreaks
	Initial fruit development	Nutrients & irrigation. ***Spray NAA 20 ppm + 2% urea Mulching, Shelter belts/Windbreaks
	Maturity stage	Irrigation, Mulching, *** Sod culture Shelter belts/Windbreaks

*ABA-Abscisic acid, **NAA-Naphthalene acetic acid, ***Sod culture- Green cover on soil by growing fodder or green manure crop to reduce soil temperature.

Threshold Temperature- Temperature increases or decreases over normal and for several days (e.g., an increase of 3 degrees over normal for 5 days)

Note: Management practices should be implemented at the occurrence of Threshold temperature.

a. Srikakulam district, Andhra Pradesh

Heatwave	Before the event	During the event	After the event
A. Capture			
Marine	Avoidance of fishing	Avoidance of fishing	No intervention
Inland	Monitoring dissolved oxygen levels	Monitoring dissolved oxygen levels	No intervention
B. Aquaculture			
(i) Changes in pond environment (water quality)	Reduction of biomass by partial harvest in the event of heat as the DO levels will be very low.	Avoidance of fishing	Compensatory stocking of seed and restoration of all physical and chemical parameters
(ii) Health and Disease management	Removal of stress-causing factors to maintain the health of the animal	Removal of stress-causing factors to maintain the health of the animal	Compensatory stocking of seed and restoration of all physical and chemical parameters

b. Kurnool district, Andhra Pradesh

Suggested contingency measures for animals		
Before the event	During the event	After the event
As the district is chronically prone to heat waves the following permanent measures are suggested i) Plantation of trees like Neem, Pipal, Subabul around the shed ii) Spreading of husk/straw/ coconut leaves over the rooftop of the shed iii) Water sprinklers/foggers in the animal shed iv) Application of white reflector paint on the roof to reduce the thermal radiation effect	Allow the animals preferably early in the morning or late in the evening to graze during heat waves Feed green fodder/silage/concentrates during day time and roughages/hay during night time in case of heat waves Put on the foggers/sprinklers during heat weaves in case of highly productive animals In severe cases, vitamin 'C' (5-10ml per litre) and electrolytes (Electoral powder @ 20g per litre) should be added to water during severe heat waves.	Feed the animals as per the routine schedule Allow the animals to graze (normal timings)

c. Khurda district, Odisha

Extreme event type	Suggested contingency measure[r]			
	Seedling/ nursery stage	**Vegetative stage**	**Reproductive stage**	**At harvest**
Heat Wave				
Paddy	Irrigate the nursery bed, Spray water on the seedlings in the evening hours	Irrigate the field with sufficient water	Keep sufficient water in the field Spray water to avoid chaff seeds/grains, if the availability of irrigation water is limited	Harvest at the physiological maturity stage to avoid crop damage due to excessive heat
Pulses	Provide sprinkle irrigation to the crop field to avoid water stress	Provide light / sprinkler irrigation to the crop field to avoid water stress	Sprinkle irrigation to the crop field to avoid water stress, if necessary	Harvest early and keep in the field for one day only to avoid shattering of grains in the field itself

Horticulture				
Coconut	Shedding of nursery, frequent irrigation, sprinkling/ spraying of water, live fence barrier	Windbreak on the north side, irrigate in basins (or) use drip irrigation	Windbreak on the north side. Irrigate in basins (or) use drip irrigation	-
Banana	Shedding of nursery, frequent irrigation, sprinkling/ spraying of water, live fence barrier	Windbreak on the north side, irrigate in furrows (or) use drip irrigation	Windbreak on the north side, irrigate in basins (or) use drip irrigation, wrapping up the banana bunches	-
Mango	Providing shade in the nursery, frequent irrigation, sprinkling/ spraying of water, live fence barrier	Windbreak on the north side, Water channels around the crop, Spraying of water	Windbreak on the north side, Water channels around the crop, Spraying of water	-
Cashew	Providing shade in the nursery, frequent irrigation, sprinkling/ spraying of water, live fence barrier	Windbreak on the north side, irrigate in basins (or) use drip irrigation, sprinkling/spraying of water to the plants	Windbreak on the north side, irrigate in basins (or) use drip irrigation, sprinkling/ spraying of water to the plants	-
Vegetables	Providing shade in the nursery, frequent irrigation, sprinkling/ spraying of water, and live fence barrier	Increase the frequency of irrigation. Irrigate in furrows, sprinkling/spraying water to the crop in evening hours, avoid foliar application of fertilizer (or) plant protection chemical during day hours	Increase the frequency of irrigation. Irrigate in furrows, sprinkle/ spraying of water to the crop in evening hours, avoid foliar application of fertilizer (or) plant protection chemical during day hours	Harvest and dispose of the produce

d. Patiala, Punjab

	Seedling/nursery stage	Vegetative stage	Reproductive stage	At harvest
Heat Wave				
Rice	Correct Iron deficiency with 0.5 % iron sulphate spray, light, and frequent irrigation	Pounding of water for fifteen days after transplanting to check iron deficiency and for crop establishment	Apply irrigations at 8-10 days intervals for good growth of field crops. The crop should not be under stress at flowering, soft dough, and hard dough stages.	-
Wheat			Apply light irrigation	-
Citrus	Light and frequent irrigation and shelter from the western side to check sun scald and burning injuries, application of whitewash paint on main stems,	Apply light and frequent irrigation to check the flower and fruit drops with a growth regulator like 2-4-D/GA	NA	

9.3. Heatwave Action Plans for Indian Farming Community

Indian agriculture is extremely vulnerable to the effects of climate change, particularly because almost half of the population works in agriculture and other climate-sensitive sectors (Chand and Singh, 2022). Heat Wave Action Plans have been implemented in 17 states and more than 130 cities which are designed to give early warnings and reduce the negative health impacts of extreme heat and prevention and control of heat-related illnesses (Golechha *et al.,* 2021). Indian farmers are highly exposed to heatwave conditions during the crop season, mainly during summer. So far, there is no such action plan initiated to safeguard the farming community, especially from a health point of view as they fall under the unorganized sector.

10. Monitoring and management of heatwaves

Monitoring

Coordination among authorities such as IMD, revenue department, State Agricultural Universities, ICAR, and other institutes for data sharing on temperature, collective monitoring, and creating alerts on heat waves to different stakeholders should be on priority. Though complete avoidance of farm losses due to weather is not possible, losses can be minimized to a considerable extent by timely agricultural operations based on accurate weather forecasts. IMD issues special heat wave warning guidance bulletins (1600 hours IST) at meteorological sub-division & district levels to different users like the Ministry of Home Affairs, National Disaster Management Authority, State Disaster Management Authority, Deputy Commissioner/District Magistrates of different districts of states, health department, Indian Railway, Road transport, Media, etc. IMD conducts the preseason exercise at the state & national level. IMD also contributes to the preparation of heat wave guidelines and heat action plans. IMD provides the required past data for heat wave advisories and development.

Management

- o Departments need to access and monitor the heat waves in real-time to inform farmers in real time about impending heat waves and coordinate with state agriculture universities, and KVKs for transferring technologies to different stakeholders
- o Coordination is needed for implementing adaptation measures at farmer fields through farmer groups
- o The research system needed to develop protocols for the implementation of mitigation measures, wherever needed.
- o Since some of the mitigation measures include irrigation, identification of water sources for critical irrigations, and machinery for providing irrigation to be identified and kept ready for implementation of mitigation measures.
- o Departments of agriculture and allied sectors need to take cognizance of forecasts being made by IMD etc. on maximum and minimum temperatures and identify the regions prone to higher deviation from temperature so that appropriate measures can be taken.
- o Since heat waves in the summer season impact horticulture crops and summer crops, departments of horticulture and agriculture need to be much more vigilant for signs of heat waves. Measures to conserve moisture are to be promoted for all systems across systems.

11. Way Forward

The impact of climate change on agriculture and allied sectors is evident now. Recognizing the urgency faced by the increased frequency and intensity of heat-related extremes, it is important to strengthen the heatwave monitoring network of the country. Assessing extremes at a higher spatial resolution will let us identify localized hot spots, however, prediction of localized hot spots still will be a challenge as internal variability of the climate system implies that the specific location of extremes will vary between years. These challenges motivate us to accelerate heat-stress-related agricultural research toward developing resilient technologies and their upscaling. The available resilient technologies for field/horticultural crops, livestock, and poultry are to be made accessible through adequate extension mechanisms. It is pertinent that a region of higher variability is likely to experience more severe heatwaves, in terms of absolute magnitude, but might be able to adapt more easily due to past experiences. Therefore, a proper understanding of the localized hotspots, coordination, and collaboration among various agencies/institutions will certainly bring enhanced resilience in the vulnerable regions of India to the recurrent heat waves.

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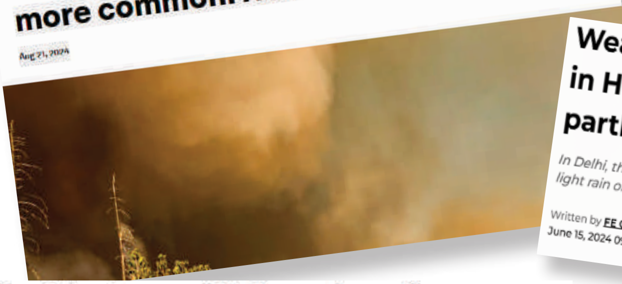
Aug 21, 2024



Weather update: Heatwave to continue in Himachal, Punjab and Haryana; partly cloudy skies in Delhi

In Delhi, the IMD predicted partly cloudy skies with a possibility of thunderstorms and light rain or drizzle in a few places towards the afternoon and evening on Saturday.

Written by EE Online
June 15, 2024 09:46 IST

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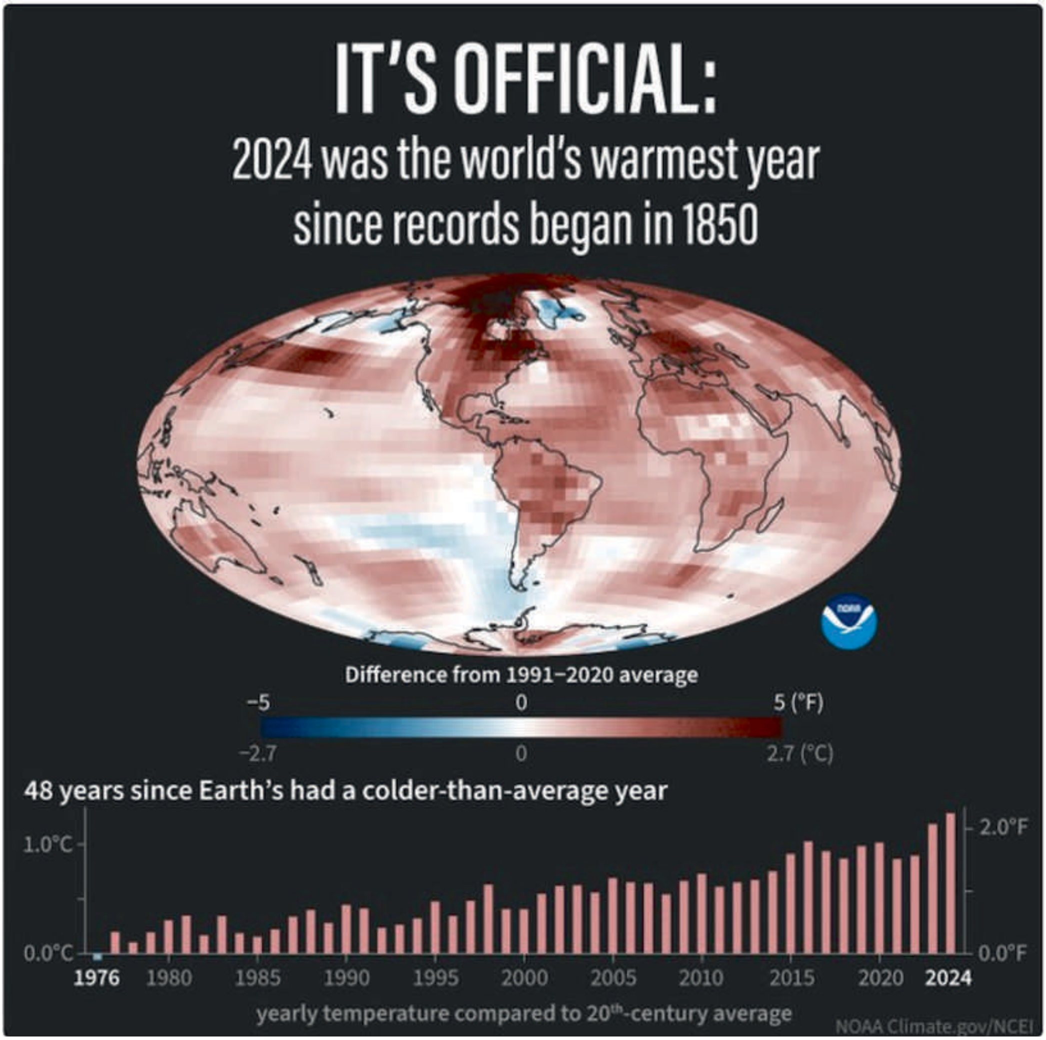
NOTES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Difference from 1991–2020 average
−5
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5 (°F)
−2.7
0
2.7 (°C)
48 years since Earth's had a colder-than-average year
1.0°C
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1976
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