Impact of Climate Change in India with reference to Human Health

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❑ Abstract:

Climate change poses a significant risk to human health, by acting as a threat multiplier, impacting not only the physical environment but also all aspects of natural and human systems. It affects social, economic as well as physiological functioning of health systems. With continuous shifts in climatic conditions, there is a noticeable increase in the frequency and intensity of weather and climate events, such as heat waves cold waves, tropical cyclones, precipitation, thunderstorm, lightning etc. These weather and climate-related hazards have direct and indirect implications for health, amplifying the risks of mortality, noncommunicable diseases, the emergence and spread of infectious diseases, and health emergencies. In view of these exigencies, the effective, efficient and skilled early weather warning system can play an important role in reducing the harm caused by these events by alerting general public, disaster managers, stakeholders and healthcare sector with sufficient lead time and actionable forecasts & warnings.

Keywords: - Climate-Change, Heat Wave, Cold Wave, Early Warning System, Impact based forecasting, Weather Extreme.

Introduction:

Climate, Weather and Health are interrelated in different facets. Weather and climate have direct and indirect effects on health in any place. The people over any region have adapted to these weather and climatic conditions after many years of evolution customizing their social, economic, customary and food habits. However, in the present times these practices are under stress due to climate change and global warming. Different weather phenomenon is getting affected in terms of their occurrence (temporal & spatial), intensity and impact under these changing scenarios. These are also adversely impacting the human being through different direct and indirect ways.

Numerous researches have studied the relationship between disease/human health and weather, and it has long been acknowledged and proven. Seasonal occurrences of diseases have also been documented in traditional literature and knowledge systems [1]. The abundance and behavior of vectors that spread diseases such as mosquitoes and ticks are influenced by temperature, humidity, and precipitation. Warmer temperatures and increased rainfall promote vector (mosquito) reproduction, which can lead to higher transmission rates of diseases such as malaria, dengue fever, Chikungunya, Japanese encephalitis, and Zika virus, among others [2][3].

Cold and dry weather have been linked to an increase in the transmission of respiratory viruses,

including influenza. Low humidity levels can cause mucous membranes to dry up, rendering people more susceptible to respiratory illnesses. Extreme weather events such as excessive rainfall, floods, and storms can contaminate water supplies and spread waterborne infections [4]. Furthermore, stagnant weather patterns might contribute to increased levels of air pollution, worsening respiratory disorders. The integration of weather forecast and weather warning in the context of health impact in need of the day. Over the past few decades, vector borne diseases have been steadily increasing due to reasons such as climatic variability and change, increased international travel and trade, urbanization, and population development. These all provide an ideal breeding ground for dengue vectors and viruses [5].

An increasingly warm global climate can contribute to more severe heat waves by raising the likelihood of exceptionally hot days and nights. The warming climate also intensifies the evaporation of water from land, potentially worsening drought and creating conditions more prone to wildfires, consequently leading to an extended wildfire season. Moreover, a warmer atmosphere is associated with heightened occurrences of intense precipitation events, including heavier rain and snowstorms, owing to the air's increased capacity to retain moisture. El Niño phenomena typically induce drought in many tropical and subtropical regions, whereas La Niña events promote wetter conditions in various locations. These short-term and regional fluctuations are expected to become more significant in a warming climate. The Earth's warmer and more humid atmosphere, in conjunction with warmer oceans, increases the likelihood that the most powerful cyclones will become more vigorous, produce more rainfall, affect new regions, and potentially become larger and longer-lasting. Additionally, the rise in sea levels results in more seawater being pushed onto shore during coastal storms, which, in combination with the increased rainfall from the storms, can lead to more destructive storm surges and flooding. This impactful weather brings the risk and hazard of direct and indirect health impacts.

In view of the multifaceted challenges of climate change with respect to health in India, the following sections covers the evolution of important disastrous weather events with climate change and their impacts on human health.

❑ Evolution of major weather events with climate change

a) Heat Wave

Climate change has led to an increase in frequency of heatwave and hot days, and the days where temperature are remaining above normal have also increased. Sometimes, beyond the period of summer season, many places realize heat wave like condition and meeting the criteria. Heatwaves are becoming more intense, with record-breaking temperatures being observed in many regions and also lasting long, and mainly caused due to global warming with addition to anthropogenic activities and natural disaster (forest fires, War, volcanic eruptions etc.). Temperatures during heat waves are regularly surpassing those formerly considered rare or extreme. Heat islands are being created as a result of rapid and unplanned urbanization, which has established a new maximum temperature normal. This exacerbates the health risks associated with weather exposure, given that a significant portion of the population in India depends on outdoor activities for their means of livelihood. Significant health consequences result from heatwaves, high temperatures, and hot days, including heat-related illnesses, heat stress, and even death, especially among vulnerable populations such as the elderly, infants, and those with preexisting conditions. The association between climate change

and the increase of heatwave occurrences emphasizes the essential importance of adaptation strategies, such as public health interventions, heatwave early warning systems, and measures aimed at lowering greenhouse gas emissions in order to prevent further warming.

A significant increase was noticed in the frequency, persistency and spatial coverage of high frequency temperature extreme events (heat waves) during the decade (1991-2000) [6][7]. In their 2022 study, [8] examined the impact of human activity on the shifting trends of heat waves in India, utilizing the Heat Wave Magnitude Index daily (HWMId). Their research revealed that anthropogenic influences have doubled the likelihood of severe heat waves occurring in central and central-southern India throughout the twentieth century. According to the findings of a study, it is proposed that forthcoming climate warming will result in a notable surge in heat-related fatalities, particularly in lower-latitude developing nations such as India, where the occurrence of heat waves is expected to be more recurrent, and the population is especially susceptible to these extreme temperatures [9]. The study further demonstrates that even a slight elevation in average temperatures could result in a significant increase in heat-related mortality, underscoring the importance of initiatives required to mitigate these effects. Based on the analysis of CMIP data in a study [10] indicated that heat waves are anticipated to become more severe, persist for longer durations, and manifest more frequently and earlier in the year. Additionally, it is projected that by the conclusion of the 21st century, Southern India, presently unaffected by heat waves, will be significantly impacted. Projections suggest that a considerable portion of India will encounter heat stress conditions in the years to come. A study regarding escalating trends in temperature and moisture-induced heat index, and its potential impact on human health within the context of climate change across the Indian subcontinent found that on average across the country, Heat Index (considering cumulative impact of temperatures and relative humidity) is increasing during the summer and monsoon seasons at rates of +0.560°C per decade and +0.320°C per decade, respectively [11]. This is indicating increasing effect of discomfort. The overall situation considering the observed heat waves from 1961 onwards indicate increase in heat wave frequency and heat wave days as shown in Fig 1 (a) & 1 (b) respectively.

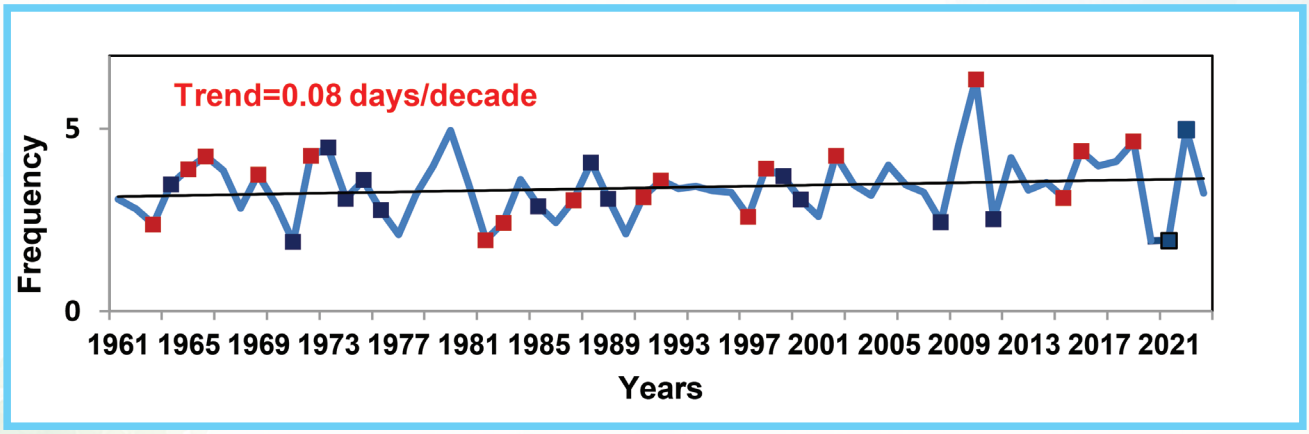


Fig. 1 (a) Heat wave Frequency since 1961

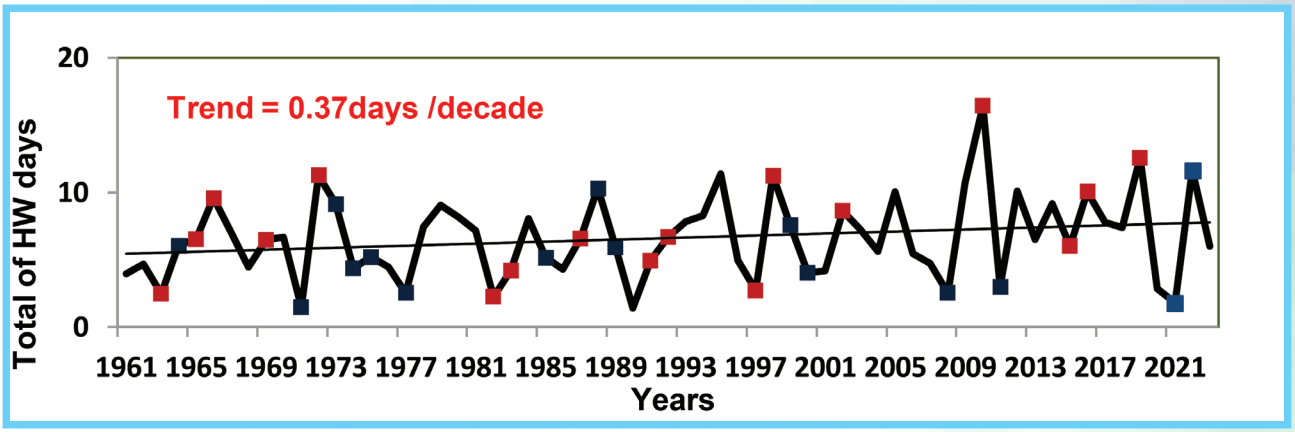


Fig. 1 (b) Heat wave days since 1961

b) Cold Wave

The information sourced from the annual reports of the India Meteorological Department, "Disastrous Weather Events" for a period of 37 years (1978-2014), shows that total 606 cold wave events have resulted in a cumulative 8520 fatalities, or an annual average of 230 fatalities during this period. Bihar and Uttar Pradesh account for only 24% and 31%, respectively, of the total cold wave mortalities. Between the years 1978 and 1999, a total of 3264 fatalities were reported due to cold waves in the northern parts of India [12]. As per a report (NDMA 2021) cold wave has caused 4,712 deaths from 2001 to 2019 across various states. A survey assessing the influence of cold waves on Rabi crops revealed economic losses amounting to 6230 million Indian rupees in the state of Rajasthan during the 2005-2006 Rabi season alone. The impact of cold waves affects agriculture and extends to the Rabi crops, which are sown in winter and harvested the following spring in the northern regions of India.

Cold waves and frost represent significant factors that exert a notable influence on the growth and productivity of crops, horticultural plantations, and orchards, consequently bearing a substantial impact on agriculture and the livelihoods of people. The degree of impairment caused by a cold wave is contingent upon various factors such as temperature, duration of exposure, humidity levels, and the rate at which freezing temperatures are reached. Numerous crops and orchards in the northern and northeastern regions of the country have experienced the detrimental consequences of cold waves and frost. Lower temperatures lead to two types of harm to plants. The first type is chilling injury, which occurs within the temperature range of 2°C to 0°C. The second type is freezing injury, which arises when the external temperature falls below the freezing point of water.

The recent study highlights a noticeable decline in the number of cold wave days at various stations across the northern regions of India [13]. Conversely, only a limited number of stations in the central and eastern parts of the country exhibit an upward trend. The overall situation considering the observed cold waves from 1971 onwards indicate decrease in cold wave frequency and cold wave days as shown in Fig 2 (a) & 2 (b) respectively. However, still the lower temperatures and associated impact are one of the major threats for survivability of human beings in terms of their health impact, impact on agriculture, horticulture, transportation etc.

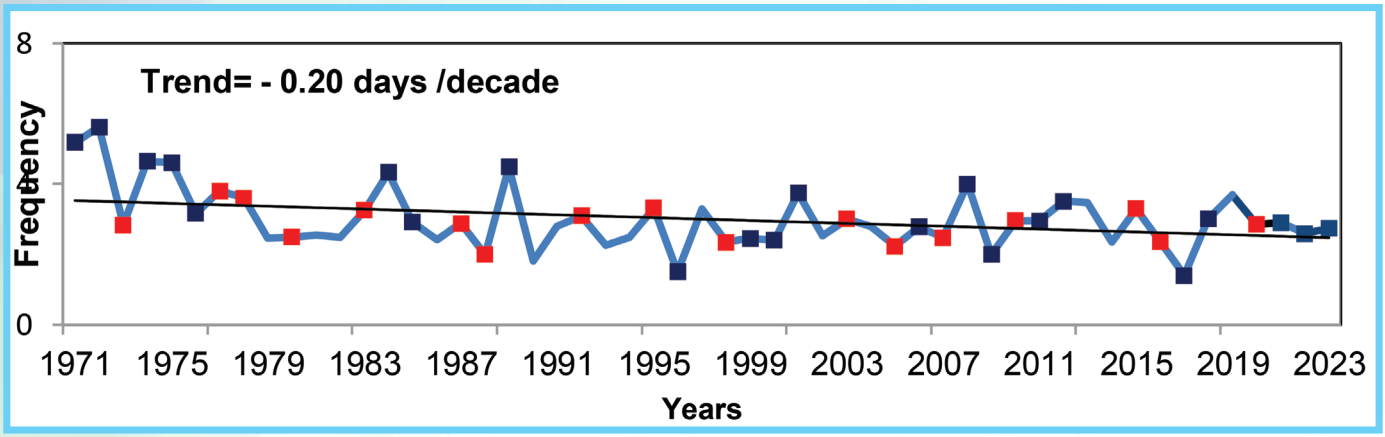


Fig. 2 (a) Cold wave Frequency since 1971

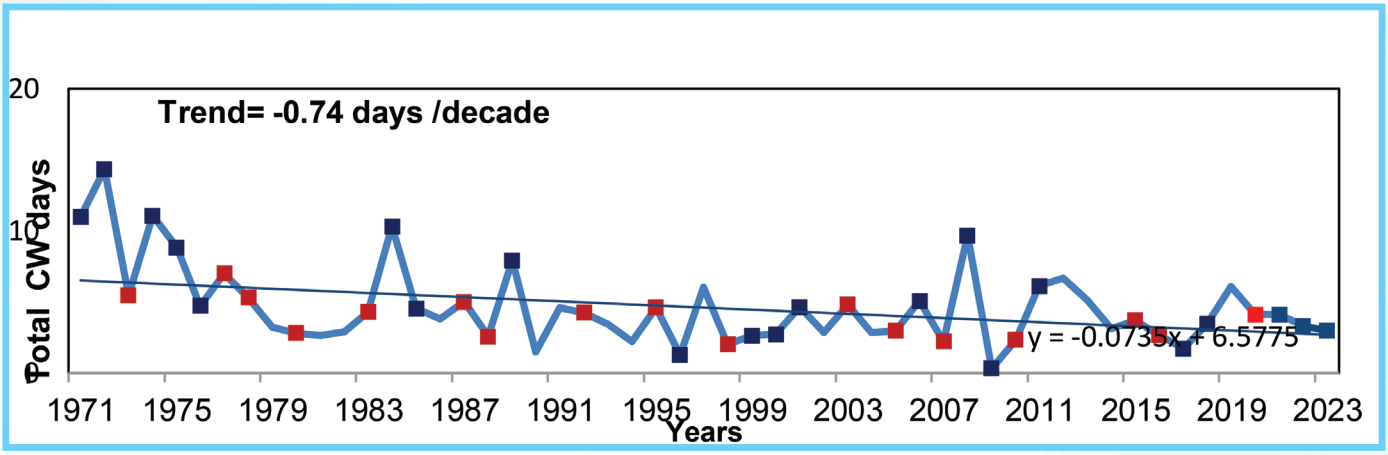


Fig. 2 (b) Cold wave days since 1971

c) Tropical Cyclones

The impact of the shifting climate on extreme phenomena like tropical cyclones stands as a significant societal and scientific concern. Various studies have demonstrated an upward trend in the occurrence of intense tropical cyclones (TCs) in the Northern Indian Ocean (NIO), particularly during the months of heightened TC activity, namely November and May [14][15][16]. Traditionally, the Bay of Bengal (BoB) has experienced a higher frequency of tropical cyclones (TCs) compared to the Arabian Sea (ARB). However, recent years have seen a greater number of TCs forming in the ARB than in the BoB. As per a study the frequency of tropical cyclones indicates a declining trend in recent decades compared to earlier decades however, the frequency of intense cyclones has escalated in the North Indian Ocean (NIO) region, posing substantial risks and vulnerabilities to coastal areas [17]. In a study for period from 1982 to 2019, a noteworthy upward trend in the intensity, frequency, and duration of cyclonic storms (CS) and very severe cyclonic storms (VSCS) has been observed over the ARB [18]. Specifically, there has been a 52% increase in the frequency of cyclonic storm during the recent epoch (2001–2019) in the Arabian sea, while there has been an 8% decrease in the Bay of Bengal [18]. This study also pointed out that over the Arabian Sea, there has been an 80% increment in cyclonic storm duration and a nearly threefold increase in very severe cyclonic storm during the recent epoch compared to the earlier period (1982–2000). Additionally, both the lifetime maximum intensity and accumulated cyclone energy have shown an increase over the Arabian Sea, indicating a strengthening of tropical cyclones in this region. Detailed analysis distinctly indicated a notable upward trend of approximately 16.75%

in the intensity of severe cyclonic storms that developed over the North Indian Ocean in the preceding four decades [19]. According to the sixth assessment report by the Intergovernmental Panel on Climate Change (IPCC), there is a highlighted emphasis on the heightened occurrence of more powerful tropical cyclones (TC, falling within categories 3–5) during the past four decades. The Northern Indian Ocean displays similar trends in this regard and is a cause of concern for human health and safety.

The analysis of data during 1965-2022 as shown in Fig.3, indicate that there is decreasing trend in frequency of genesis of all categories of cyclonic storms over Bay of Bengal and North Indian Ocean except extremely severe cyclonic storm (ESCS) category. There is no significant change in frequency of ESCS category over the Bay of Bengal and NIO. Similarly, there is no significant change in different categories of cyclonic storms over the Arabian Sea except ESCS category. ESCS category shows significant increasing trend over the Arabian Sea. The analysis of data during 1965-2022 as shown in Fig. 4, indicate that there is decreasing trend in cumulative frequency of genesis of all categories of cyclonic storms & above over the Bay of Bengal and NIO except the ESCS & above category. The ESCS & above category shows no significant trend over the Bay of Bengal and NIO. Over the Arabian Sea, all categories show increasing trend, being significantly increasing trend for ESCS & above.

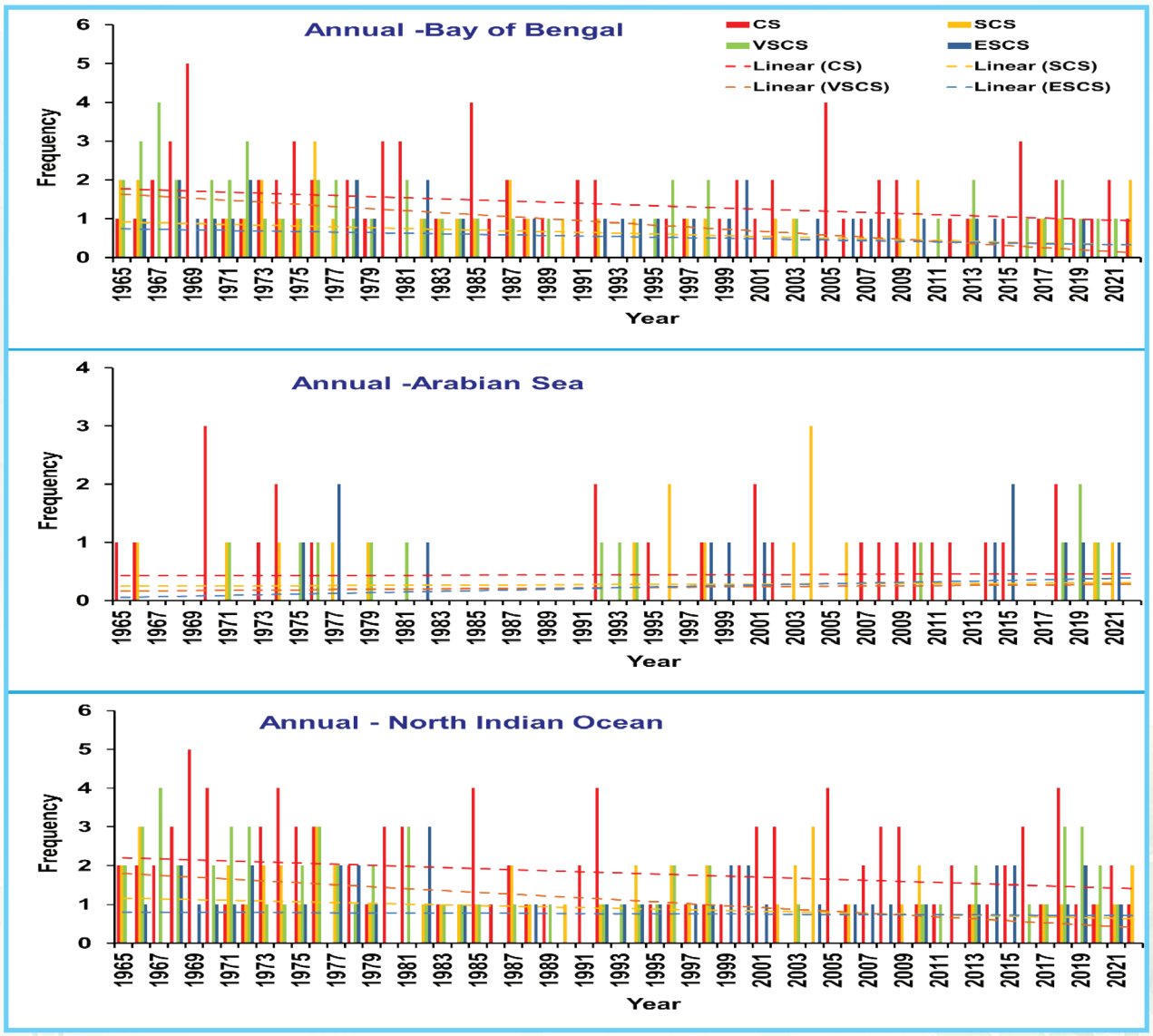


Fig. 3 Annual Frequency (individual category) of genesis of cyclonic storm and above category (≥ 34 knots) over (a) Bay of Bengal, (b) Arabian Sea and (c) North Indian Ocean.

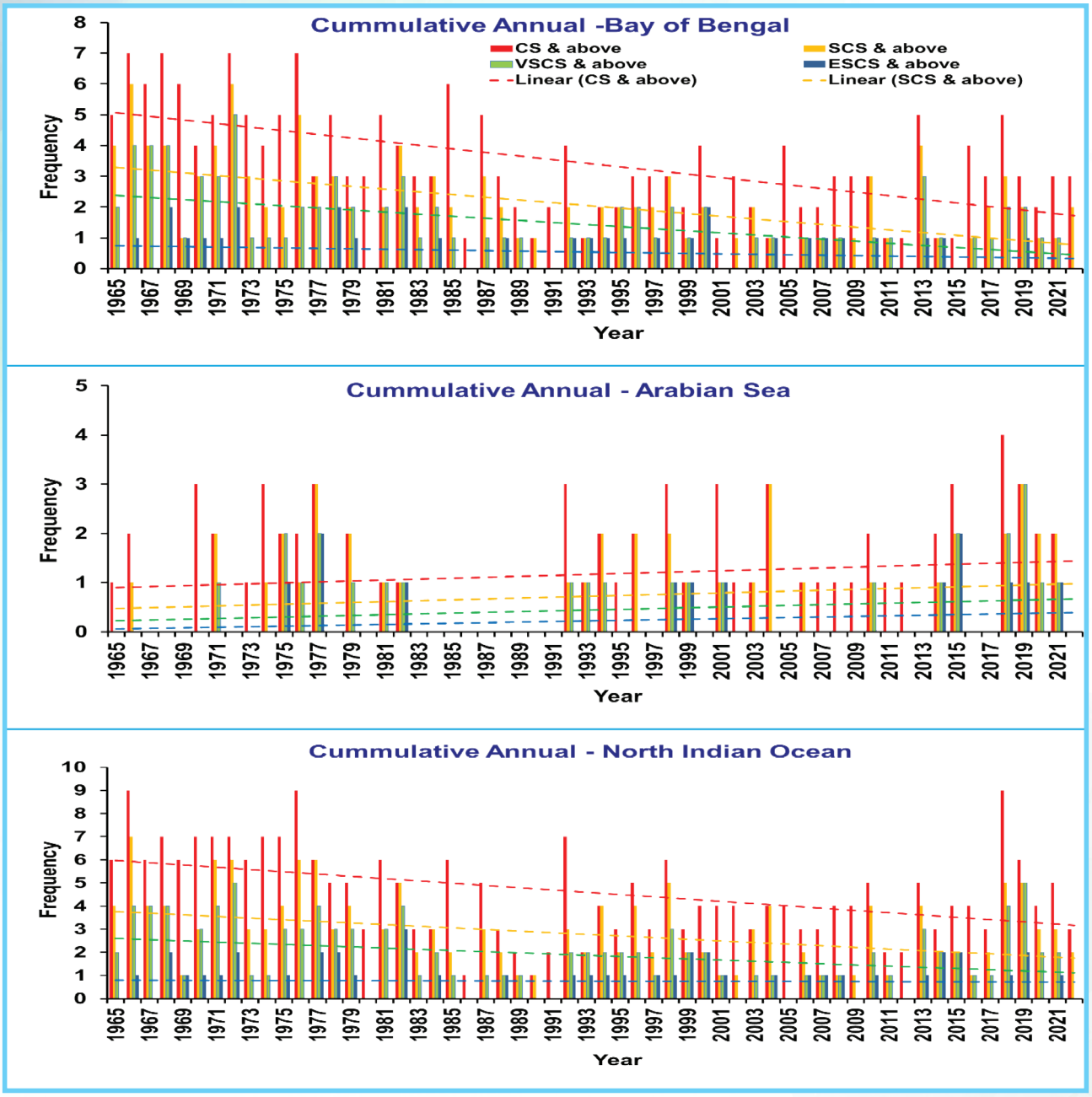


Fig. 4 Cumulative Annual frequency of genesis of cyclonic storm & above category (≥ 34 knots), severe cyclonic storm & above (≥ 50 knots), very severe cyclonic storm & above (≥ 64 knots) and extremely severe cyclonic storm & above (≥120 knots) over (a) Bay of Bengal, (b) Arabian Sea and (c) North Indian Ocean during 1965-2022

These extreme and hazardous weather events pose direct and indirect risks to human health in terms of accidents due to flying objects, snake bites in the coastal flooded regions and different other tertiary health impacts due to improper maintenance of hygiene during these natural calamities. Epidemiological research relates cyclones to mortality, noncommunicable diseases, adverse birth outcomes, infectious diseases, and mental health issues. Cyclones can displace communities, causing a major health problem. The overcrowded temporary shelters can spread respiratory, cutaneous, vector-borne and other epidemiological diseases. Diseases might spread faster in these settings due to poor sanitation and hygiene. Mental health issues are also vital as post-traumatic stress disorder, anxiety, and depression can result from cyclones. Losing homes, livelihoods, and loved ones can have long-term mental health impacts.

d) Thunderstorms & Lightning

Thunderstorm along with Lightning activity represents a significant destructive element of force of nature across India. Moreover, the intensity of these lightning strikes is notably pronounced along the coastal regions and in the Bay of Bengal. Thunderstorm is also seen to be changing its characteristics in terms of spatial and temporal displacements thereby beating the adaptability capabilities of human being and bringing more damage to human health. It is found in a study based on 50 years of data (1967-2016) that there is a decreasing trend in thunderstorm activity over the thunderstorm maximum region in east and northeast India in the monthly as well as annual scale, and a corresponding increasing trend over west central India, where thunderstorm frequency is less [20]. A study found that during the period from 1998 to 2014, lightning exhibited a significant intensification, growing annually by approximately 1% to 2.5% across all Indian regions, with the most pronounced trends observed along the coasts [21]. Rising surface temperatures have led to increased instability and subsequent stronger moisture transport to the upper-troposphere and lower-stratosphere regions, particularly along the coasts. This transported moisture contributes to a reduction in ozone concentration, resulting in decreased temperatures and heightened equilibrium levels, ultimately leading to more robust and frequent lightning events, as confirmed by trend analysis [21]. This study also predicts that the lightning frequency and intensity across the Indian region will increase by approximately 10% to 25% and 15% to 50%, respectively, by the end of the century, with the highest risks anticipated along the coasts, necessitating immediate attention from disaster managers and healthcare professionals. Long-term trends in the frequency of thunderstorm days, investigated using fifty years of data during 1967-2016, as recorded by weather observatories throughout India, indicates that there are spatially cohesive trends in thunderstorm activity. Fig. 5 (a) displays three separate boxes for analysing the trends over three specific regions: East Central Indian region (outlined as “A” in Figure 5 (a)), west central Indian region (outlined as “B” in Figure 5 (a)) and northeast Indian region, (outlined as “C” in Figure 5 (a)). The trends of thunderstorm day occurrence over these regions is displayed in fig 5 (b). The data indicates that, annually, in the areas of east central and northeast India where the climatological frequency of thunderstorm activity is most pronounced, there was initially a cohesive spatial decline, succeeded by a subsequent increase in recent years. In east central India, the minimum was observed in 1991, followed by a subsequent upward trend. In northeast India, the frequency of thunderstorm days declined until 2001 before exhibiting an upward trajectory

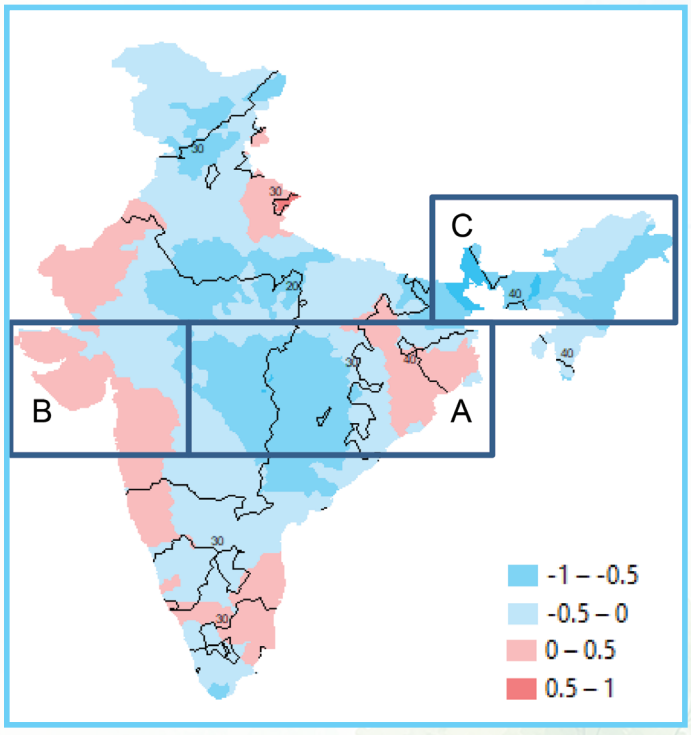


Figure 5 (a): Climatology of average number of thunderstorm days per year over the Indian region (black contours). Boxes demarcate sub regions for detailed analysis.

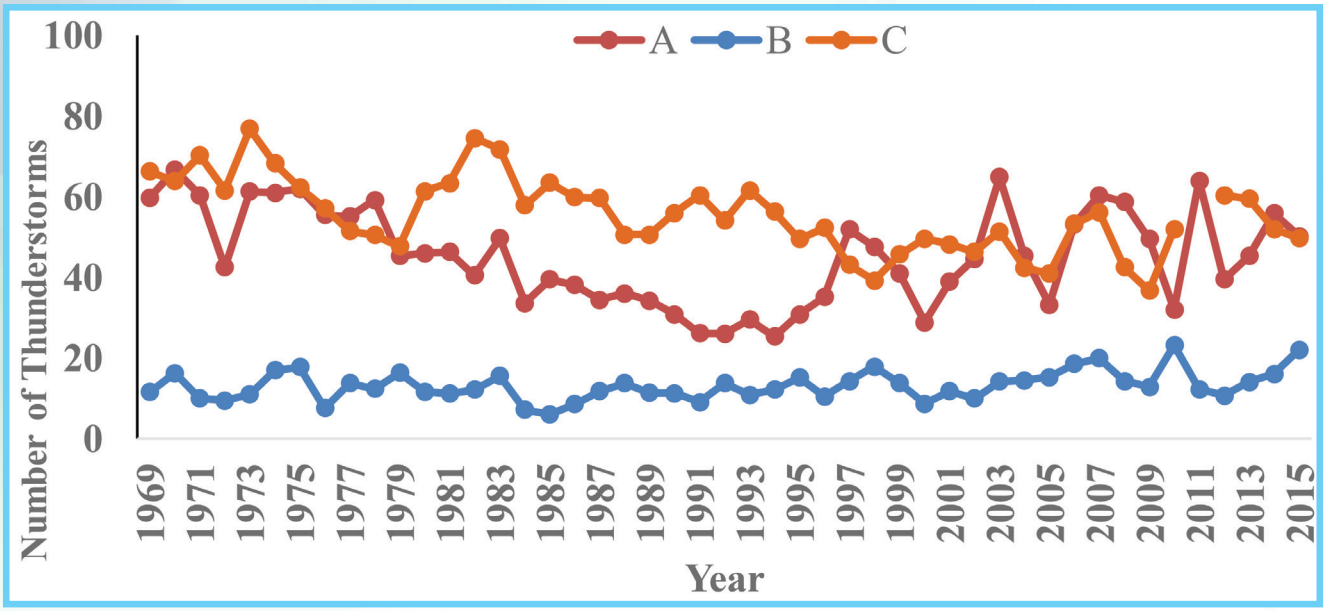


Figure 5 (b): Annual variations in frequency of thunderstorms for all stations of the subregions inside each box

e) Precipitation

Precipitation plays a vital role in the global water cycle and economy [22]. In the case of India, the monsoon rains during the June-September period, which account for over 75% of the yearly rainfall are crucial for the nation's agriculture and economy [23][24]. The Indian monsoon precipitation has been seeing abrupt variations over decades and centuries [25][26]. The all-India annual and summer monsoon mean rainfall have displayed a declining trend from 1951 to 2015, particularly evident in regions across the Indo-Gangetic Plains and the Western Ghats [27]. Over the last 15 years, beginning in 2005 and concluding in 2020, there has been a temporary decline in the temporal frequency of monsoonal precipitation extremes specifically over Central India [28]. Meanwhile, the occurrences of low and moderate precipitation events have displayed upward trends during this period [28]. These alterations seem to be influenced by amplified levels of human-generated aerosols over the northern hemisphere [27]. Between 1951 and 2015, there has been a notable rise in the frequency of localized heavy rain occurrences across India. It is probable that this increase is influenced by urbanization, other land-use changes, and aerosols, which collectively contribute to the occurrence of localized heavy rainfall [27]. The fig 6 (a) and fig 6 (b) are also depicting the declining trend in the annual and southwest monsoon rainfall during 1901 to 2021. It is also indicated in few reports that the Dry years are expected to be drier and wet years wetter (https://www.worldbank.org/en/news/feature/2013/06/19/india-climate-change-impacts). Not only the amount of precipitation is shifting but studies are also suggesting shifting nature of precipitation activities for instance west coast of India largely dominated by stratiform rainfall saw more of convective rainfall activity during monsoon 2019 [29].

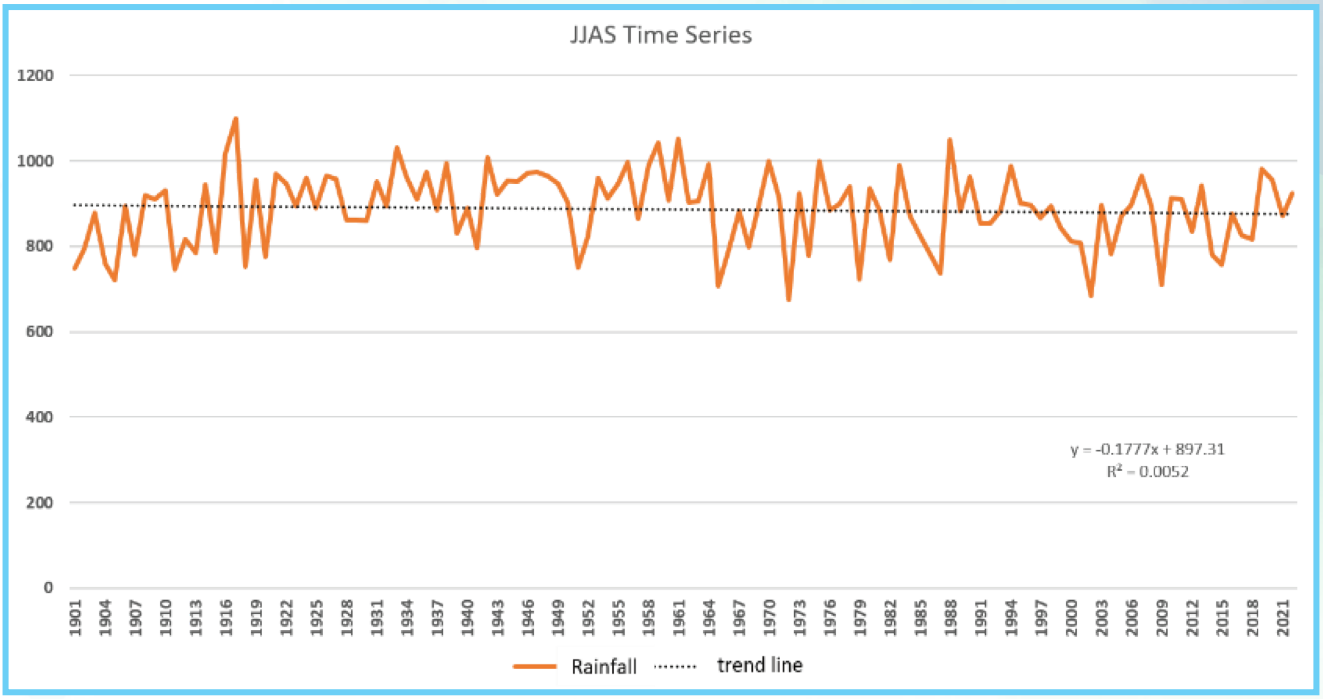


Figure 6 (a): All India Rainfall annual time series and trendline.

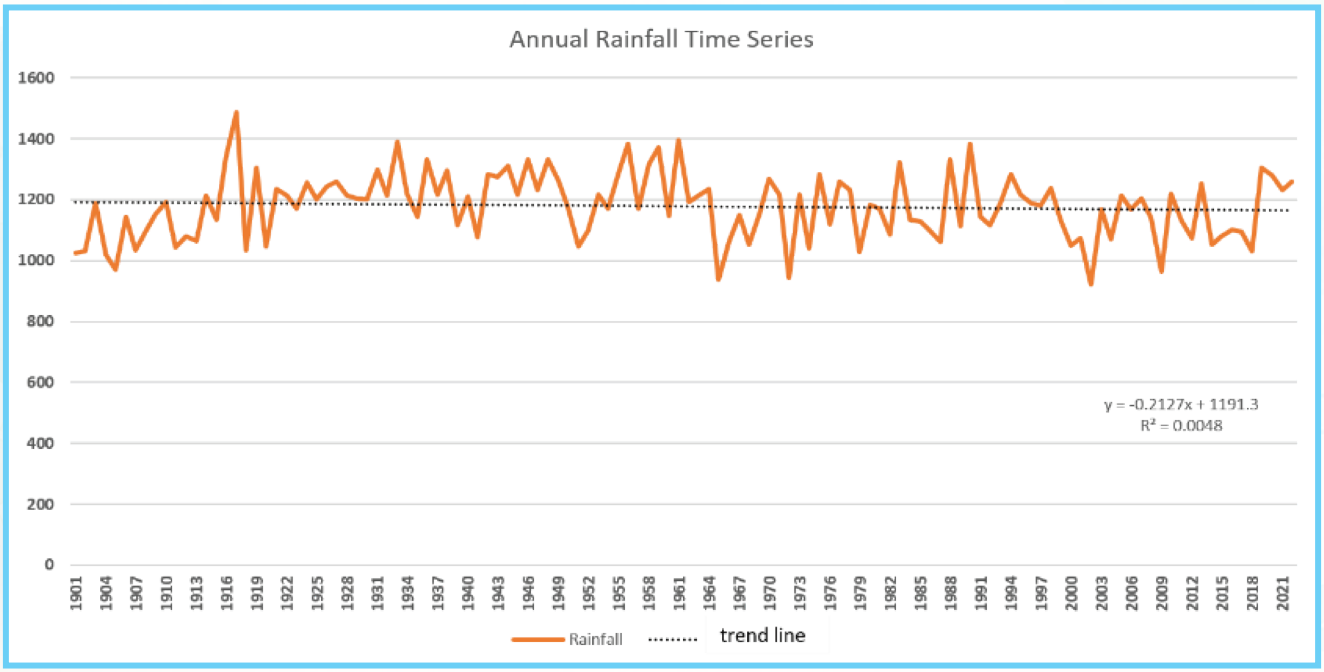


Figure 6 (b): All India Rainfall time series and trendline during monsoon (Jun-Sep).

Rainstorm is a storm characterized by substantial heavy rainfall. It is an extreme rainfall event experienced over a particular area for a particular period, in association with various weather systems of different spatial scales. Many times, it has been observed that rainstorms lead to floods and landslides. India Meteorological Department has classified the rainfall events into different categories based on the intensity of the rainfall. The fig 7 (a) illustrates the patterns of station-specific rainfall events categorized as heavy (64.5 to 115.5mm), very heavy (115.6 to 204.4mm), and extremely heavy (greater than 204.4mm) for the South-West Monsoon season (JJAS) and fig 7 (b) for the annual rainfall from 1951 to 2022. Only trends with a statistical significance exceeding 95% for the period 1951-2022 are considered here. Blue arrows indicate a notably negative trend, while red arrows signify a significantly increasing trend. Between 1951

and 2022, it has been noted that for Southwest monsoon season 1215 stations exhibit a significant rise in heavy rainfall, 974 stations in very heavy rainfall, and 511 stations in extremely heavy rainfall. Conversely, 1492 stations show a statistically insignificant decrease in heavy rainfall, 1171 stations in very heavy rainfall, and 514 stations in extremely heavy rainfall. Whereas, with respect to annual rainfall consideration it is observed that 1303 stations experienced a significant increase in heavy rainfall, 1056 stations in very heavy rainfall, and 534 stations in extremely heavy rainfall. Conversely, 1722 stations displayed a statistically insignificant decrease in heavy rainfall, 1259 stations in very heavy rainfall, and 578 stations in extremely heavy rainfall over the same period. Thereby indicating statistically significant increasing trend in heavy, very heavy and extremely heavy rainfall during southwest monsoon as well as during entire year.

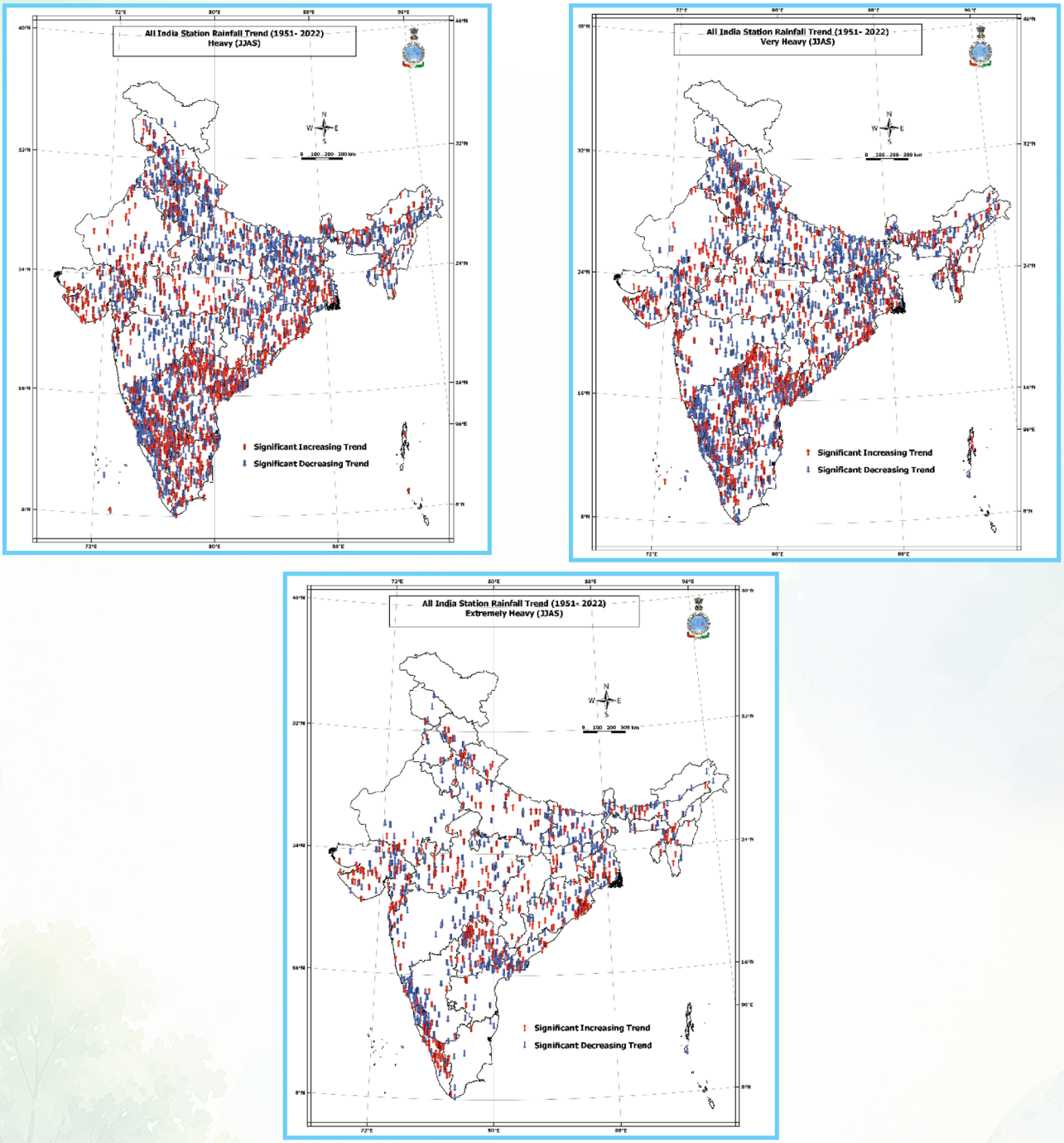


Fig 7 (a): Patterns of station-specific rainfall events categorized as heavy (64.5 to 115.5 mm), very heavy (115.6 to 204.4 mm), and extremely heavy (greater than 204.4 mm) for the South-West Monsoon season (June to September).

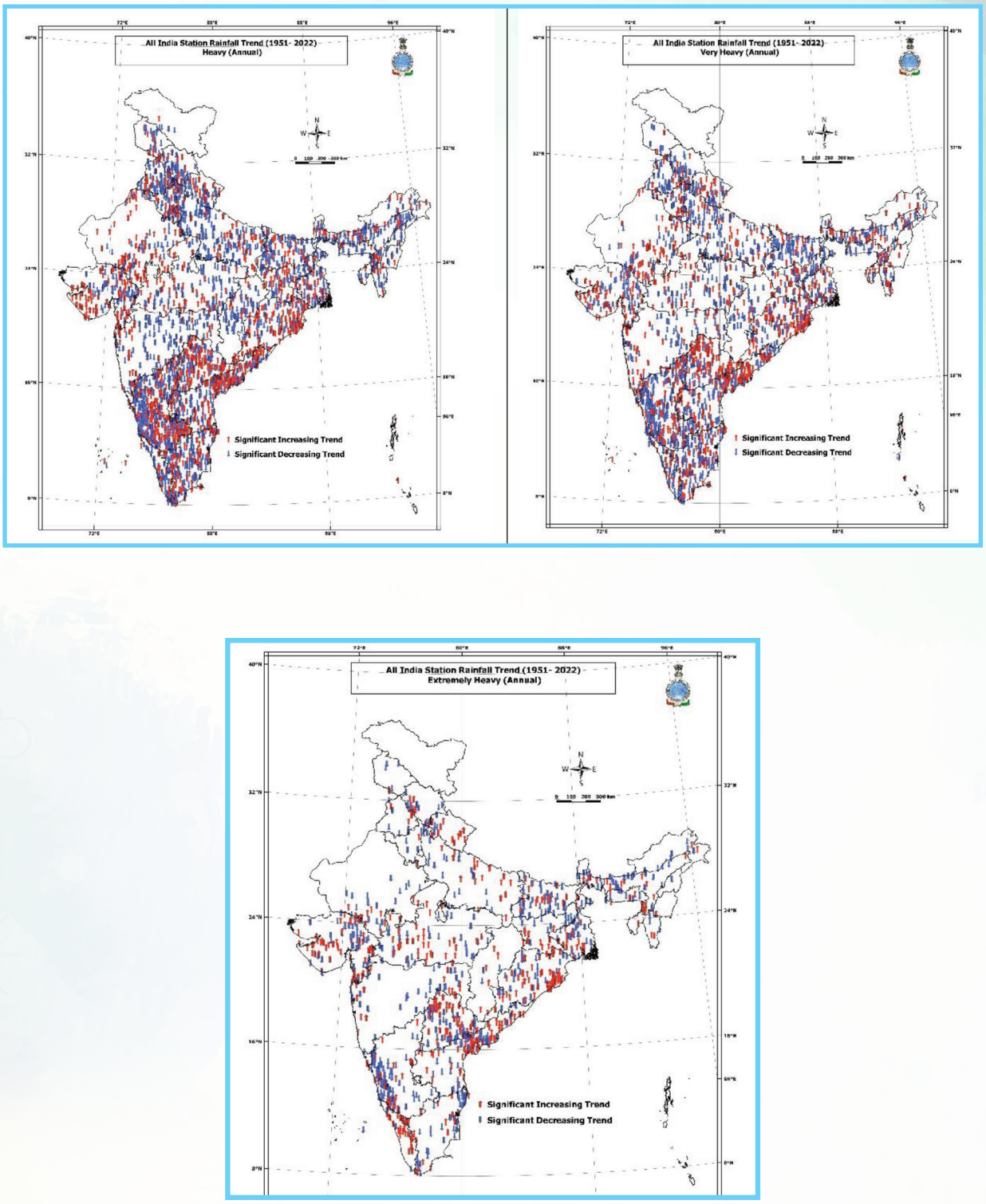


Fig 7 (b): Patterns of station-specific rainfall events categorized as heavy (64.5 to 115.5 mm), very heavy (115.6 to 204.4 mm), and extremely heavy (greater than 204.4 mm) for entire year (January to December)

In future also, different climate projections are indicating variation in precipitation activities. Anticipated projections indicate a potential escalation in the frequency and intensity of events, characterized by an average daily rainfall exceeding 20 mm [30]. As a whole, this study suggests that water-related disasters, including flooding and landslides, may considerably exacerbate in India due to the effects of climate warming. In a study which examined 90 climate models from four consortium CMIP5, CMIP6, NEX-GDDP, and CORDEX suggested increased precipitation over central eastern

and north-eastern India in the monsoon season, and over peninsular India during post-monsoon months [31]. A growing consensus, supported by numerous datasets and simulations from climate models, indicates that the radiative impact of human-induced aerosol forcing across the Northern Hemisphere has substantially counteracted the anticipated rise in precipitation resulting from greenhouse gas (GHG) warming. This counteraction has contributed significantly to the observed reduction in summer monsoon precipitation. Based on CMIP5 models and the expectation of ongoing global warming along with predicted decreases in anthropogenic aerosol emissions in the future, projections indicate a likely surge in both the average and variability of monsoon precipitation by the conclusion of the twenty-first century. Moreover, these models also suggest significant amplification in the occurrences of extreme daily precipitation events.

❑ Impact of changing weather characteristics on health

i. Mortality and Morbidity in association with different weather events

The changing weather patterns are also bringing up different direct and indirect tertiary hazards. These threats with respect to health, life and wellbeing of human beings have been a major concern while dealing with the changing climate. The impacts of climate change on health, encompassing heightened exposure to heat, compromised air quality, extreme weather occurrences, altered transmission of vector-borne diseases, diminished water quality, and compromised food security, affect men and women, children and aged differentially. Within India, where rapid environmental shifts are occurring, climate change poses a threat to exacerbating pre-existing gender-based health inequalities [32]. Increasing frequency of extreme heat events and rising average seasonal temperatures leads to increased morbidity and mortality. Annually, a significant number of hospitalizations are linked to exposure to extreme ambient temperatures, particularly in the context of heatwaves and cold spells [33][34][35][36]. The elderly is more susceptible to both heat- and cold-related health issues, as indicated by research [37][38][39][40]. Additionally, urban residents are often exposed to higher temperatures compared to those living in suburban and rural areas due to the “heat island effect.” This phenomenon is caused by various factors, including increased heat absorption by dark surfaces, heat emissions from vehicles and air conditioning units, a lack of vegetation and trees, and poor ventilation [41][42][43]. As a result, people in urban areas face an increased risk of health problems due to heightened ambient heat exposure [43]. The findings by few studies indicate that forthcoming climate warming is likely to result in significant upsurges in heat-related mortality, particularly in developing nations situated at lower latitudes, like India. This prediction is primarily attributed to the projected increase in the frequency of heatwaves and the heightened vulnerability of populations in these regions to extreme temperatures [9]. These impacts of temperatures are getting amplified in view of the global rise in temperatures.

Tropical cyclones are also witnessing increased intensity over North Indian Ocean. The torrential rain and high windspeed accompanying the cyclone cause lot of damage to life and property. There has been considerable reduction in the deaths directly associated with the tropical cyclones due to improved accuracy in the forecast and lead times [44][45]. However, still the tertiary health conditions are a challenge for the healthcare sector. The global recognition of an elevation in diarrheal diseases following various types of natural disasters highlights a concerning

trend [46]. Significant natural calamities, including floods, tsunamis, earthquakes, tropical cyclones, and tornadoes, can intensify the risk factors for the spread of infectious diseases [47]. This exacerbation is primarily due to the disruption of already inadequate water, sanitation, and sewage systems [48]. During a cyclone, the breakdown of the water distribution system, coupled with insufficient hygiene, sanitation, and limited access to healthcare services, notably elevates the likelihood of cholera outbreaks within affected areas [49][50]. Similar results were found with respect to cholera outbreak in Puducherry aftermath of Severe cyclonic storm "Thane" making landfall from Bay of Bengal on 30th December 2011[51].

The impact of cyclonic storms on waterborne diseases can vary, depending on the specific characteristics of the storm that dictate the level of flooding and destruction [52]. Storms are typically characterized by their wind speed and rainfall, which are often weakly correlated upon making landfall and can result in differing conditions within affected regions [53]. Slower-moving storms tend to bring about a significant accumulation of rainfall and more extensive flooding, while tropical cyclones with higher wind speeds might lead to less precipitation but cause property or infrastructure damage due to strong winds [54]. The type of storm can also influence decisions related to disaster management and individual-level responses, including the ability to comply with evacuation orders. Furthermore, the severity of the storm impacts healthcare-seeking behavior and healthcare infrastructure. Storm-related disturbances might deter individuals with mild or moderate conditions from seeking medical attention [55], whereas catastrophic storms can hinder those with urgent medical needs from accessing healthcare systems [56].

The projected escalation in storm severity owing to atmospheric warming underscores the critical need for a thorough understanding of the impact of storms on waterborne diseases, offering valuable insights for the development of effective climate change adaptation strategies and public health policies [52]. Apart from communicable diseases, there is substantial evidence supporting the concept that high-intensity cyclones could notably elevate the risks of mental disorders, particularly post-traumatic stress disorder (PTSD), alongside heightened mortality rates and hospitalizations. However, the evidence pertaining to other health outcomes, such as chronic diseases (e.g., cardiovascular diseases, cancer, diabetes) and adverse birth outcomes, remains either limited or inconsistent [57]. In view of climate change more research focused on storms, outbreaks, general gastrointestinal illnesses, comprehensive investigations encompassing multiple storm seasons are required in the Indian setup to formulate public health plans and interventions aimed at mitigating the adverse health consequences stemming from tropical cyclones.

Lightning, often coupled with severe weather phenomena such as thunderstorms and hailstorms, stands as one of the most fatal localized natural occurrences. It represents the primary cause of injury and fatality compared to other natural hazards [58]. The combination of hot weather and humidity fosters the optimal environment for the development of thunderstorms. Climate change, resulting in localized heating of the Earth's surface and an influx of moisture, contributing to a notable surge in the frequency of large-scale lightning occurrences. The increased incidence of lightning brings with in increased risk of deaths and injuries to humans as well as livestock's. While a direct strike is frequently perceived as the most prevalent cause of injury, it is relatively uncommon. In contrast, ground current, side

flash, upward leader, and direct contact are more frequently observed mechanisms of injury [59]. Lightning not only is fatal to human beings but in case of survivals may bring permanent damages to the human beings requiring long-term medical interventions. When a large amount of energy in form of lightning enters human body, it can disrupt the electric signals that govern the functioning of the heart, lungs, and nervous system. This disruption can lead to several potential consequences, including: cardiac arrest, brain injury, seizures, spinal cord damage and amnesia etc. In developed countries, lightning tends to result in neurological injuries rather than substantial burn injuries in the majority of cases. However, in developing nations, it can lead to notable burn injuries under specific conditions, in addition to causing neurological and long-term harm [59]. In view of the increasing incidences of lightning attributed to climate change increased burden on health care sector with respect to injuries and fatalities due to lightning could be a reality in coming years.

Thunderstorm on the other hand in conjunction with lightning are fatal but also generates different medical requirements. Thunderstorm asthma pertains to an observed surge in cases of acute bronchospasm subsequent to the occurrence of thunderstorms within the local vicinity [22]. While rainfall can alleviate symptoms for individuals with asthma and allergies by cleansing the environment of dust and pollen, the occurrence of thunderstorms can trigger what is commonly referred to as 'thunder fever.' This phenomenon arises when the downward-moving cold air currents, typically associated with warm weather and thunderstorms, lead to the concentration of mold or pollen. Subsequently, these air particles are lifted up to the clouds, where the interplay of wind, moisture, and lightning breaks them down into smaller particles. These smaller allergens are then dispersed by gusty winds during the thunderstorm, intensifying the severity of asthma attacks and allergic reactions. While there is no precise definition based on the extent of the increase in asthma cases, thunderstorm asthma epidemics are infrequent and occur only when specific factors related to the population, meteorology, and environment align [60]. Individuals affected by this phenomenon typically present with characteristic symptoms of acute asthma, including coughing, wheezing, and shortness of breath [60]. The substantial number of people affected has the potential to overwhelm locally available healthcare services and in rare cases, thunderstorm asthma can result in fatalities [61]. In a study based on the data from 1990 to 2016 an increase of 8.6% is seen in the prevalence of respiratory conditions, including asthma [62]. Thereby, making the thunderstorm and their shifting patterns in view of climate change a concern for the healthcare sector with respect to respiratory diseases in general and asthma in particular.

The frequency of intense precipitation events has increased and climate projections indicate that it is expected to continue in the future. This rise in both extreme precipitation and overall precipitation has significantly contributed to the occurrence of severe flooding events in different areas [63]. Furthermore, the acceleration in the rate of multi-day flood events is anticipated to surpass that of single-day events in the future, carrying significant implications for both agriculture, infrastructure and healthcare sector [63]. Different studies have indicated a surge in outbreaks of waterborne diseases in the weeks following heavy rainfall, although various factors may influence these connections. Water seepage into buildings can lead to mold contamination later on, exacerbating indoor air quality issues. Structures damaged

during hurricanes are particularly vulnerable to water intrusion. Individuals living in damp indoor environments are more susceptible to an increased prevalence of asthma and other upper respiratory tract symptoms, such as coughing and wheezing, as well as lower respiratory tract infections, including pneumonia and respiratory syncytial virus (RSV) infections and RSV pneumonia [64]. Conversely, at the other end of the spectrum, drought conditions also pose significant risks to public health and safety. Droughts can increase exposure to various health hazards, including wildfires, dust storms, extreme heat events, flash flooding, degraded water quality, and reduced water availability. Dust storms associated with drought conditions contribute to compromised air quality due to particulate matter and have been linked to an increased incidence of coccidioidomycosis (valley fever), a fungal pathogen etc. [64]. Between 1951 and 2015, there has been a marked increase in the frequency and geographical coverage of droughts across India [84]. The severity of droughts has particularly intensified in the central regions of the country, encompassing sections of the Indo-Gangetic Plains [65]. On the other hand, the heightened occurrence of localized heavy rainfall at sub-daily and daily intervals has notably amplified the risk of flooding throughout India, particularly within urban regions [65]. According to climate model projections, there is a forecasted rise in the frequency, geographical coverage, and severity of droughts across India during the twenty-first century. Simultaneously, there is a high level of confidence in the projection that the susceptibility to flooding will intensify in the major Himalayan River basins, including the Indus, Ganga, and Brahmaputra, in the coming years [65]. Thereby, making a complex challenge for the healthcare sector to deal with the flood as well as droughts related medical complications.

ii. Vector Borne Diseases: (Dengue, Malaria, Japanese encephalitis etc.)

Outbreaks of Vector borne disease (VBD) pose a serious challenge to healthcare professionals in terms of managing disease mortality, controlling disease transmission, and preventing financial loss. The World Health Organization identifies a list of major vectors borne diseases such as malaria, dengue, chikungunya, yellow fever, Zika virus disease, lymphatic filariasis, schistosomiasis, onchocerciasis, Chagas disease, leishmaniasis, and Japanese encephalitis [66]. Among all these diseases, the mosquito borne diseases (MBD) such as dengue pose a serious threat in different parts of India as shown in data from National Center for Vector Borne Disease Control (Table-1). India shows marked regional, spatial and temporal variations in terms of number of malaria and dengue cases [67][68][69]. Most of these incidents are localized in urban or rural areas. Prevention of such localized MBD outbreaks such as malaria and dengue and timely intervention to reduce the disease burden is important from community health practice perspective. Even though several intervention techniques are available, sometimes predictive outlooks can be useful for preparation against such outbreaks. There are several reasons for MBD outbreaks. Epidemiological modeling and simulation studies often relate the MBD outbreaks to vector growth and proliferation on different spatial and temporal scales, which are known to be related to the ambient weather and climatic factors like temperature, humidity, rainfall, etc. [69][70]. These studies showed that the temporal evolution of these climate factors act as “environmental drivers” for temporal evolution dynamics [71]. Several studies also assume environmental forcing as a driving factor for a near future estimation/ outlooks of such outbreaks using linear, non-linear, dynamical as well as statistical forecasting models [72][73][74].

Table 1. Dengue Cases and Deaths in the Country since 2018

(Source: https://ncvbdc.mohfw.gov.in/index4.php?lang=1&level=0&linkid=431&lid=3715)

Sl. No.	Affected States/UTs	2018		2019		2020		2021		2022		2023*	
		C	D	C	D	C	D	C	D	C	D	C	D
1	Andhra Pradesh	4011	0	5286	0	925	0	4760	0	6391	0	3926	0
2	Arunachal Pradesh	1	0	123	0	1	0	7	0	114	0	17	0
3	Assam	166	0	196	0	33	0	103	0	1826	2	5604	6
4	Bihar	2142	0	6712	0	493	2	633	2	13972	32	2515	7
5	Chattisgarh	2674	10	722	0	57	0	1086	0	2679	10	733	0
6	Goa	335	1	992	0	376	0	649	0	443	1	264	0
7	Gujarat	7579	5	18219	17	1564	2	10983	14	6682	7	3334	1
8	Haryana	1898	0	1207	0	1377	0	11835	13	8996	18	2892	4
9	Himachal Pradesh	4672	7	344	2	21	0	349	0	3326	1	596	0
10	J & K	214	0	439	0	53	0	1709	4	8269	18	1192	0
11	Jharkhand	463	1	825	0	79	0	220	1	290	0	958	2
12	Karnataka	4427	4	16986	13	3823	0	7393	7	9889	9	9185	0
13	Kerala	4083	32	4652	16	4399	5	3251	27	4432	29	9770	37
14	Lakshadweep	0	0	0	0	0	0	1	0	67	0	286	0
15	Madhya Pradesh	4506	5	4189	2	806	0	15592	11	3318	2	1544	0
16	Meghalaya	44	0	82	0	4	0	129	0	26	0	59	0
17	Maharashtra	11011	55	14907	29	3356	10	12720	42	8578	27	8496	2
18	Manipur	14	0	359	0	37	0	203	0	503	4	521	0
19	Mizoram	68	0	42	0	67	0	83	0	1868	5	821	1
20	Nagaland	369	0	8	0	1	0	24	0	154	0	400	0
21	Odisha	5198	5	3758	4	496	0	7548	0	7063	0	6563	0
22	Punjab	14980	9	10289	14	8435	22	23389	55	11030	41	4246	0
23	Rajasthan	9587	10	13706	17	2023	7	20749	96	13491	10	5094	6
24	Sikkim	320	0	444	0	11	0	243	1	264	0	163	0
25	Tamil Nadu	4486	13	8527	5	2410	0	6039	8	6430	8	4148	3
26	Tripura	100	0	114	0	24	0	349	0	56	0	744	0
27	Telangana	4592	2	13331	7	2173	0	7135	0	8972	0	5138	0
28	Uttar Pradesh	3829	4	10557	26	3715	6	29750	29	19821	33	5742	5
29	Uttrakhand	689	3	10622	8	76	1	738	2	2337	0	1588	14
30	West Bengal			NR	NR	5166	0	8264	7	67271	30	NR	NR
31	A& N Island	49	0	168	0	98	0	175	0	1014	3	540	0
32	Chandigarh	301	0	286	0	265	0	1596	3	910	1	93	0
33	Delhi	7136	4	5077	0	1269	0	13089	23	10183	9	5221	1
34	D&N Haveli	493	0	1491	2	248	0	547	0	685	0	478	0
35	Daman & Diu	163	0	625	2	71	0	279	0	228	0	94	0
36	Puduchery	592	2	2030	2	633	1	1625	1	1673	3	1233	2
	Total	**101192**	**172**	**157315**	**166**	**44585**	**56**	**193245**	**346**	**233251**	**303**	**94198**	**9**

Although the epidemiological model of malaria and dengue outbreaks relates several external factors to the growth of the parasite/mosquito, temperature and other climate-derived factors are known to be important driving factors for the growth of both the parasite and mosquito. This is shown in Fig. 8 for the malaria and dengue cases and rainfall interannual variability over the state of Kerala. Fig. 9 shows the monthly distribution of outbreaks. Outbreaks are defined to occur when the numbers of cases cross above a threshold value for a particular month (Fig. 9). For the state of Kerala, the panel shows that the outbreak peaks during the monsoon months indicating a relationship with rainfall.

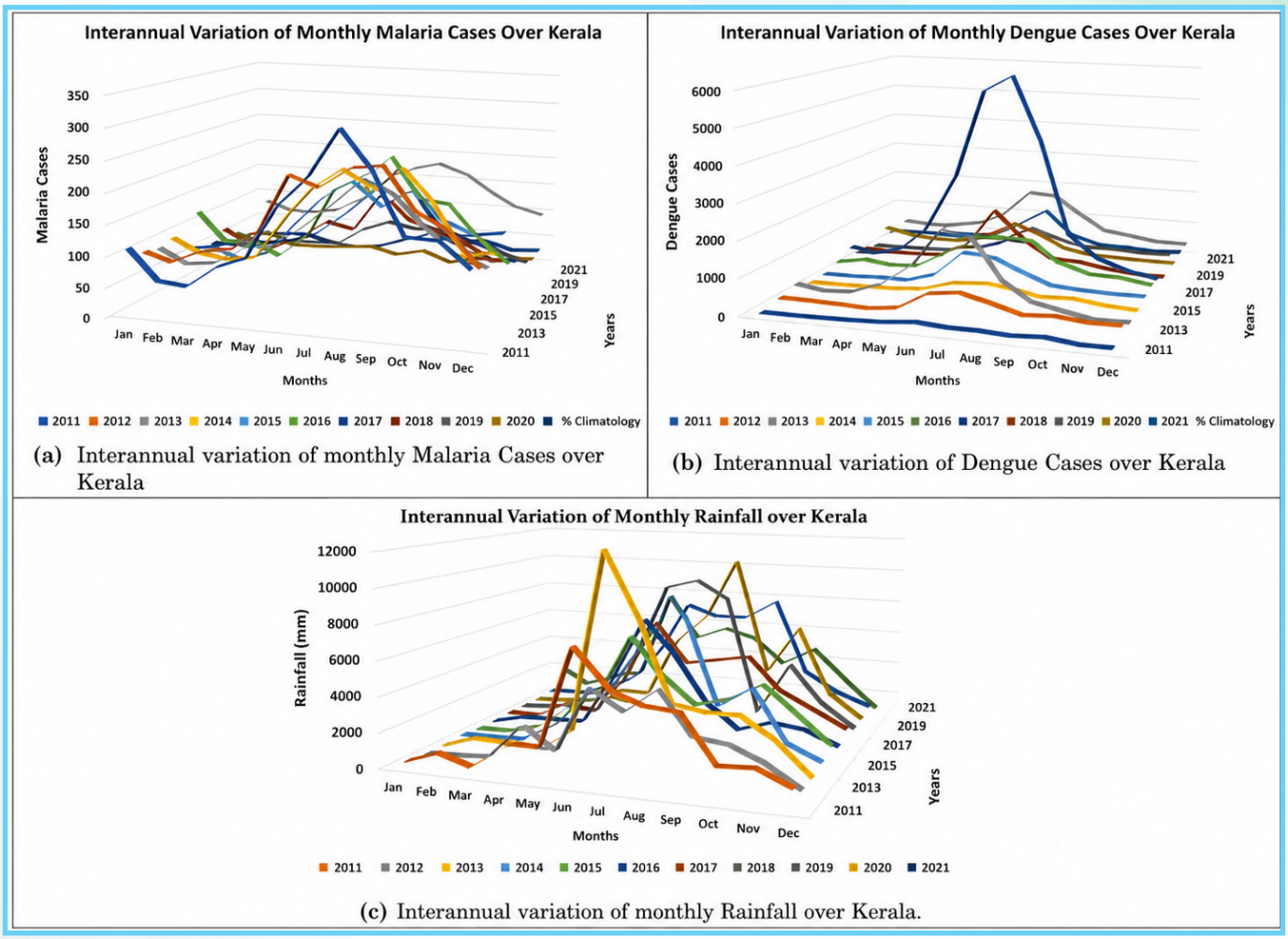
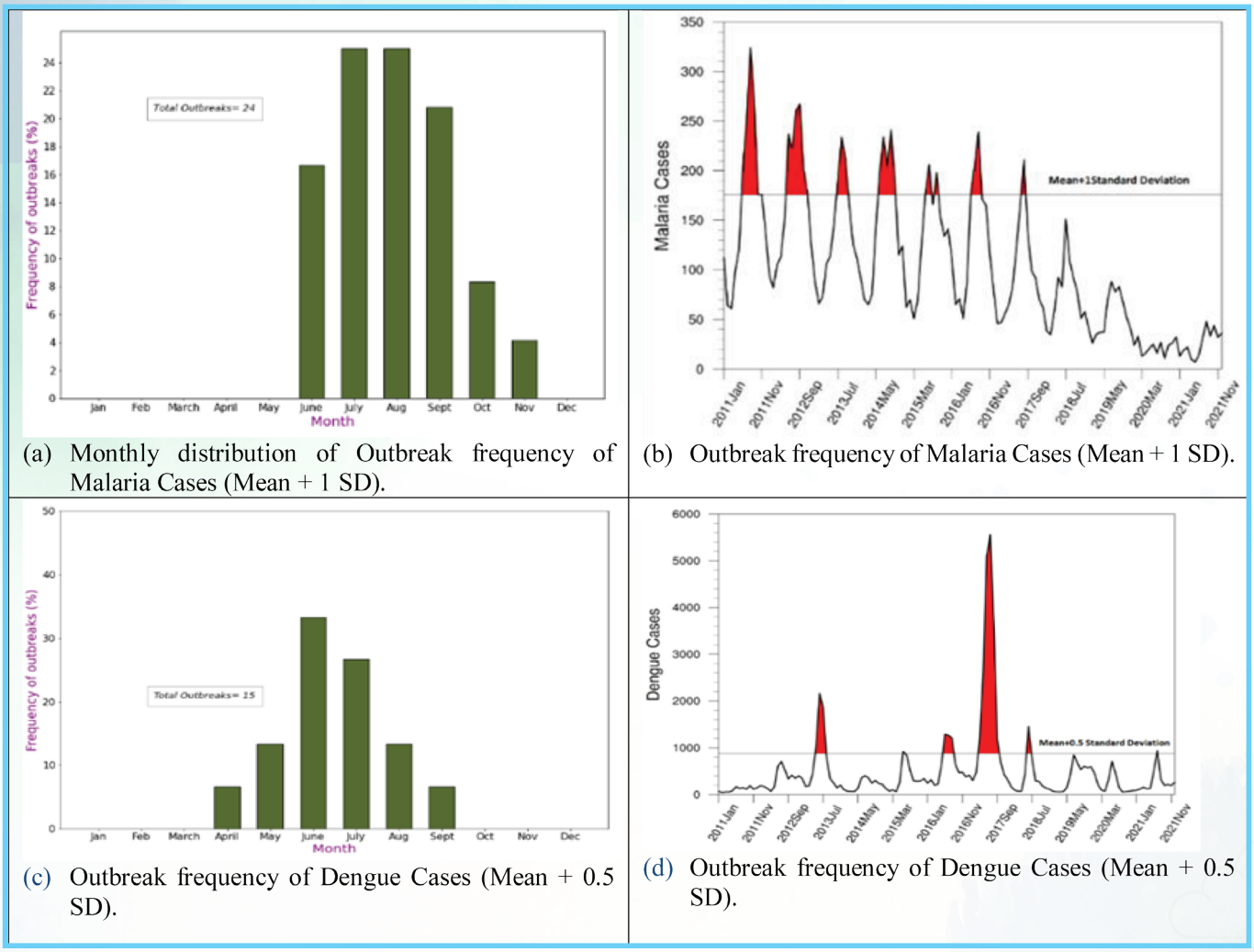


Fig 8: Interannual variation of Malaria cases, Dengue Cases and monthly Rainfall over Kerala.



(a) Monthly distribution of Outbreak frequency of Malaria Cases (Mean + 1 SD).

(b) Outbreak frequency of Malaria Cases (Mean + 1 SD).

(c) Outbreak frequency of Dengue Cases (Mean + 0.5 SD).

(d) Outbreak frequency of Dengue Cases (Mean + 0.5 SD).

Fig 9: Monthly distribution and outbreak frequency of Dengue and Malaria over Kerala.

The life cycle of malaria and dengue viruses involves two hosts: humans and mosquitoes. The viruses spread through bites from female Anopheles and Aedes mosquitoes, respectively, on infected people. The viruses undergo multiple developmental stages within the mosquito before being transmitted to another human. Both viruses are transmitted by mosquitoes, and their life cycle is closely linked to climatic factors. Since mosquitoes are ectotherms, temperature heavily affects the development of malaria and dengue viruses in mosquitoes. Elevated temperatures expedite the virus's growth, whereas lower temperatures decelerate it. Similarly, increased humidity levels likewise promote its progression. However, extreme temperatures can have a negative impact on virus transmission [75]. The extrinsic incubation period (EIP) is the time it takes for the pathogen to develop inside the mosquito before it can be transmitted to a human host. The EIP of malaria varies depending on the species of mosquito vector and the temperature. It typically ranges from 10 to 21 days. Dengue has an EIP of around 8 to 12 days, but similar to malaria, this can vary depending on temperature and other environmental factors. For both diseases, higher temperatures shorten the EIP, while lower temperatures lengthen it. Climate forcing can affect the transmission of both diseases by changing the distribution and abundance of mosquito vectors, which can impact their life cycle and the extrinsic incubation period [76]. Hence, such studies conclude that climatic factors are extremely important for MBD outbreaks.

In the context of climate change scenario and rise in global mean temperature, studies report frequent proliferation of MBD outbreaks [77][78][79]. In a study the sensitivity of extrinsic incubation

period (EIP) with respect to temperature was studied and found to be consequent upon the temperature fluctuations [80]. In the context of climate change scenarios, the result suggests the sensitivity of EIP with temperatures. It is clear that climate change can affect the incubation period thereby changing the malarial infection rate. In India, several studies suggest the development of favorable conditions for malaria transmission in a warming scenario in different regions where microclimates are affected by climate change. In a study related to the climatic trends in the state of Mizoram and adjoining areas near the Bangladesh border from 1981 to 2021 a statistically significant increasing trend in minimum temperature, relative humidity, rainfall, and the associated shift of regional climatic patterns from temperate to tropical monsoon, which could facilitate an increase in malaria transmission in this region was seen [81]. Similarly, analysis of near and far future temperature, humidity and rainfall trend suggest changes in the transmission pattern [82][83]. Utilising models one of the studies suggested that climate change may significantly increase the spatial spread of P. vivax (Pv) and P. falciperum (Pf) malaria with an increase in the transmission window's month and a shift in the pattern of the mean monthly cycle of transmission [83]. The study also pointed out regions of increase and decrease in transmission. For example, some areas in the western Himalaya are likely to have a new epicenter of Pv malaria transmission. Interior parts of some southern and eastern states are likely to become more suitable for Pf malaria Tran malaria. Study has also identified regions with a reduction in transmission months by the 2030s, leading to unstable malaria and a higher potential for malaria outbreaks. Similarly, another study over state of Odisha suggested that malaria transmission during the summer and winter monsoon seasons may decrease in the future due to climate change, except in a few districts with high elevations and dense forest regions, such as Kandhamal, Koraput, Raygada, and Mayurbhanj districts, where an increase in malaria transmission is found [84]. Thus, climate change projects the appearance of newer hotspots and a reduction in the transmission of malaria in some new hotspots. For policymakers and public health planners, this indicates the development of dynamic strategies of risk reduction depending on risk profiles and hotspots.

❑ Role of weather forecasting in mitigating impact of climate change on health.

India Meteorological Department (IMD) being a nodal agency, provides the weather forecast and weather warning in different spatial and temporal scale. The lead time for weather forecast and warning varies from nowcast (next few hours), very short range (next 12 hours), short range (up to 01-03 days), medium range (04-07 days), extended range (07-14 days), monthly (up to one month) and long range (1-3 months). IMD issues forecast and warning at block level, district level, city level, location-specific, sectoral, sub-divisional and national level. All these forecasts are disseminated to stakeholders including to healthcare sectors too. The skill for forecast and warning has been improving and is been effectively utilized in mitigation activities. As the extreme weather events (heavy rainfall, heat wave, cold wave, floods, etc.) have increased in both frequency and severity as a result of climate change. Hence, accurate weather forecast helps in predicting those extreme well, in advance with an actionable lead time thereby playing a crucial role in mitigating their impact on human health.

Weather forecasting helps in the development and implementation of early warning systems for extreme weather events like heat waves, cold waves, flash floods etc. These systems with proper health advisories may allow the public to prepare and take necessary precautions to minimize health risks. Similarly, the air quality is impacted by climate change, which results in

the accumulation of air pollutants like ozone and particulate matter. The ability to predict air quality conditions through the use of weather forecasting allows public health agencies to issue advisories regarding air quality and implement preventative measures to mitigate exposure to pollutants in the air. This entails providing guidance on mask usage and instructing susceptible demographics to remain indoors throughout episodes of increased pollution, and follow other measures as possible.

Concurrently, climate change has increased the occurrence and severity of weather-related natural disasters, such as flash floods, landslides, dust storms, and wildfires, among others. Weather forecasting plays a crucial role in the anticipation of the extent of such disasters, enabling authorities to issue evacuation directives and effectively coordinate disaster response attempts. Furthermore, the utilization of weather forecasts plays a crucial role in the evaluation of potential health risks that may arise following a disaster, such as the presence of contaminated water, and the occurrence of waterborne disease outbreaks, etc. There early warning services could be effectively utilized in the strategy ensuring the adequate availability of health care professionals, infrastructure and pharmaceutical interventions.

❑ Summary

The impacts of climate change on health are varied and far-reaching, resulting in fatalities and illnesses stemming from more frequent extreme weather events such as heatwaves, storms, and floods. Additionally, climate change disrupts food systems and contributes to the rise of zoonotic, food-, water-, and vector-borne diseases, while also fostering mental health issues. Moreover, climate change undermines several critical social determinants for good health, such as livelihoods, equality, and access to healthcare and social support structures. These health risks sensitive to climate disproportionately affect the most vulnerable and disadvantaged populations, including women, children, ethnic minorities, impoverished communities, migrants or displaced individuals, the elderly, and those with preexisting health conditions.

Current efforts aimed at tackling global warming primarily emphasize the mitigation of climate change. However, considering the projected implications such as increased temperatures, lightning intensity, varying precipitation levels, and evolving disease patterns in India, there is an urgent need for heightened scientific research and the development of strategies focused on climate adaptation and mitigation, especially concerning public health for the most vulnerable populations. Addressing climate risks necessitates collaborative efforts across multiple sectors, enhanced data collection, monitoring of gender-specific objectives, and inclusive stakeholder involvement. The role of efficient and effective early weather warning system for all is the cogwheel while transitioning towards climate change ready India.

References

1. Wu X, Lu Y, Zhou S, et al (2016) Impact of climate change on human infectious diseases: Empirical evidence and human adaptation. Environ Int 86:14–23. doi: 10.1016/j.envint.2015.09.007
2. Dhiman RC, Pahwa S (2010) Climate change and threat of vector-borne diseases in India: are we prepared? 763–773. doi: 10.1007/s00436-010-1767-4
3. Singh PK, Dhiman RC (2012) Climate change and human health: Indian context. 55–60
4. Moors E, Singh T, Siderius C, et al (2013) Climate change and waterborne diarrhoea in northern India: Impacts and adaptation strategies. Sci Total Environ 468–469:. doi: 10.1016/j.scitotenv.2013.07.
5. Messina JP, Brady OJ, Golding N, et al (2020) population at risk of dengue. Nat Microbiol 4:. doi: 10.1038/s41564-019-0476-8
6. Pai DS, Thapliyal V, Kokate PD (2004) Decadal variation in the heat and cold waves over India during 1971–2000. Mausam 2:281–92. https://doi.org/10.54302/mausam.v55i2.1083
7. Pai DS, Nair SA, Ramanathan AN (2013) Long term climatology and trends of heat waves over India during the recent 50 years (1961-2010). Mausam 64:585–604. https://doi.org/10.54302/mausam.v64i4.742
8. Kishore P, et al. Anthropogenic influence on the changing risk of heat waves over India. Sci. Rep. 2022;12:3337. doi: 10.1038/s41598-022-07373-3.
9. Mazdiyasni O, AghaKouchak A, Davis SJ, Madadgar S, Mehran A, Ragno E, Sadegh M, Sengupta A, Ghosh S, Dhanya CT, Niknejad M. Increasing probability of mortality during Indian heat waves. Sci Adv. 2017 Jun 7;3(6):e1700066. doi: 10.1126/sciadv.1700066. PMID: 28630921; PMCID: PMC5462497.
10. Murari, K. K., Gosh, S., Patwardhan, A., Daly, E., & Salvi, K. (2015). Intensification of future severe heat waves in India and their effect on heat stress and mortality. Regional Environmental Change, 15(4), 569 - 579. https://doi.org/10.1007/s10113-014-0660-6
11. Jaswal, A. K., Padmakumari, B., Kumar, N. & Kore, P. A. Increasing trend in temperature and moisture induced heat index and its effect on human health in climate change scenario over the Indian sub-continent. J. Clim. Change 3, 11–25. https://doi.org/10.3233/JCC-170002 (2017).
12. Ratnam, J. V., Behera, S. K., Ratna, S. B., Rajeevan, M. & Yamagata, T. Anatomy of Indian heat waves. Sci. Rep. 6, 24395. https://doi.org/10.1038/srep24395 (2016).
13. IMD Met. Monograph: MoES/IMD/Synoptic Met/01(2023) Heat and Cold Waves in India Processes and Predictability.
14. Singh OP (2007) Long-term trends in the frequency of severe cyclones of Bay of Bengal: observations and simulations. Mausam 58:59-6
15. Singh OP, Khan TMA, Rahman S (2001) Has the frequency of intense tropical cyclones increased in the North Indian Ocean? Curr Sci 80:575-580

16. Srivastav AK, Sinha Ray KC, De US (2000) Trends in the frequency of cyclonic disturbances and their intensification over Indian Seas. Mausam 51:113-118

17. Bhatla, R., Raj, R., Mall, R.K. and Shivani, (2020). Tropical Cyclones Over the North Indian Ocean in Changing Climate. In Techniques for Disaster Risk Management and Mitigation (eds P.K. Srivastava, S.K. Singh, U.C. Mohanty and T. Murty). https://doi.org/10.1002/9781119359203.ch5

18. Deshpande, M., Singh, V.K., Ganadhi, M.K. et al. Changing status of tropical cyclones over the north Indian Ocean. Clim Dyn 57, 3545–3567 (2021). https://doi.org/10.1007/s00382-021-05880-z

19. Albert, J., Krishnan, A., Bhaskaran, P.K. et al. Role and influence of key atmospheric parameters in large-scale environmental flow associated with tropical cyclogenesis and ENSO in the North Indian Ocean basin. Clim Dyn 58, 17–34 (2022). https://doi.org/10.1007/s00382-021-05885-8

20. Sen Roy, S., Roy, S.S. Spatial patterns of long-term trends in thunderstorms in India. Nat Hazards 107, 1527–1540 (2021). https://doi.org/10.1007/s11069-021-04644-6

21. Chakraborty, R., Chakraborty, A., Basha, G., and Ratnam, M. V.: Lightning occurrences and intensity over the Indian region: long-term trends and future projections, Atmos. Chem. Phys., 21, 11161–11177, https://doi.org/10.5194/acp-21-11161-2021, 2021.

22. Kulkarni, A. et al. (2020). Precipitation Changes in India. In: Krishnan, R., Sanjay, J., Gnanaseelan, C., Mujumdar, M., Kulkarni, A., Chakraborty, S. (eds) Assessment of Climate Change over the Indian Region. Springer, Singapore. https://doi.org/10.1007/978-981-15-4327-2_3.

23. Parthasarathy B, Diaz HF, Eischeld JK (1988) Prediction of all-India summer monsoon rainfall with regional and large-scale parameters. J Geophys Res 93:5341–5350. https://doi.org/10.1029/JD093iD05p05341.

24. Gadgil S (2007) The Indian monsoon: 3. Physics of the monsoon. Resonance 12(5):4–20. https://doi.org/10.1007/s12045-007-0045-y

25. Berkelhammer M, Sinha A, Stott L, Cheng H, Pausata FSR, Yoshimura K (2012) An abrupt shift in the Indian monsoon 4000 years ago. In: Giosan Let al (eds) Climates, landscapes, and civilizations, vol 198. American Geophysical Union Geophysical Monograph, pp 75–87. https://doi.org/10.1029/2012GM001207

26. Sanyal P, Sinha R (2010) Evolution of the Indian summer monsoon: synthesis of continental records. Geol Soc Lond Spec Publ 342:153–183. https://doi.org/10.1144/SP342.11

27. Kulkarni, S., Ghude, S., Jena, C., Karumuri, R. K., Sinha, B., Sinha, V., et al. (2020). How much large scale crop residue burning affect the air quality in Delhi? Environmental Science & Technology, 54(8), 4790–4799. https://doi.org/10.1021/acs.est.0c00329.

28. Bajrang, C., Attada, R. & Goswami, B.N. Possible factors for the recent changes in frequency of central Indian Summer Monsoon precipitation extremes during 2005–2020. npj Clim Atmos Sci 6, 120 (2023). https://doi.org/10.1038/s41612-023-00450-y

29. Sreenath, A.V., Abhilash, S., Vijaykumar, P. et al. West coast India's rainfall is becoming more convective. npj Clim Atmos Sci 5, 36 (2022). https://doi.org/10.1038/s41612-022-00258-2

30. Nayak, S. Exploring the Future Rainfall Characteristics over India from Large Ensemble Global Warming Experiments. Climate 2023, 11, 94. https://doi.org/10.3390/cli11050094

31. Salunke, Popat & Keshri, Narayan & Mishra, Saroj & Dash, Sushil. (2023). Future projections of seasonal temperature and precipitation for India. Frontiers in Climate. 5. 1069994. 10.3389/fclim.2023.1069994.

32. Sorensen C, Saunik S, Sehgal M, Tewary A, Govindan M, Lemery J, Balbus J. Climate Change and Women's Health: Impacts and Opportunities in India. Geohealth. 2018 Oct 17;2(10):283-297. doi: 10.1029/2018GH000163. PMID: 32159002; PMCID: PMC7007102.

33. Juopperi K, Hassi J, Ervasti O, Drebs A, Nayha S. Incidence of frostbite and ambient temperature in Finland, 1986–1995. A national study based on hospital admissions. Int J Circumpolar Health. 2002; 61:352–362.

34. Michelozzi P, Accetta G, De Sario M, D'Ippoliti D, Marino C, Baccini M, et al. High temperature and hospitalizations for cardiovascular and respiratory causes in 12 European cities. Am J Respir Crit Care Med. 2009;179:383–389.

35. Schwartz J, Samet JM, Patz JA. Hospital admissions for heart disease: the effects of temperature and humidity. Epidemiology. 2004;15:755–761

36. Semenza JC, McCullough JE, Flanders WD, McGeehin MA, Lumpkin JR. Excess hospital admissions during the July 1995 heat wave in Chicago. Am J Prev Med. 1999;16:269–277.

37. Johnson H, Kovats RS, McGregor G, Stedman J, Gibbs M, Walton H, et al. The impact of the 2003 heat wave on mortality and hospital admissions in England. Health Stat Q. 2005;25:6–11.

38. Knowlton K, Rotkin-Ellman M, King G, Margolis HG, Smith D, Solomon G, et al. The 2006 California heat wave: impacts on hospitalizations and emergency department visits. Environ Health Perspect. 2009;117:61–67.

39. Kovats RS, Hajat S, Wilkinson P. Contrasting patterns of mortality and hospital admissions during hot weather and heat waves in Greater London, U.K. Occup Environ Med. 2004;61:893–898.

40. Panagiotakos DB, Chrysohoou C, Pitsavos C, Nastos P, Anadiotis A, Tentolouris C, et al. Climatological variations in daily hospital admissions for acute coronary syndromes. Int J Cardiol. 2004;94:229–233.

41. Barry RG, Chorley RJ. 2003. Atmosphere, Weather and Climate. 8th ed. New York:Methuen & Co. Ltd.

42. Hajat S, Kosatsky T.2009Heat-related mortality: a review and exploration of heterogeneity. J Epidemiol Community Health; doi: 10.1136/jech.2009.087999[Online 19 August 2009]

43. O'Neill MS, Ebi KL. Temperature extremes and health: impacts of climate variability and change in the United States. J Occup Environ Med. 2009;51:13–25.

44. Mohapatra, Mrutyunjay & NAYAK, D & SHARMA, R & BANDYOPADHYAY, B. (2013). Evaluation of official tropical cyclone track forecast over north Indian Ocean issued by India Meteorological Department. Journal of Earth System Science. 122. 10.1007/s12040-013-0291-1.

45. Srivastava. A., Mrutyunjay Mohapatra, Ananda Kumar Das et al. A New Approach to Generate Dynamical Cone of Uncertainty for Cyclone Track Forecast over North Indian Ocean, 17 May 2023, PREPRINT (Version 1) available at Research Square [https://doi.org/10.21203/rs.3.rs-2885247/v1]

46. World Health Organization. Communicable diseases following natural disasters: risk assessment and priority interventions. Geneva: World Health Organization; 2006. p. 19.

47. Ahern M, Kovats RS, Wilkinson P, Few R, Matthies F. Global health impacts of floods: epidemiologic evidence. Epidemiol Rev. 2005; 27:36–46.

48. Kouadio IK, Aljunid S, Kamigaki T, Hammad K, Oshitani H. Infectious diseases following natural disasters: prevention and control measures. Expert Rev Anti Infect Ther. 2012;10:95–104.

49. Toole MJ. Communicable diseases and disease control. In: Noji E, editor. The public health consequences of disasters. New York, NY: Oxford University Press; 1997. pp. 97–100.

50. Shultz JM, Russell J, Espinel Z. Epidemiology of tropical cyclones: the dynamics of disaster, disease, and development. Epidemiol Rev. 2005;27:21–35.

51. Fredrick T, Ponnaiah M, Murhekar MV, Jayaraman Y, David JK, Vadivoo S, Joshua V. Cholera outbreak linked with lack of safe water supply following a tropical cyclone in Pondicherry, India, 2012. J Health Popul Nutr. 2015 Mar;33(1):31-8. PMID: 25995719; PMCID: PMC4438646.

52. Lynch VD, Shaman J. Waterborne Infectious Diseases Associated with Exposure to Tropical Cyclonic Storms, United States, 1996-2018. Emerg Infect Dis. 2023 Aug;29(8):1548-1558. doi: 10.3201/eid2908.221906. PMID: 37486189; PMCID: PMC10370842.

53. Anderson GB, Ferreri J, Al-Hamdan M, Crosson W, Schumacher A, Guikema S, et al. Assessing United States county-level exposure for research on tropical cyclones and human health. Environ Health Perspect. 2020;128:107009. 10.1289/EHP6976

54. Kruk MC, Gibney EJ, Levinson DH, Squires M. A climatology of inland winds from tropical cyclones for the Eastern United States. J Appl Meteorol Climatol. 2010;49:1538–47. 10.1175/2010JAMC2389.1

55. Radcliff TA, Chu K, Der-Martirosian C, Dobalian A. A model for measuring ambulatory access to care recovery after disasters. J Am Board Fam Med. 2018;31:252–9. 10.3122/jabfm.2018.02.170219

56. Noe RS, Schnall AH, Wolkin AF, Podgornik MN, Wood AD, Spears J, et al. Disaster-related injuries and illnesses treated by American Red Cross disaster health services during Hurricanes Gustav and Ike. South Med J. 2013;106:102–8. 10.1097/SMJ.0b013e31827c9e1f

57. Huang W, Gao Y, Xu R, Yang Z, Yu P, Ye T, Ritchie EA, Li S, Guo Y. Health Effects of Cyclones: A Systematic Review and Meta-Analysis of Epidemiological Studies. Environ Health Perspect. 2023 Aug;131(8):86001. doi: 10.1289/EHP12158. Epub 2023 Aug 28. PMID: 37639476; PMCID: PMC10461789

58. National Crime Records Bureau: Accidental deaths and suicides in India 2021, NCRB. Ministry of Home Affairs, Government of India (2021)

59. Cooper, M.A., Holle, R.L. (2019). Lightning Effects on the Body. In: Reducing Lightning Injuries Worldwide. Springer Natural Hazards. Springer, Cham. https://doi.org/10.1007/978-3-319-77563-0_3

60. Kevat A. Thunderstorm Asthma: Looking Back and Looking Forward. J Asthma Allergy. 2020 Sep 8;13:293-299. doi: 10.2147/JAA.S265697. PMID: 32982317; PMCID: PMC7501467.

61. Thien F, Beggs PJ, Csutoros D, et al. The Melbourne epidemic thunderstorm asthma event 2016: an investigation of environmental triggers, effect on health services, and patient risk factors. Lancet Planet Health. 2018;2(6):e255–63. doi: 10.1016/S2542-5196(18)30120-7

62. Salvi S, Kumar GA, Dhaliwal RS, Paulson K, Agrawal A, Koul PA, et al. The burden of chronic respiratory diseases and their heterogeneity across the states of India: the Global Burden of Disease Study 1990–2016. Lancet Glob Heal. 2018;6(12):e1363–74.

63. Ali, Haider & Modi, Parthkumar & Mishra, Vimal. (2019). Increased flood risk in Indian sub-continent under the warming climate. Weather and Climate Extremes. 25. 100212. 10.1016/j.wace.2019.100212.

64. Center for Disease Control CDC Precipitation Extremes: Heavy Rainfall, Flooding, and Droughts https://www.cdc.gov/climateandhealth/effects/precipitation_extremes.html accessed on October 2023.

65. Mujumdar, M. et al. (2020). Droughts and Floods. In: Krishnan, R., Sanjay, J., Gnanaseelan, C., Mujumdar, M., Kulkarni, A., Chakraborty, S. (eds) Assessment of Climate Change over the Indian Region. Springer, Singapore. https://doi.org/10.1007/978-981-15-4327-2_6

66. Rocklöv, J., Dubrow, R. Climate change: an enduring challenge for vector-borne disease prevention and control. Nat Immunol 21, 479–483 (2020). https://doi.org/10.1038/s41590-020-0648-y

67. A. Das, A.R. Anvikar, L.J. Cator, R.C. Dhiman, A. Eapen, N. Mishra, B.N. Nagpal, N. Nanda, K. Raghavendra, A.F. Read, S.K. Sharma, O.P. Singh, V. Singh, P. Sinnis, H.C. Srivastava, S.A. Sullivan, P.L. Sutton, M.B. Thomas, J.M. Carlton, N. Valecha, Malaria in India: The Center for the Study of Complex Malaria in India, Tackling Malar. End Game Reg. Needs Chall. Success. Malar. Elimin. 121 (2012) 267–273.

68. N. Gupta, S. Srivastava, A. Jain, U.C. Chaturvedi, Dengue in India, Indian J. Med. Res. 136 (2012) 373–390

69. R. Singh Parihar, P.K. Bal, V. Kumar, S.K. Mishra, S. Sahany, P. Salunke, S.K. Dash, R.C. Dhiman, Numerical Modeling of the Dynamics of Malaria Transmission in a Highly Endemic Region of India, Sci. Rep. 9 (2019) 11903. https://doi.org/10.1038/s41598-019-47212-6.

70. S. Patil, S. Pandya, Forecasting Dengue Hotspots Associated With Variation in Meteorological Parameters Using Regression and Time Series Models, Front. Public Health. 9 (2021). https://www.frontiersin.org/articles/10.3389/fpubh.2021.798034

71. Shocket, Marta S., and others, 'Environmental Drivers of Vector-Borne Diseases', in John M. Drake, Michael Bonsall, and Michael Strand (eds), Population Biology of Vector-Borne Diseases (Oxford, 2020; online edn, Oxford Academic, 18 Feb. 2021), https://doi.org/10.1093/oso/9780198853244.003.0006, accessed 14 Oct. 2023.

72. K. Laneri, A. Bhadra, E.L. Ionides, M. Bouma, R.C. Dhiman, R.S. Yadav, M. Pascual, Forcing Versus Feedback: Epidemic Malaria and Monsoon Rains in Northwest India, PLOS Comput. Biol. 6 (2010) e1000898. https://doi.org/10.1371/journal.pcbi.1000898

73. K. Zinszer, R. Kigozi, K. Charland, G. Dorsey, T.F. Brewer, J.S. Brownstein, M.R. Kamya, D.L. Buckeridge, Forecasting malaria in a highly endemic country using environmental and clinical predictors, Malar. J. 14 (2015) 245. https://doi.org/10.1186/s12936-015-0758-4.

74. Y.L. Hii, H. Zhu, N. Ng, L.C. Ng, J. Rocklöv, Forecast of Dengue Incidence Using Temperature and Rainfall, PLoS Negl. Trop. Dis. 6 (2012) e1908. https://doi.org/10.1371/journal.pntd.0001908.

75. Brady, O.J., Golding, N., Pigott, D.M. et al., Global temperature constraints on Aedes aegypti and Ae. albopictus persistence and competence for dengue virus transmission, (n.d.). https://doi.org/10.1186/1756-3305-7-338

76. N.B. Tjaden, C. Caminade, C. Beierkuhnlein, S.M. Thomas, Mosquito-Borne Diseases: Advances in Modelling Climate-Change Impacts, Trends Parasitol. 34 (2018) 227–245. https://doi.org/10.1016/j.pt.2017.11.006

77. C. Caminade, S. Kovats, J. Rocklov, A.M. Tompkins, A.P. Morse, F.J. Colón-González, H. Stenlund, P. Martens, S.J. Lloyd, Impact of climate change on global malaria distribution, Proc. Natl. Acad. Sci. 111 (2014) 3286–3291. https://doi.org/10.1073/pnas.1302089111.

78. Reiter P, Climate change and mosquito-borne disease., Environ. Health Perspect. 109 (2001) 141–161. https://doi.org/10.1289/ehp.01109s1141.

79. F.J. Colón-González, M.O. Sewe, A.M. Tompkins, H. Sjödin, A. Casallas, J. Rocklöv, C. Caminade, R. Lowe, Projecting the risk of mosquito-borne diseases in a warmer and more populated world: a multi-model, multi-scenario intercomparison modelling study, Lancet Planet. Health. 5 (2021) e404–e414. https://doi.org/10.1016/S2542-5196(21)00132-7.

80. K. P. Paaijmans, A. F. Read, and M. B. Thomas. Understanding the link between malaria risk and climate. 106(33):13844–13849, August 2009. doi: 10.1073/pnas. 0903423106. URL https://doi.org/10.1073/pnas.0903423106.

81. Lalmalsawma, P., Balasubramani, K., James, M.M., et al. Malaria hotspots and climate change trends in the hyper-endemic malaria settings of Mizoram along the India–Bangladesh borders. Sci Rep 13, 4538 (2023). https://doi.org/10.1038/s41598-023-31632-6.

82. Bhattacharya, Sumana & Sharma, Chhemendra & Dhiman, Ramesh & Mitra, A.. (2005). Climate change and malaria in India. Curr Sci India. 90.

83. Sarkar, S., Singh, P., Lingala, M. A. L., Verma, P., & Dhiman, R. C. (2019). Malaria risk map for India based on climate, ecology and geographical modelling. Geospatial Health, 14(2). https://doi.org/10.4081/gh.2019.767.

84. Parihar, R.S., Bal, P.K., Saini, A. et al. Potential future malaria transmission in Odisha due to climate change. Sci Rep 12, 9048 (2022). https://doi.org/10.1038/s41598-022-13166-5