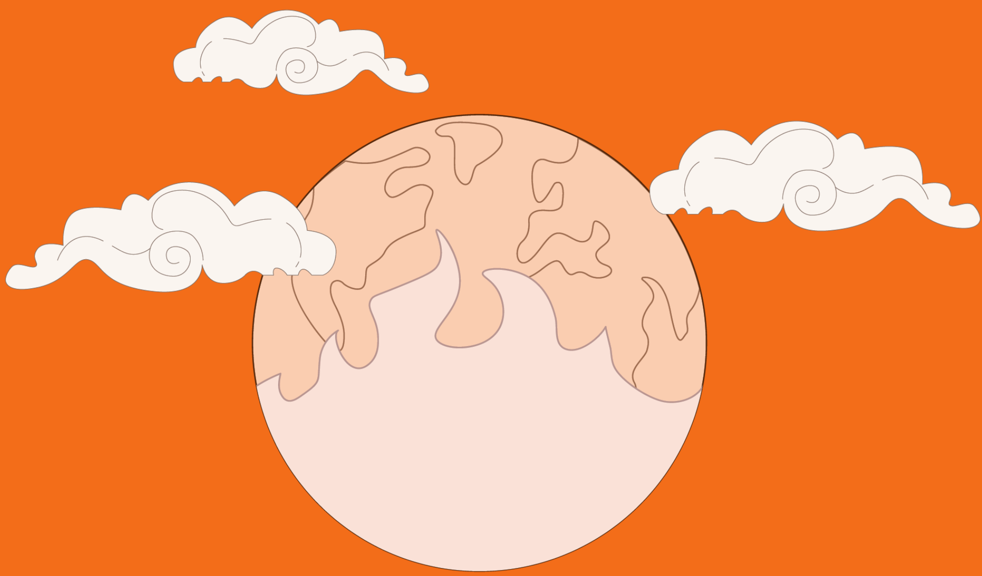
# INDIA'S TRYST WITH HEATWAVES & CHANGING MONSOON PATTERNS



Background reading material for the National Conference on Heatwaves and Changing Monsoon Patterns amid Climate Change

# SUMMARY

India is one of the most vulnerable countries in the world to projected climate change impacts. The country is already witnessing notable impacts of climate change, with intense heat waves and erratic Monsoon patterns topping the list. Other impacts include drought, cyclogenesis, flooding, water stress and associated negative consequences on health and livelihoods. Some changes like extreme rainfall and frequency of heatwaves are happening faster than scientists previously assessed.

With a 1.4 billion and growing population, India is expected to be severely by continuing climate change. Global climate projections indicate several uncertainties for India's future climatic conditions.

# What does the science say?

- Meteorological models show a trend of general warming in mean annual temperature over the Indian subcontinent. India's average temperature has risen by around 0.7˚C during 1901–2018. By the end of the 21st century, the average temperature over India is projected to rise by approximately 4.4˚C.
- According to 'Assessment of Climate Change over the Indian Region', in the recent 30-year period (1986–2015), temperatures of the warmest day of the year have risen by about 0.63˚C. By the end of the 21st century, these temperatures are projected to rise by approximately 4.7˚C.
- A World Weather Attribution study (2024) has found that human-induced climate change influenced the events, making them around 30 times more likely and much hotter.
- By the end of the 21st century, the frequencies of occurrence of warm days and warm nights are projected to increase by 55% and 70%, respectively.
- Heat waves have claimed more lives in India than other natural hazards, with the exception of tropical cyclones. According to a report 'An assessment of long-term changes in mortalities due to extreme weather events in India', mortality due to heat waves has increased by 62.2% between 2000-2019.
- A 2˚C rise in the world's average temperatures will make India's summer monsoon highly unpredictable. At 4˚C warming, an extremely wet monsoon that used to have a chance of occurring only once in 100 years is projected to occur every 10 years by the end of the century.
- Glaciers disappeared 65% faster in the 2010s than in the previous decade. On current emissions pathways, 80% of glaciers' current volume will be gone by 2100. Global observations of melting glaciers suggest that climate change is well underway in the region, with glaciers receding at an average rate of 10-15 meters per year. If the rate increases, flooding is likely in river valleys, followed by diminished flows, resulting in water scarcity for drinking and irrigation.
- There has been a 52% increase in the number of cyclones in the Arabian Sea. Very severe cyclones have increased by 150%. The duration of cyclones and very severe cyclones is up by 80% and 260% in the last four decades. The increase in cyclone activity in the Arabian Sea is closely linked to rising ocean temperatures and increased availability of moisture under global warming.

# HEATWAVES

Heatwaves are known to be the “Silent killers” amongst the natural disasters triggered by human-caused climate change. The impact of rising temperatures and increasing frequency, duration and intensity of hot spells poses a challenge to human safety and sustainability. Heat waves have claimed more lives in India than other natural hazards, with the exception of tropical cyclones. According to a report ‘An assessment of long-term changes in mortalities due to extreme weather events in India’, mortality due to heat waves has increased by 62.2% between 2000 and 2019.

The heatwave phenomenon can be divided into two sections: Dry Heatwave and Humid Heatwave. During hot weather conditions, the human body normally cools itself by perspiration, or sweating, in which the water in the sweat evaporates and carries heat away from the body. However, during the humid heatwave, where the relative humidity is high, the evaporation rate of sweat is reduced. It means heat is removed from the body at a lower rate, causing it to retain more heat than it would in dry air.

This combination of land surface temperature, air temperature and relative humidity is also known as heat index and wet bulb temperature(TW). TW is increasingly becoming a deadlier threat for India’s coastal cities as it has a direct correlation with mortality and heat-related health impacts as it can compromise the human body’s main cooling mechanism of sweating.

Despite differences in the nature and impact of these events, for instance, drier heat in 2022 led 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 mre likely and much hotter.

According to the research paper ‘Trends of the observed temperature and its variations in the Tamil Nadu State of India, the increasing trends in Mean Maximum Temperature (MMaxT), Mean Minimum Temperature (MMinT), and mean annual temperature (MAT) are observed at the majority of the stations between 1969–2016. Approximately, 82% of the total stations have shown a significant positive trend in MAT and MMaxT at the 95% confidence level. The MAT has increased up to 1.4 ˚C with a variation in the rate of change from 0.01 to 0.29 ˚C per decade. MMaxT has shown a significant increase with a variation in the rate of change from 0.01 to 0.54 ˚C per decade for the last 47 years.

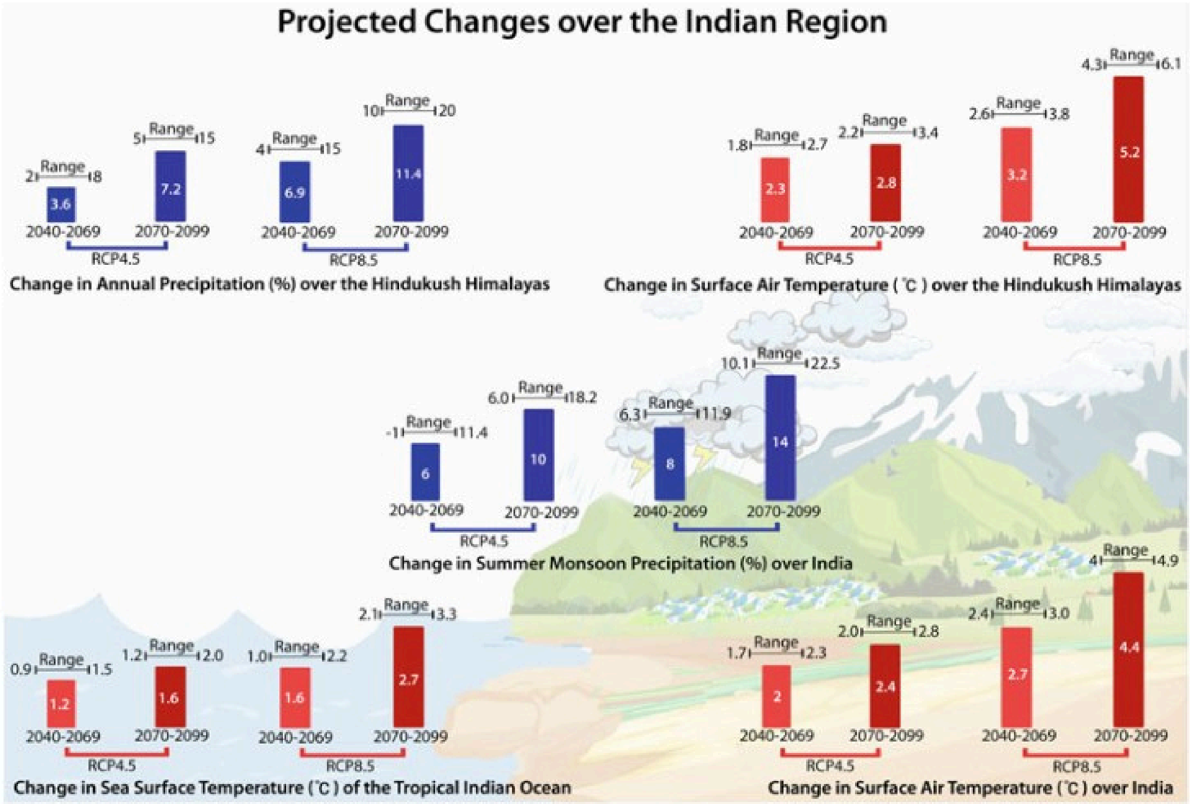



**Fig. 1** Best estimate and range in climate model projections of future changes in 1. Surface air temperature over India (°C; bottom right panel), 2. Sea surface temperature of the tropical Indian Ocean (°C; bottom left panel), 3. Surface air temperature over the Hindu Kush Himalayas (°C; top right panel), 4. Summer monsoon precipitation over India (% change; centre panel), 5. Annual precipitation over the Hindu Kush Himalayas (% change; top left panel). All the changes are computed relative to their climatological average over the 30-year period 1976–2005. Projected changes are reported for the middle and end of the 21st century under the RCP4.5 and RCP8.5 scenarios (defined in Box 1). Details regarding the models and computations are discussed in the respective chapters

# ERRATIC MONSOON PATTERNS

The Southwest Monsoon, which spans from June to September, accounts for 80% of the annual rainfall in India. Human-caused climate change has altered the weather patterns over the years, resulting in erratic weather conditions.

As per a study, the summer monsoon precipitation over India has declined by around 6% from 1951 to 2015, with notable decreases over the Indo-Gangetic Plains and the Western Ghats. There is an emerging consensus, based on multiple datasets and climate model simulations, that the radiative effects of anthropogenic aerosol forcing over the Northern Hemisphere have considerably offset the expected precipitation increase from greenhouse gases warming and contributed to the observed decline in summer monsoon precipitation.

There has been a shift in the recent period toward more frequent dry spells (27% higher during 1981–2011 relative to 1951–1980) and more intense wet spells during the summer monsoon season. The frequency of localized heavy precipitation occurrences has increased worldwide in response to increased atmospheric moisture content. Over central India, the frequency of daily precipitation extremes with rainfall intensities exceeding 150 mm per day increased by about 75% during 1950–2015.

With continued global warming and anticipated reductions in anthropogenic aerosol emissions in the future, CMIP5 models project an increase in the mean and variability of monsoon precipitation by the end of the twenty-first century, together with substantial increases in daily precipitation extremes. According to an analysis by the Council for Energy, Environment and Water (CEEW), more than 75% of Indian districts are exposed to extreme climate events. Subsequently, over 40% have experienced climatic disruptions such as a shift from being flood-prone to being drought-prone, or vice-versa.

In the past 40 years during the southwest monsoon, we found that India as a whole experienced 29 'normal', 8 'above-normal', and 3 'below-normal' monsoon years. However, analysis of these trends at the district level showed that approximately 30 per cent of India's districts witnessed a high number of deficient rainfall years and 38 per cent witnessed a high number of excessive rainfall years. Of this, 23 per cent of districts such as New Delhi, Bengaluru, Nilgiris, Jaipur, Kachchh, and Indore, witnessed both a high number of deficient as well as excessive rainfall years.

# COMPOUNDING IMPACTS

## *Health*

Heat waves are already significantly impacting human health, particularly for vulnerable populations. Human skin is usually around 35˚C, and as it sweats it draws heat away from the warmer core of the body. Exposure to TW of 35˚C for more than around six hours is lethal even for heat-acclimated healthy humans under ideal conditions (indoors, unclothed, not moving, with a fan, and with unlimited drinking water), because at these levels of heat and humidity sweating no longer functions to cool the body.

According to the IPCC's latest report, the occurrence of climate-related food-borne and water-borne diseases has increased, along with a spike in the incidence of vector-borne diseases. Higher temperatures, increased rain and flooding have increased the occurrence of diarrheal diseases, including cholera and other gastrointestinal infections. Mental health challenges including mood imbalances, anxiety, and depression are also associated with increasing temperatures, trauma from weather and climate extreme events, and loss of livelihoods and culture. Increased exposure to wildfire smoke, atmospheric dust, and aeroallergens have been associated with climate-sensitive cardiovascular and respiratory distress.

## *Urbanisation*

Cities are more vulnerable to the compounding effects of urbanisation and climate change. The latest research suggests that urbanisation alone is responsible for 60% of the warming trend in India cities. Persistently rising average temperatures coupled with rapid expansion of urban areas have resulted in the urban heat island (UHI) effect, which subsequently affects other climate parameters (rainfall, pollution and so on).

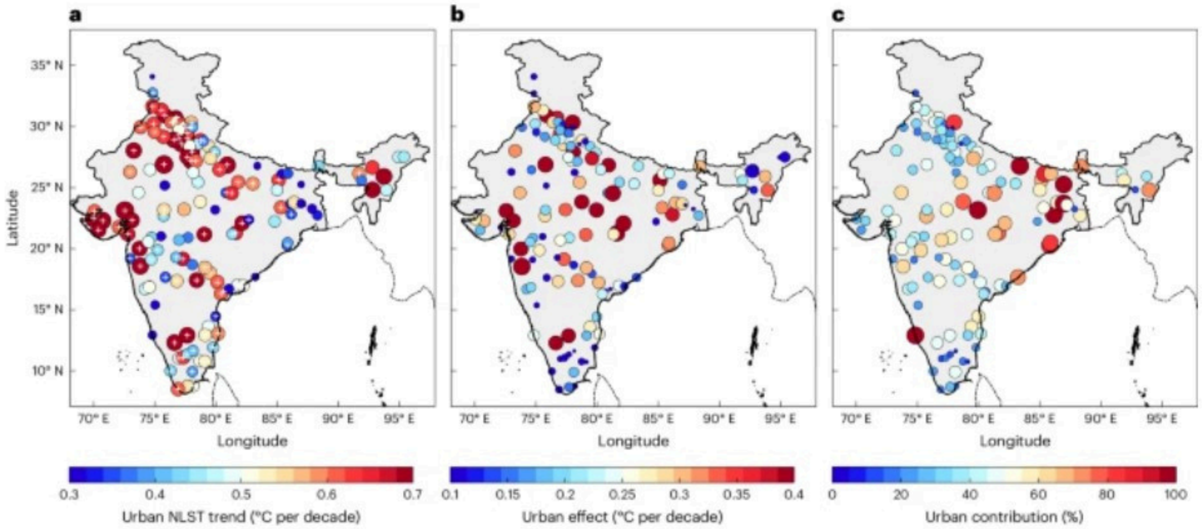
Warming in urban areas results from a combination of general climatic warming and the heat island effect, wherein high levels of pollution and the built environment trap heat thereby preventing cities from cooling down as fast as rural areas. Urbanisation leads to changes in land use patterns and the gradual replacement of the natural environment by the urban built-up areas and infrastructures.

Green covers and vegetation are replaced by barren lands, industrial units, pavements, buildings and roads. These artificial surfaces largely absorb the shortwave radiation from the Sun and store the energy within due to their high thermal conductivity. At night, while rural areas cool down, urban areas with their complicated geometry of streets and tall buildings are slow in releasing the heat absorbed during the day. The sustained high temperatures at night result in thermal discomfort and pose greater threats to human life as the body does not get time to recover from the exposure to daytime extreme heat.

Cities in the warm-humid and moderate climate zones show an increase, with ambient air temperature having changed by less than 0.5˚C between 2001-10 and 2014-23. According to recent research 'Decoding the Urban Heat Stress among Indian cities', decadal summer-time average ambient temperature has risen by about 0.5˚C in Mumbai, Bengaluru and Chennai compared to 2001-10. Kolkata's decadal average is also up by 0.2˚C. Delhi and Hyderabad, two metros which are located in composite climate zones known for the driest and harshest summers, have registered lower decadal averages compared to 2001-10. Decadal summer-time average for Delhi is down by 0.6˚C and for Hyderabad, by 0.9˚C, compared to 2001-10.

An increase in paved surfaces such as roads and buildings irreversibly changes natural infrastructure, ecosystems, and hydrological surface and subsurface flows in urban areas. The loss of natural infrastructure has complex interlinked consequences such as reduced groundwater recharge leading to dropping aquifer levels and increased rainwater runoff leading to higher flood risk. In addition, the high pressure of development in and around urban centres leads to new development being sited on high-risk, vulnerable zones such as floodplains, lake beds, and low-lying areas. The current form of urbanisation is disconnected from the natural environment and is associated with various negative outcomes for cities, such as water scarcity, increased groundwater stress, and increasing incidence of urban flooding.

**Fig. 1: Extracting urbanization-driven warming in Indian cities.**

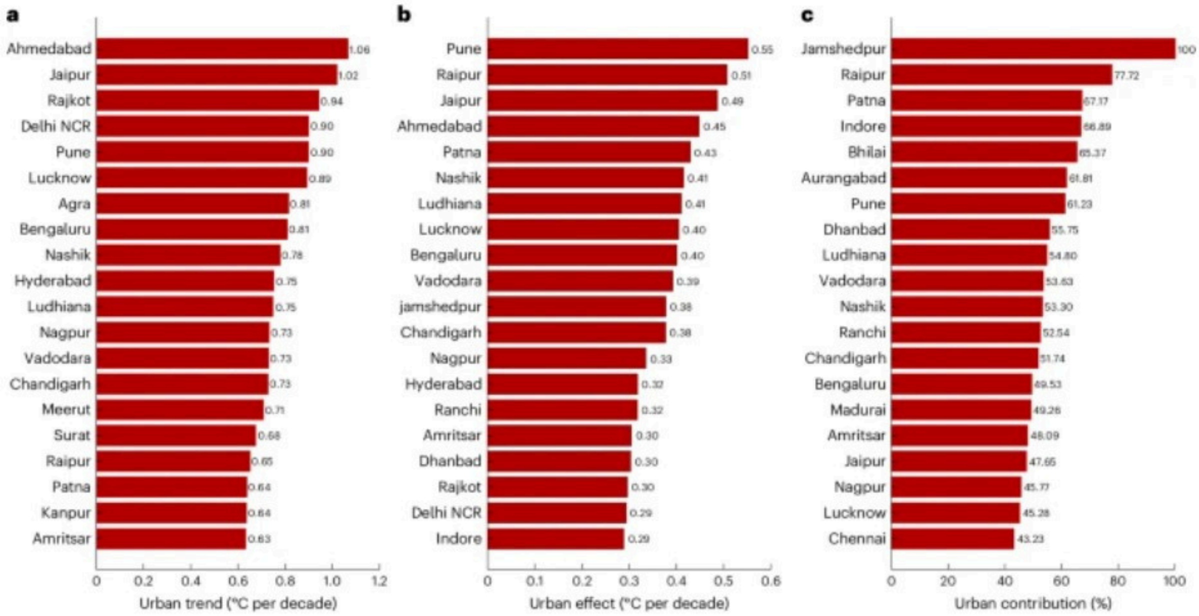



**a**–**c**, Strength of total urban NLST (annual mean) trends during the period 2003–2020 (**a**), urban effect, that is, urbanization-driven warming in absolute terms (**b**), and urban contribution, that is, urbanization-driven warming in relative terms (**c**) across Indian cities. The '+' symbols (**a**) indicate a trend value significant at the 95% confidence level. Both the color and size of the bubbles represent the strength of estimated values for the respective panels. Maps are created using MATLAB R2022b.

At the same time, urbanization and the associated energy demands lead to the production of greenhouse gases and associated emissions, contributing to climate change. Furthermore, due to the dense population and infrastructure of urban areas, they are on the frontlines of climate-change impacts such as heatwaves, extreme weather events and flooding.

Various studies indicate that India will be one of the most vulnerable countries to the impact of climate change, with its cities at the forefront. Consequently, given the scale and scope of urbanisation (both ongoing and projected) and exposure to climate-change-related risk, the synergistic effect of the two will make Indian cities particularly vulnerable.

**Fig. 2: Ranking of the top 20 warming Indian cities.**

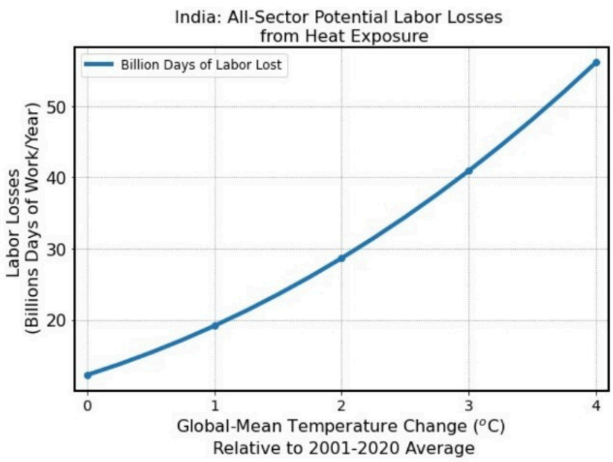



**a–c**, Ranking based on urban NLST trends (**a**), urban effect (that is, urbanization-driven warming in absolute terms) (**b**), and urban contribution (that is, urbanization-driven warming in relative terms) (**c**). Indian cities are ranked that have a population of more than a million based on the 2011 census and have an urban NLST trend significant at the 95% confidence level.

## *Labour hours lost*

At around 32˚C TW (wet-bulb temperatures), it becomes impossible even for healthy, heat-acclimated people to work. Even at TW 26˚C elderly people, those with respiratory, cardiovascular, or renal issues, the elderly, and people performing strenuous activity are at risk of serious or fatal heat stroke.
If simplified Wet Bulb Globe Temperatures increase globally by 2˚C, global labour capacity could fall from 80% to around 70%, while at 4˚C that falls to under 60%. The drop in capacity will be even greater in the tropics (Buzan and Huber 2020).

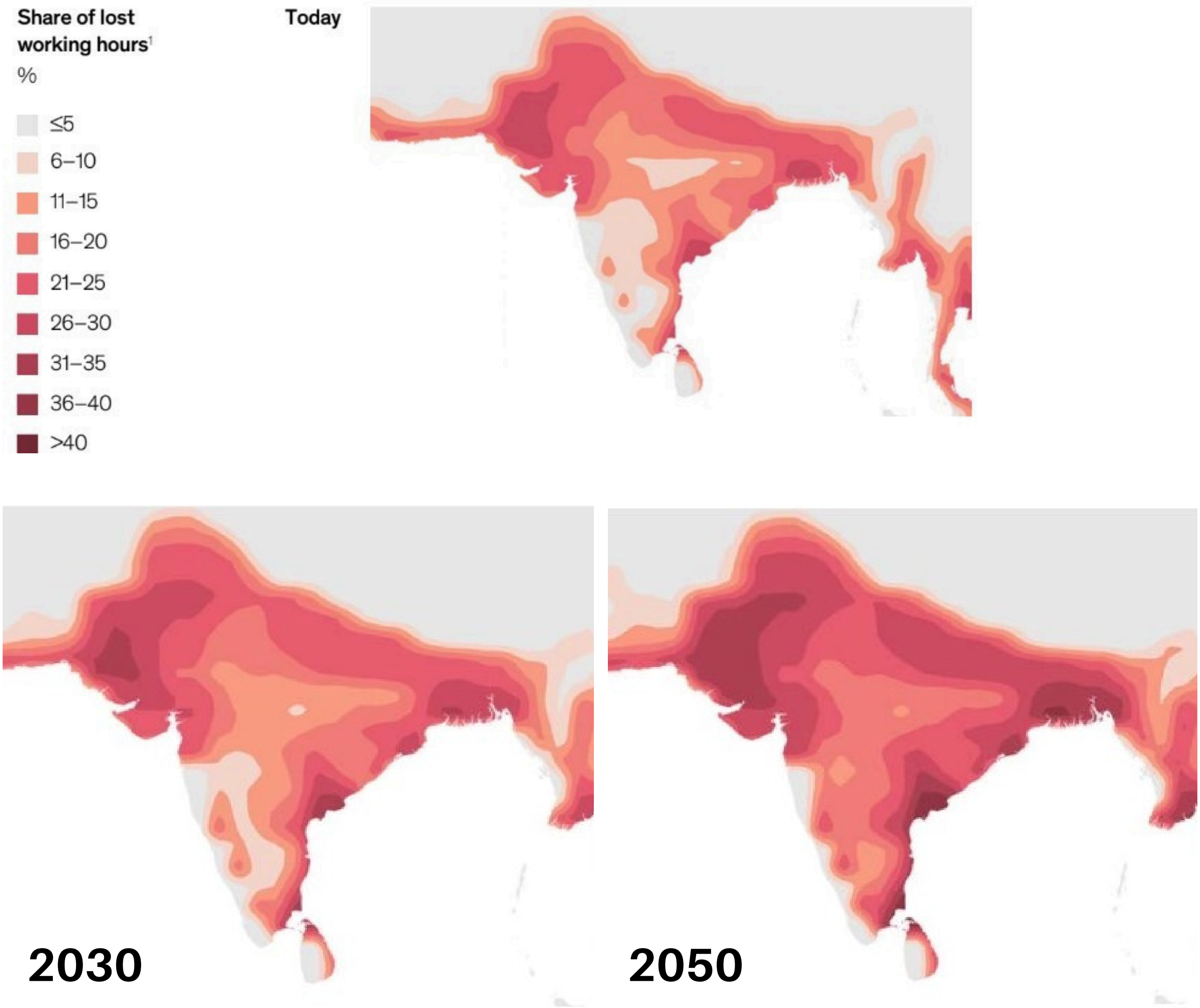
Diminishing productivity and decreasing numbers of labour hours propelled by rising temperatures directly affect the gross output produced by workers and result in economic loss for the country. National-level GDP losses are projected to be substantial in 2030, with reductions in GDP of more than 5 per cent expected to occur in India.



Research found out that India could potentially become one of the first places in the world to experience heat waves that cross the survivability limit for a healthy human being sitting in the shade. Without targeted adaptation action, around 160-200 million people in India could annually bear a 5 per cent chance of being exposed to a lethal heat wave as early as 2030, a ~40 per cent cumulative likelihood over the decade centred on 2030. It is further estimated that the effective number of outdoor working hours lost will increase approximately 15 per cent by 2030, resulting in approximately 2.5-4.5 per cent, or $150-250 billion, risk to GDP. By 2050, both the intensity of and exposure to lethal heat waves, as well as the impact on outdoor work, could increase in a nonlinear way.

**The affected area and intensity of extreme heat and humidity is projected to increase, leading to a higher expected share of lost working hours in India and surrounding areas.**

Based on RCP 8.5




1. Lost working hours include loss in worker productivity as well as breaks, based on an average year that is an ensemble average of climate models.

Note: See the Technical Appendix of the full report for why we chose RCP 8.5. All projections based on RCP 8.5, CMIP 5 multi model ensemble. Heat data bias corrected. Following standard practice, we define current and future (2030, 2050) states as the average climatic behavior over multidecade periods. Climate state today is defined as average conditions between 1998 and 2017, in 2030 as average between 2021 and 2040, and in 2050 as average between 2041 and 2060.

Source: Woodwell Climate Research Center

Another study reiterates similar findings, which stated countries with large populations in South and East Asia experience the most work hours lost, both in the coolest hours and in the full workday, with India showing the largest heat exposure impacts on heavy labour (>101 billion hours lost/year), despite its modest average per-capita labour losses (162 lost hours/person/year).

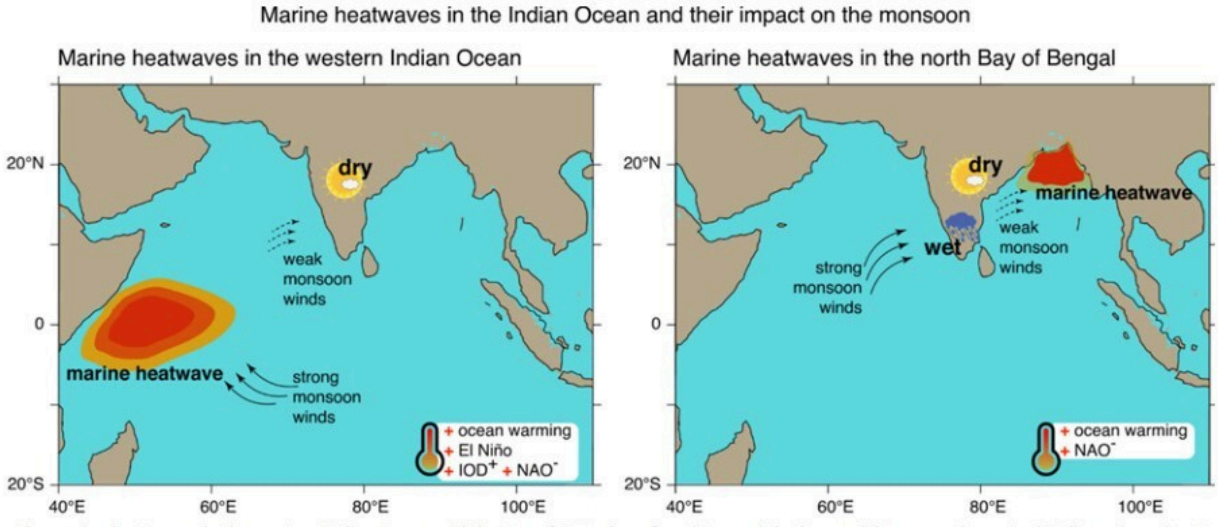
Heat and humidity levels too extreme for indoor work will occur in some parts of Africa, the Middle East, South Asia, and Australia under 1.5˚C global warming. With 3˚C coastal areas of the USA, the Amazon, much of west and central Africa, coastal Middle Eastern Areas, much of South Asia, much of mainland South East Asia, and parts of Australia could suffer these unworkable conditions.

# *Marine heatwaves*

Marine heatwaves are periods of extremely high temperatures in the ocean (above the 90th percentile). These events cause habitat destruction due to coral bleaching, seagrass destruction, and loss of kelp forests, affecting the fisheries sector adversely. An underwater survey showed that 85% of the corals in the Gulf of Mannar near the Tamil Nadu coast got bleached after the marine heatwave in May 2020.

These heatwaves used to be rare in the tropical Indian Ocean, but now they have become an annual affair. The western Indian Ocean region experienced the largest increase in marine heatwaves at a rate of about 1.5 events per decade (four-fold rise), followed by the north Bay of Bengal at a rate of 0.5 events per decade (two-to-three fold rise). During 1982–2018, the western Indian Ocean had a total of 66 events while the Bay of Bengal had 94 events.

As per research, the marine heatwaves in the western Indian Ocean and the Bay of Bengal are found to result in dry conditions over the central Indian subcontinent. At the same time, there is a significant increase in rainfall over south peninsular India in response to the heatwaves in the north Bay of Bengal. These changes are in response to the modulation of the monsoon winds by the heatwaves.

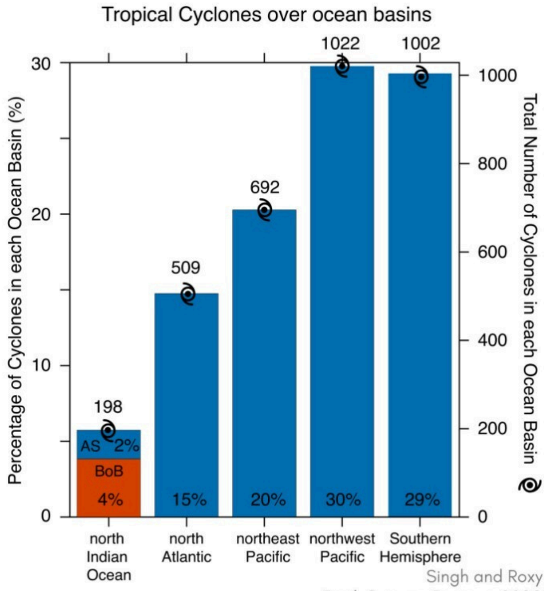



*The marine heatwaves in the western Indian Ocean and the Bay of Bengal are found to result in dry conditions over the central Indian subcontinent. At the same time, there is a significant increase in rainfall over south peninsular India in response to the heatwaves in the north Bay of Bengal. The legend next to the thermometer indicates the climatic factors responsible for the marine heatwaves— ocean warming, El Niño, Indian Ocean Dipole (IOD), and North Atlantic Oscillation (NAO).*

# *Cyclogenesis and Ocean Warming*

The north Indian Ocean accounts for 6% of the global tropical cyclones annually. Despite the small fraction of cyclones, some of the most devastating cyclones have formed in this basin, causing extensive damage to life and property in the north Indian Ocean rim countries, including India.

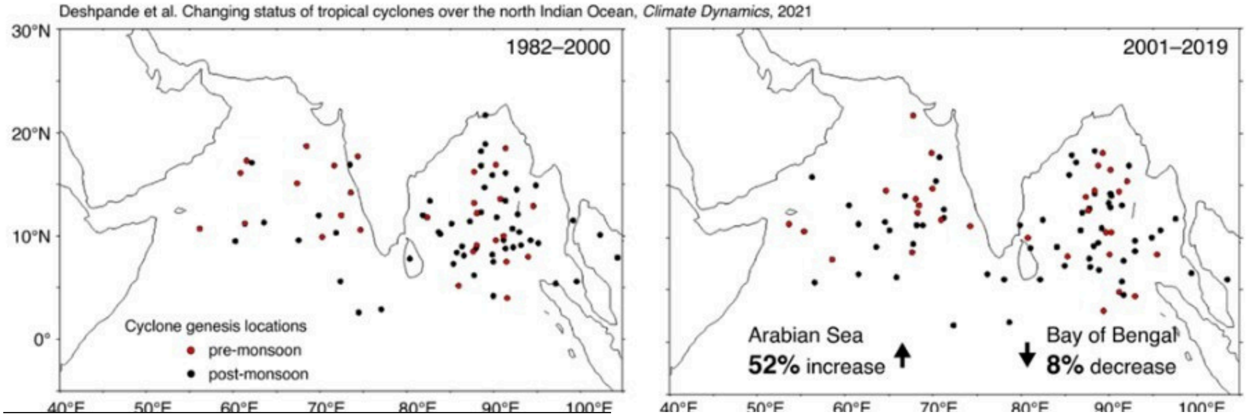
Sea surface temperatures (SSTs) leading to cyclogenesis in the Arabian Sea are 1.2–1.4˚C higher in recent decades, compared to SSTs four decades ago. Rapid warming in the north Indian Ocean, associated with global warming, tends to enhance the heat flux from the ocean to the atmosphere and favour the rapid intensification of cyclones.




Singh and Roxy
*Earth Science Reviews*, 2022

The intensity of cyclones has increased in the Arabian Sea by 20–40%. During the last four decades, the maximum intensity of cyclones has increased by 40% (from 100 km/hr to 140 km/hr), in the Arabian Sea, during the pre-monsoon season (April–May). The Arabian Sea during the post-monsoon season (October–December) has witnessed a 20% increase in the intensity (from 100 km/hr to 120 km/hr). As a result, the total energy used up by a tropical cyclone during its lifetime (known as the accumulated cyclone energy) has also gone up. The changes in the Bay of Bengal are not significantly large.

Deshpande et al. Changing status of tropical cyclones over the north Indian Ocean, *Climate Dynamics*, 2021



Changes in ocean-cyclone interactions are emerging in recent decades in response to Indian Ocean warming. Future climate projections demonstrate continued warming of the Indian Ocean at a rapid pace along with an increase in the intensity of cyclones in this basin. Rapid warming in the north Indian Ocean, associated with global warming, tends to enhance the heat flux from the ocean to the atmosphere and favour the rapid intensification of cyclones.

In the north Indian Ocean, every 4th cyclone during the pre-monsoon season intensifies to a severe cyclone of category 3 or more (wind speed > 175 km/hr) and every 7th cyclone in post-monsoon season intensifies into a severe cyclone of category 3 or more.

As the ocean is becoming more conducive to fuel intense cyclones, a large number (62%) of intense cyclones (wind speed > 185 km/hr) attain their maximum intensity within 200 km away from the coast.

## *Agricultural impacts*

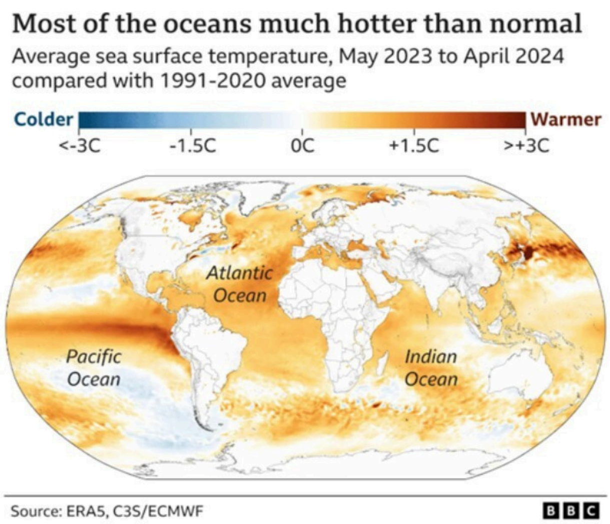
Heat waves can have a significant impact on agriculture in India, with potentially serious consequences for food security and the livelihoods of farmers.

- **Crop failure:** Heat waves can cause crops to wilt and die, leading to reduced yields or even total crop failure. The high temperatures can also cause damage to plant cells, reducing their ability to photosynthesize and produce food.
- **Reduced soil moisture:** High temperatures can lead to increased evaporation of water from soil, reducing soil moisture levels and making it more difficult for crops to grow. This can lead to drought-like conditions, which can be devastating for farmers.
- **Pest infestations:** Heat waves can create ideal conditions for pests and insects to thrive. This can lead to increased damage to crops and the need for more pesticides, which can be costly for farmers.
- **Livestock health:** Heat stress can be a significant issue for livestock, causing reduced milk production, lower fertility rates, and even death in extreme cases. Farmers may need to take extra precautions to protect their animals during heat waves.
- **Water scarcity:** Heat waves can exacerbate existing water scarcity issues, as water sources dry up more quickly and demand for irrigation increases. This can lead to conflicts between farmers and other water users and can make it difficult for farmers to grow crops. The water situation in major cities of India such as Bengaluru, Mumbai, Delhi and Chennai mirror global trends, where erratic rainfall patterns and increasing temperatures led to higher evaporation rates along ever-expanding urban areas have been exacerbating water scarcity.

# Sea level rise

With India close to the equator, the sub-continent would see much higher rises in sea levels than higher latitudes. A significant amount of sea level rise has likely resulted from the observed warming of the atmosphere and the oceans.

Global warming has increased sea level rise by 10%-15% across the Indian seas. This coupled with episodes of heavy rainfall can amplify the damage. A rise in sea surface temperatures also leads to stronger storm surges. Storm surge is an abnormal rise of water generated by a storm, over and above the astronomical tide.

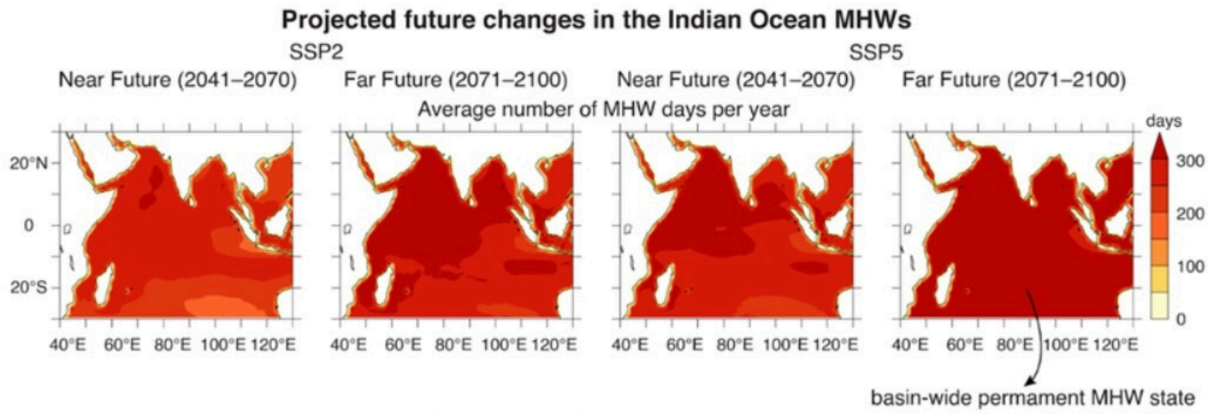



Sea-level rise and storm surges lead to saltwater intrusion in the coastal areas, impacting agriculture, degrading groundwater quality, contaminating drinking water, and possibly causing a rise in diarrhoea cases and cholera outbreaks, as the cholera bacterium survives longer in saline water.

Kolkata, Chennai and Mumbai, densely populated cities, are particularly vulnerable to the impacts of sea-level rise, tropical cyclones, and riverine flooding. As per the Climate Assessment Report of the Ministry of Earth Sciences (MoES), the sea level in the Indian Ocean was observed to be rising at an average rate of about 1.7 mm/year with 3.3 mm/year in the recent decades (1993-2015). It was observed that the sea levels are changing at different rates along the Indian coast.

As per the Intergovernmental Panel on Climate Change (IPCC) Working Group I report released in August 2021, global mean sea level increased by 0.20 (0.15-0.25) m between 1901 and 2018. The average rate of sea level rise was 1.3 (0.6-2.1) mm/year between 1901-1971, increasing to 1.9 (0.8-2.9) mm/year between 1971 and 2006, and further increasing to 3.7 (3.2 to 4.2) mm/year between 2006 and 2018.

According to a study, from 1950 to 2020, the ocean's temperature rose by about 1.2˚C per century. Scientists predict it could warm by 1.7˚C to 3.8˚C per century from 2020 to 2100. While the whole ocean is heating up, the northwestern part, including the Arabian Sea, is experiencing the most intense warming.




Source: Future projections for the tropical Indian Ocean Study

# INSTITUTIONAL RESPONSES TO EXTREME WEATHER EVENTS

## *Short-term responses*

Early warning systems and disaster alerts coupled with community preparedness and outreach are crucial for immediate disaster recovery and rehabilitation. Public service provisions pertaining to emergency healthcare, access to community cooling centres or cyclone shelters, availability of adequate shaded areas, public toilets and water ATMs, changing working hours during heat waves or heavy rainfall events and compensation for working hours lost can enable vulnerable groups cope with such hazards.

## *Long-term responses*

**Nature Based Solutions:**
Natural infrastructure in urban areas also functions as a buffer against climate change driven extreme weather events and therefore is an important adaptation and mitigation measure for increased urban resilience. Mangroves buffer coastal areas from storm surges and cyclones, tree planting in riparian areas can mitigate floodwaters, rain gardens and green roofs can regulate local stormwater runoff and contribute to indoor cooling.

### Urban Climate Resilience:

- Through restoration, conservation and expansion of blue-green spaces, cities can benefit from the ecosystem services they provide. The concept of sponge cities is gaining currency. A Sponge City is one that relies on the installation of additional green areas and replaces concrete with permeable surfaces. These surfaces absorb water during times of rainfall. Designing the city to absorb, clean, and reuse rainwater, much like a sponge, can greatly minimise flooding risks. Green infrastructure also contributes to cooling.
- Climate risk-informed urban planning is the way forward. Mapping flood hazard risks and integrating them in land use planning can minimise development in flood-prone zones. Improved drainage and flood control mechanisms can reduce water runoff during extreme rainfall events.
- Urban infrastructure and land use patterns are identified as key factors that can potentially amplify the temperature and exacerbate health risks of the population through heat island effects. Increasing green covers in the urban landscape or integrating them into the man-made built environment (e.g., buildings and roads) can induce a cooling effect in the surroundings. A focus on urban infrastructure, including 'cool roofs', shifting away from heat-absorbing building materials, focusing on sustainable architectural practices, increasing vegetation, and urban water features will potentially reduce ambient temperatures in urban areas.

### Agricultural Resilience:

Climate-smart agricultural practices, changing cropping patterns, diversification of crops, use of a stress-tolerant variety of seeds, sustainable land and water management practices, rainwater harvesting, soil moisture conservation and crop storage facilities can lessen the impacts of climate hazards on the agriculture sector. The availability of crop insurance in the face of climate uncertainties can safeguard farmers from losses accrued by farmers during disasters.

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