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# Climate Parameter Variability and Health

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## Abstract

Over the past 50 years, human activities such as burning fossil fuels have released huge quantities of greenhouse gases, which have trapped additional heat in the lower layers of atmosphere, changed global climate and led to more intense and frequent weather events. The overall health effects of climate change are likely to be extremely negative. Climate change affects social and environmental factors related to health, such as drinking water, food and shelter. It also imposes new disease and mortality on human populations. Extreme high temperatures increase deaths from trauma, diabetes, mental disorders and cardiovascular, respiratory and renal disease. As the number of weather-related natural disasters increase every year, these disasters result in more deaths and slams the basic living need of people, mainly in developing countries. Intense rainfall and flood, ruin agricultural land, contaminate freshwater supplies, increase the risk of waterborne diseases, and create breeding grounds for disease-carrying insects and increase the incidence of infectious diseases. All populations will be affected by climate change, but some are more vulnerable than others. Areas with weak health infrastructure, low socioeconomic status and elderly populations especially in developing countries will be the least able to cope with the hazardous effects of climate change.

**Keywords:** climate variables, temperature, humidity, health, mortality

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## 1. Introduction

Over the past 50 years, burning fossil fuels have released sufficient quantities of greenhouse gases including carbon dioxide in the lower atmosphere to trap heat and affect global climate. Average world temperature has increased about 0.85°C in the past 130 years, and the last three decades has been warmer than decades before 1850 [1].

These climate changes have made sea levels rise, glaciers melt and precipitation patterns change. Climate change affects clean air, safe drinking water, sufficient food and secure shelter. Rising sea levels destroy homes, medical and other facilities. More than half of the world’s population lives within 60 km of the coastal line and they may be forced to move [1] and leave their properties, which in turn can increase social displacement, mental disorders, unemployment and crime rates.

Climate variable	Unit	Definition
Mean temperature	°C	The average temperature in the specified time frame
Maximum temperature	°C	The maximum temperature in the specified time frame
Minimum temperature	°C	The minimum temperature in the specified time frame
Apparent temperature (AT)	°C	AT combines temperature and humidity (and occasionally wind) into a single index for the assessment of human comfort in the warm season. It can be calculated in different ways [5]
Diurnal temperature range (DTR)	°C	The daily maximum temperature minus the daily minimum temperature within 1 day [4]
Wet-bulb temperature (Tw)	°C	The temperature at which air becomes saturated by evaporation at constant pressure [5]
Temperature humidity index (THI)	°F	Is calculated as $THI = 0.4(T + T_W) + 15$ T and Tw are in degrees Fahrenheit [5]
Discomfort index	–	See temperature humidity index (THI) [5]
Humidex	–	Canada’s version of a comfort index is called the humidex (Hx) and is calculated as $Hx = T + 0.555(e - 10)$ where T is in degrees Celsius and e is in hPa [5]
Heat index (HI)	–	The HI is used to express summer comfort levels. It is based on a complex multiple regression equation that combines T and RH. It is highly correlated with both AT and THI [5]
Precipitation	millimeter	Water that falls to the ground as rain, snow, etc.
Heat/cold wave		Extreme temperature $\geq 2$ days [36]
Hot/cold wave duration		The number of consecutive days on which the threshold was exceeded [34]
Heat/cold wave number		The chronological number of a heat/cold wave in any given summer/winter [34]

Climate variable	Unit	Definition
Relative humidity (RH)	%	The amount of water vapor present in air expressed as a percentage of the amount needed for saturation at the same temperature [6]
Absolute humidity (AH)	gram per cubic meter	The water content of air at a given temperature [12]
Specific humidity	Unitless or expressed as parts per thousand	The ratio of the water vapor content of the mixture to the total air content on a mass basis [12]
Mixing ratio	Unitless or expressed as parts per thousand	Mixing ratio is the mass of moisture per mass of dry air
Dew point temperature (Td)	°C	When unsaturated air is cooled to saturation at constant pressure and without changing the air's moisture content that temperature is the dew point temperature. Dew point depends on the air's vapor pressure [5]
Dew point depression	°C	The difference between the temperature and dew point temperature at a certain height in the atmosphere. For a constant temperature, the smaller the difference, the more moisture there is, and the higher the relative humidity [5]
Vapor pressure	millibars or hPa (1 hPa = 100 Pascals = 1 mb)	The partial pressure exerted by water vapor in the atmosphere's gaseous mixture [5]

**Table 1.** Climate variables used in epidemiological research.

Extreme weather events are becoming more intense and more frequent [1]. The overall health effects of a changing climate are likely to be severely negative. The number of weather-related natural disasters in the world has more than tripled since the 1960s. Every year, these disasters result in deaths, mainly in developing countries [1].

Variables rainfall patterns and floods can contaminate freshwater supplies, heighten the risk of waterborne diseases such as diarrhea and create breeding grounds for disease-carrying insects such as mosquitoes [1]. Climate change is also likely to decrease the production of agricultural products in many regions, and this will increase malnutrition and undernutrition [1].

Although thousands of years ago, Hippocrates suggested that climate has a wide range of effects on human health [2], serious investigation about the effect of climate on health has just happened in the recent 20 years and in light of robust scientific evidence about global climate change. Now, some authors describe "Climate" as a key determinant of human health [3].

Various effects of different climate variables including temperature, humidity, precipitation, wind direction and speed; on human health have been investigated. Some of the variables used in climate and health studies are summarized in **Table 1**.

Diurnal temperature range (DTR) is known as an important meteorological indicator. It shows weather stability and authors think it is associated with global climate change and urbanization [4].

The proper humidity variable in epidemiological and environmental health research should be selected based on the research questions. The most commonly used humidity variable is relative humidity [5]. However, researchers think this variable has limited use, should be used with caution and should be avoided in research about health conditions in which proximity to saturation is not relevant [5]. Relative humidity varies as a function of both the air water vapor content and air temperature; therefore, it is difficult to figure out which variable actually relates to the dependent variable. The complexities associated with the relative humidity variable may explain some of the contrary results of epidemiological studies about how humidity influences health outcomes [5].

Variables that include thermal components, such as relative humidity, dew point depression, and vapor pressure change severely by time of day and season [5]. Researchers should be cautious in incorporating the daily or seasonal average of these variables in statistical models as they do not represent the average moisture content of the air [5]. If the research question is related to the degree of saturation, then relative humidity or dew point depression are appropriate variables to use; but their dependence on daytime or changing weather situations should be taken care of [5].

Water vapor mass-based climate variables, such as specific humidity, absolute humidity, mixing ratio, dew point temperature and vapor pressure, are often highly correlated [5] and therefore should not be used simultaneously in statistical models. These variables are used when the air's actual moisture content is important [5].

Absolute (AH) and relative humidity (RH) are related to temperature. The hotter the air, the more water it can hold and therefore a much higher AH is achievable in warmer weather. However, the amount of water that cold air can carry is low, and therefore, the relative humidity can get higher and it feels more humid in cold weather [6]. In high RH, sweat does not easily evaporate because the air is pretty much saturated and temperature does not lose by sweating [6].

If human comfort in hot environments is the research question, then wet-bulb temperature or apparent temperature is the best variable to work with [5].

Davis et al. [5] made the following recommendations for choosing the right humidity variables in epidemiological research. First, the humidity variable should be chosen based on the research question and primary health consideration. For example, specific humidity can be used when the effect of atmospheric moisture content on disease is assessed. This variable might also be important for studies on microbial or fungal disease and pulmonary diseases. Apparent temperature can be used for studies about thermal stress such as heat shock or

sudden cardiac death. Second, it is better to use several daily measurements (at least max and min values) rather than one measure for humidity variables; especially, when working in middle to high latitudes where there is large daily variation in humidity.

Researchers should also consider that the effects of climate variables can be modulated by other factors, such as social development, infrastructure, socioeconomic status and human adaptation [2].

In this chapter, we try to summarize the main health effects of climate variables reported in world studies.

## 2. Infectious diseases

Climate can determine the type of infectious diseases prevalent in different geographical areas, whereas weather can affect the time and the intensity of infectious disease outbreaks [3].

Several infectious diseases have been found related to climate variables. The more popular ones are listed below:

### 2.1. Malaria

Among different infectious diseases, the incidence of malaria, in particular, is generally thought to increase because of climate change and global warming [7]. Other vector-borne diseases may increase or decrease, but they currently make much less victims than malaria [7].

Diseases, such as malaria, which are transmitted by mosquito vectors, are sensitive to meteorological conditions. Excessive heat and cold kills mosquitoes. Malaria mosquitoes persist in a range between 17 and 33°C [8]. In this range, warmer temperatures increase mosquito reproduction and biting activity and the rate at which pathogens mature within them. For example, at 20°C, falciparum protozoa take 26 days to incubate, but at 25°C, they develop in 13 days. Also, Anopheles mosquitoes live only several weeks and warmer temperatures permit parasites to mature earlier, and the mosquitoes have more time to transfer the infection [3].

Temperature thresholds also limit the geographic range of mosquitoes. Transmission of falciparum malaria occurs in geographical areas where temperatures exceed 16°C [3].

Studies from Kerman, Iran, showed that the most effective meteorological factor on the incidence of malaria was temperature. As the mean, maximum and minimum of monthly temperature increased, the incidence rate raised significantly and models showed that a 1°C increase in maximum temperature in a given month was related to a 15 and 19% increase in malaria incidence on the same and subsequent month, respectively. Other studies from other world countries have also shown the effect of rising temperature in the incidence of malaria [9].

Dynamic models project that global warming will increase the transmission capacity of mosquitoes some 100-fold in temperate zones, and that the areas capable of sustaining transmission will grow and include more world populations [3]. The reports show that malaria

has returned to South Korea, parts of southern Europe and the former Soviet Union. Malaria has also recolonized in the Indian Ocean, coastal province of South Africa, [3] many of these changes in the pattern of diseases are indicative of long-term warming and climate changes. Similarly, climate warming and the resulting change in the length of seasons in the East African highlands have led to an increased incidence of malaria [10].

Over the past century, intense precipitation (>5 cm over 24 h) has become more frequent, and warming of land surface has apparently intensified the monsoons that are strongly associated with mosquito and waterborne diseases in India and Bangladesh [3]. Several studies showed a positive association between increases in malaria and relative humidity, which is often positively correlated with precipitation [5].

In Gao et al.'s study, in Anhui Province, China, rainfall ( $r_s = 0.48$ ) had the highest relation with malaria incidence. Malaria is a reemerging disease in this province, and rainfall is known as an important meteorological factor in the reemerging of this disease in the region. In this study, beside the effect of the same month's rainfall on malaria transmission, rainfall in the earlier 2 months also influenced malaria incidence [9]. Intense precipitation has also been reported to cause malaria outbreaks in Honduras (1998), Venezuela (1999) and Mozambique (2000) after hurricanes, torrential rains and cyclones in South America and southern Africa [3]. Climate change can allow diseases to invade immunologically naive populations with unprepared medical and health-care facilities [7].

However, very high rainfall can reduce mosquito populations by flushing larvae from their habitat in water swamps [11]. Researchers have also documented the association of malaria outbreaks with the El Niño Southern Oscillation(ENSO) cycle [11].

## 2.2. Yellow fever

Yellow fever is a climate-related viral disease that has a high rate of mortality and is carried by *Aedes aegypti*. Yellow fever is restricted by the 10°C winter isotherm and freezing kills Aedes eggs, larvae and adults [3].

## 2.3. Dengue fever

Studies suggest that there is a direct relationship between global warming and dengue fever [12]. Dengue fever is characterized by severe headaches and bone pain, and mortality occurs in case of hemorrhagic fever and shock syndrome. It is carried by *Aedes aegypti* and is restricted by the 10°C winter isotherm [3]. Climate change has helped dengue fever to spread into northern Australia and Argentina [3] as many of these changes in the pattern of diseases happened after long-term warming. Extreme weather and especially intense precipitation events after hurricanes have led to outbreaks of dengue fever in Honduras in 1998 and Venezuela in 1999 [3].

Changes in temperature and rainfall may also affect the distribution of disease vectors in dengue fever [2]. Researchers think that in the Asia-Pacific region, El Niño and La Niña events seem to affect the occurrence of dengue fever outbreaks [11].



## 2.4. Leishmaniasis

Studies have indicated that climate variability may influence changes in the vector geographical distribution as well as the density of the rodent reservoirs of leishmaniasis. In South America, climate variability based on ENSO revealed a significant effect on leishmaniasis. Also significant relationships were found between Mediterranean visceral leishmaniasis and climatic factors in some studies [5].

A study from Tunisia found that for relative humidity above 57.8% and lagged by 2 months, for each 1-unit increase in relative humidity, the disease incidence significantly increases by 5%. This study also showed seasonality during the same epidemiologic year and intervals between zoonotic cutaneous leishmaniasis (ZCL) epidemics ranging from 4 to 7 years. Mathematical models showed that ZCL incidence raises by 1.8% (95% CI: 0.0–3.6%) when there was 1-mm increase in the rainfall lagged by 12–14 months, and by 5.0% (95% CI: 0.8–9.4%) when there was a 1% increase in humidity from July to September in the same epidemiologic year. The researchers think that higher rainfall is expected to result in the increased density of plants that are food for *Psammomys obesus* (the reservoir rodent). Consequently, following an increase in the population of this rodent, the pool of *Leishmania major* transmissible from the rodents to blood-feeding female sand flies increases and can lead to a higher probability of transmission to humans over the next season [13].

## 2.5. Tick-related diseases

Warm winters have been demonstrated to facilitate northern migration of the ticks that carry tick-borne encephalitis and Lyme disease [3]. There is now evidence of vector species responding to recent climate change in Europe. For example, there has been latitudinal shifts in ticks, which carry tick-borne encephalitis in northern Europe [2]. Also tick-borne encephalitis has extended geographically in Sweden, and the tick vector of Lyme disease has spread in eastern Canada [11]. Tick-borne encephalitis in Sweden is likely related to warmer winters over the past two decades. The geographic range of ticks that transmit Lyme disease and viral encephalitis has extended to higher latitudes in Sweden and to higher altitudes in the Czech Republic [11].

Changes in climate that can affect the transmission of vector-borne infectious diseases include temperature, humidity, rainfall, soil moisture and sea level rise [1]. Research is ongoing to determine how these factors affect the risk of vector-borne diseases. Examples of vector-borne diseases likely to be sensitive to climate change has been shown in **Table 2**.

Crimean–Congo hemorrhagic fever (CCHF) is another tick-borne disease in Africa, Asia, Eastern Europe and the Middle East. It is a viral hemorrhagic fever transmitted mainly through tick bites and/or contact with blood and body fluids of patients (and/or infected animals). Studies from Iran showed that climate variables including mean temperature, accumulated rainfall and maximum relative humidity were significantly correlated with monthly incidence of CCHF. The number of cases in warmer summers was higher than the cooler ones, and also that the warmer the winters, the higher the number of cases [14].



Vector	Diseases
Mosquitoes	Malaria, Filariasis, Dengue fever, Yellow fever, West Nile fever, Chikungunya fever
Sand flies	Leishmaniasis
Triatomines	Chagas disease
Ixodes ticks	Lyme disease, Tick-borne encephalitis
Hyalomma ticks	Crimean-Congo Hemorrhagic Fever (CCHF)
Tsetse flies	African trypanosomiasis
Black flies	Onchocerciasis
Snails	Schistosomiasis

**Table 2.** Vectors and their related diseases that are likely to be sensitive to climate change [2, 14, 59].

The majority of cases of CCHF have been reported in Iran, Turkey and Bulgaria and correspond closely with the months that the temperature is between 30 and 40°C and maximum humidity is between 20 and 50% which is the favorite condition of the ticks. There are higher numbers of reported CCHF cases in warmer seasons and seasons with low rainfall [14].

**2.6. Diarrhea and gastroenteritis**

Changes in temperature and rainfall may affect the incidence of diarrheal diseases [2]. In tropical and subtropical regions with crowding and poverty, heavy rainfall and flooding may trigger outbreaks of diarrhea [11] by contaminating fresh water resources.

In Brisbane, Australia, there was a statistically significant positive relationship between diurnal temperature range (DTR) and diarrhea among children younger than five years. This effect was the greatest at one-day lag, with a 3% (95% CI: 2–5%) increase in emergency department admissions per 1°C increment of diurnal temperature range. The relative risk increased rapidly when DTRs were over 10°C [15]. Diarrheal diseases in Peru and Fiji have also accompanied short-term increases in temperature [11].

Ambient humidity has been reportedly associated with infectious enteritis. Studies in Japan, Taiwan and Peru showed negative relationships between relative humidity and infectious gastroenteritis [5]. Also similar relationships have been uncovered for rotavirus, another agent causing enteritis in Australia [5].

**2.6.1. *Salmonella***

*Salmonella* bacteria proliferate more rapidly at higher temperatures and in animal gut and food [11]. Strong linear associations have been reported between temperature and notifications of salmonellosis in European countries and Australia [11].

Some recent studies have provided evidence about associations between weather events and the incidence of *Salmonella*. For example, studies have identified associations between average temperature and the number of reported cases of *Salmonella* infection. However, coastal communities may be more vulnerable because flooding events can contaminate their water supply with bacteria. A study from the United States observed a 4.1% increase in salmonellosis

risk associated with a one-unit increase in extreme temperature events, and this increase in risk was more in coastal versus non-coastal areas (5.1% vs. 1.5%). Also they observed a 5.6% increase in salmonellosis associated with a one-unit increase in extreme precipitation events, and the effect was stronger in coastal areas (7.1% vs. 3.6%) [16].

Typhoid fever is a life-threatening illness caused by the bacterium *Salmonella typhi*. In February 2000, after torrential rains and a cyclone-inundated large parts of southern Africa and Mozambique, typhoid spread in the area [3].

#### 2.6.2. Cholera

Studies have shown that cholera bacteria proliferate more rapidly at higher temperatures and in water [11]. Intense precipitation has been reported to cause outbreaks of cholera after hurricanes in Honduras in 1998, and after torrential rains and a cyclone in Mozambique in 2000 [3]. It is possible that increases in the rate of coastal outbreaks of cholera are also related to the warming of coastal waters and El Niño events [17].

A study from Iran showed that the incidence of cholera was significantly related to higher temperature and humidity and lower precipitation. Cholera epidemics are most likely to occur in hot seasons and in countries with more than one hot season, several cholera epidemics are likely each year. The significant relationship reported between the incidence of cholera and the lack of precipitation in Iran may be due to the fact that drought leads to the use of unsafe water [18].

### 2.7. Tuberculosis (TB)

In some countries, the highest incidence of diagnosed tuberculosis (TB) was in spring. Although the exact mechanism of this seasonal pattern is not well understood, there is a possibility that factors, such as temperature, humidity and sunlight, are related to TB incidence. Some researchers hypothesize that since winter is a cold season and people live in closed environments during winter; thus, transmission of TB happens in winter, and eventually, the symptoms and diagnosis happen in spring [19, 20].

A study from Kerman, Iran, reported that the incidence of TB increased in warm months, and for each one-unit C increase in temperature, the risk of TB increased 1.03 times. Also relative humidity with one-year lag had a reverse association with TB [21].

### 2.8. Hand, foot and mouth disease (HFMD)

HFMD is a common viral illness that usually affects children under 5 years old. Symptoms include fever, mouth sores and skin rashes. A study in China found that the commonly hot days positively affected the hand, foot and mouth disease (HFMD) burdens with the relative risk (RR) peaking at around 6 days of lag. The RR of HFMD in the Pearl River Delta Region was generally higher and persisted longer than that in the remaining developing areas [22].

## 2.9. Melioidosis

Melioidosis is an infectious disease that can infect humans and is caused by the bacterium *Burkholderia pseudomallei*. It is predominately a disease of tropical climates, especially Southeast Asia and northern Australia. The bacteria causing melioidosis are found in contaminated water and soil. It is spread to humans through direct contact with the contaminated source. Symptoms and signs of melioidosis can be mild, but severe manifestations such as bacteremia, organ abscesses and severe pneumonia can lead to death. Researcher found a significant correlation of melioidosis cases in Singapore with higher rainfall and, to a lesser degree, with higher humidity levels [23].

## 2.10. Other

Studies suggest a direct relationship between global warming and schistosomiasis [7]. Inter-annual and especially ENSO-related variations in climatic conditions in Australia have been reported to affect outbreaks of Ross River virus disease [11]. Climate also effects hantavirus pulmonary syndrome (HPS) and West Nile virus (WNV) [3].

## 3. Mortality

Normal human body temperature is maintained by the hypothalamus and is 36.1–37.8°C. When the environmental temperature exceeds the regulatory capacity of the hypothalamus, this can exert substantial stress on body organs [24].

Several world studies have shown that extreme temperatures can increase mortality. These graphs generally have the shape of a U, V or J and show an increase in mortality beyond a specific threshold temperature [24]. In most of these studies, a minimum mortality temperature ( $T_{MM}$ ) or a comfort range, in which the least number of mortality per unit of time happens, has been reported.

In Greater Beirut, the  $T_{MM}$  was 27.5°C and 1°C rise in temperature yielded a 12.3% increase (95% CI: 5.7–19.4%) and 1°C drop in temperature caused 2.9% increase (95% CI: 2–3.7%) in mortality [25]. The  $T_{MM}$  in other world cities can be seen in **Table 3**.

Although temperature itself can effect mortality through physiological routes; low income, lack of air conditioning, poor access to transport, poor education, unhygienic microenvironments and older age have been recognized as risk factors which increase vulnerability to heat and cold [25]. Studies have shown that heat waves increase mortality more in vulnerable populations, such as elderly people, especially women, mentally ill people, children, those in thermally stressful occupations or people with preexisting illness [11].

It is very likely that climate change will lead to more frequent heat waves. Excess deaths were reported in England, Wales and France during the 2003 heat wave and caused a public health crisis. Much of the mortality from heat waves is due to cardiovascular, cerebrovascular and respiratory causes and happens more in the elderly [2].

Some researchers have mentioned a phenomenon called “urban heat island effect,” which refers to urban centers with temperatures being somewhat higher than the surrounding suburban and rural areas [2]. Some inner urban environments have high thermal mass and low ventilation, which absorbs and retains heat and amplifies the rise in temperatures, especially overnight [11]. The impact of extreme heat on human health may also be exacerbated by increases in humidity [2].

Populations are likely to acclimatize to climate change through a range of behavioral, technological and physiological adaptations. However, infrastructural changes are likely to happen much slower, especially in developing countries [2].

The temperature–mortality relation varies greatly by latitude and climatic zone. People in hotter cities are more commonly affected by low temperatures, and people in colder cities are more affected by high temperatures. Other factors such as housing that may provide poor protection against cold or heat can cause higher excess winter mortality than expected [11]. However, cold also shows its deadly effect through infectious diseases such as influenza in elderly people or respiratory syncytial virus in infants [11].

City	Latitude	T <sub>MM</sub> (°C)	Shape of curve
Salvador, Brazil [26]	12.97 S	23	J
Bangkok, Thailand [26]	13.75 N	29	J
Chiang Mai, Thailand [26]	18.79 N	19–28	U
Mexico City, Mexico [26]	19.43 N	15–18	Wide U
Taishan, China [8]	22.25 N	25.7	J
Zhuhai, China [60]	22.27 N	25.9	J
Shenzhen, China [29]	22.55 N	33	J
Guangzhou, China [60]	23.13 N	26	J
Sao Paulo, Brazil [26]	23.55 S	21–23	Wide U
Taipei, Taiwan [27]	25.03 N	25.2–31.5	Asymmetric V
Nanxiong, China [8]	25.11 N	24	J
Monterrey, Mexico [26]	25.66 N	17–31	Asymmetric U
Miami, USA [25]	25.77 N	27.2	
Tampa, Florida, USA [61]	27.96 N	27.1	
New Delhi, India [26]	28.61 N	19–29	J
Chongqing, China [29]	29.55 N	34	J
Shiraz, Iran [41]	29.61 N	20–25	J
Kerman, Iran [40]	30.28 N	21.1–25.1	Wide J
Jacksonville, Florida, USA [61]	30.33 N	24.8	
Shanghai, China [38]	31.20 N	28	Reversed J
Nanjing, China [29]	32.05 N	35	J

City	Latitude	T <sub>MM</sub> (°C)	Shape of curve
Santiago, Chile [26]	33.45 S	16	Wide U
Tehran, Iran [40]	33.69 N	28.5	
Beirut, Lebanon [25]	33.88 N	27.5	Wide asymmetric V
Cape Town, South Africa [26]	33. 92 S	17	Wide U
Tokyo, Japan [27]	35.68 N	29.4–30.8	V
Seoul, South Korea [27]	37.56 N	30.1–33.5	Asymmetric V
Seoul, South Korea [24]		29.5	J
Athens, Greece [35]	37.58 N	22.7–25.7	
Baltimore, USA [25]	39.28 N	21.4	
Valencia, Spain [25]	39.46 N	15 (winter), 24 (summer)	
Beijing, China [27]	39.91 N	31.3–32.3	J
Beijing, China [38]		25	U
Castile-La Mancha, Spain [34]	40.10 N	37	
Boston, USA [25]	42.36 N	21	
Sofia, Bulgaria [26]	42.70 N	16	J
Christchurch, New Zealand [40]	43.53 S	20.5	
Bucharest, Romania [26]	44.42 N	22	Wide U
Harbin, China [29]	45.75 N	29	J
Ljubljana, Slovenia [26]	46.05 N	17	J
Kings County, Washington, USA [30]	47.47 N	seems like 22.1	J
London, UK [35]	51.50 N	19.3–22.3	
Holland [25]	52.31 N	16.5	
North Finland [35]	67 N	14.3–17.3	

**Table 3.** The reported minimum mortality temperature, latitude and the shape of the mortality curve, in different world cities sorted based on latitude.

McMichael et al. estimated the temperature threshold below which cold-related mortality begins to increase, to range from 15 to 29°C, and the threshold for heat-related deaths to range from 16 to 31°C in different world cities. These researchers found heat thresholds were generally higher in cities with warmer climates, but cold thresholds were unrelated to climate [26]. Other researchers have reported lower latitude cities to have higher threshold temperatures [27]. The reported minimum mortality temperature for some world cities, sorted by latitude, has been shown in **Table 3**.

A meta-analysis showed that the effect of cold on mortality were delayed and lasted at least 10 days, whereas heat effects appeared quickly and lasted usually only 3–4 days. Interestingly, despite widely ranging climates, the  $T_{MM}$  were close to the 75th percentile of temperature in all 12 countries/regions studied in the meta-analysis, suggesting that people have probably adapted to their local climates [28]. This finding is consistent with  $T_{MM}$  in communities with colder climates being lower than in communities with warmer climates [28].

In China, associations between daily maximum temperature and daily mortality from all-causes were observed in different cities, with increases in 3.2–5.5%, with each 1°C increase in the daily maximum temperature over the threshold. Also a stronger temperature-associated mortality was detected in females and adults over 30 years [29]. Isaksen et al. [30] in King County, Washington, showed that heat, expressed as humidex, is associated with increased mortality and that the risk increases with heat's intensity.

In China, researchers also observed statistically significant associations of DTR with total, cardiovascular and respiratory mortality in most cities in the full year and in cool seasons. However, few significant results were found in warm seasons. The researchers think that wide DTR might be a source of additional stress on the cardiorespiratory systems in low temperatures, and this stress might have more detrimental effects in older people and those with underlying cardiovascular disease [31]. Increase in mortality with increase in DTR was also seen in other Chinese cities and a multicity study in Korea. Researchers have suggested that the consistency in the literature shows the association of DTR with mortality are not likely to be substantially changed by geography, climate, population, publication bias or model specifications [31].

A study from a coastal city in India showed a clear effect of ambient heat in the increase in all-cause mortality and suggested that heat index has a stronger effect than maximum temperature on mortality. This study also showed an inverse relationship between mean mortality and relative humidity [32].

In a high plateau area in southwest China, risk assessments showed a strong increase in mortality starting at a DTR of approximately 16°C. The risk of mortality with extreme high DTR was greater for males and aged under 75 years. Researchers suggested that DTR of 16°C may be a good cutoff point for epidemiological mortality studies [4].

Researchers in Australia found that winters that were colder or drier had significantly increased death risks in most cities, whereas warmer or more humid summers did not increase the risk of death. The strongest increase in deaths for a colder winter was in Brisbane, the city with the warmest climate and the mildest winter. This again shows that warmer cities are more vulnerable to cold. Also, studies have showed that drier winters are associated with more influenza outbreaks [33].

Linares et al. [34] in Spain found that the variable, heat wave duration, was of major importance in mortality. The significant lags between temperature and mortality during heat waves range from 0 to 6 days. But for cold waves, this impact was extended to 12-day lag for respiratory deaths [34].



The variable, relative humidity, is usually present in mortality models with a negative sign showing inverse association and is thought to reduce the effect of heat and cold on mortality. Some researchers think that it is preferable to address temperature and relative humidity separately in epidemiological studies, especially when it comes to defining heat and cold waves and estimating their effect [34]. However, in Shanghai, Philadelphia and Sydney extreme maritime tropical (warm and moist) air mass was associated with high mortality, indicating that extreme humidity may be as dangerous as extreme temperature [5].

Researchers have reported that the  $T_{MM}$  in different world cities correlates with the latitude. Others have mentioned that  $T_{MM}$  varies with temperature of the place and humans adapt to local climatic conditions. In France, 80% of  $T_{MM}$  variance was accounted for by the mean summer temperatures (MST), and  $T_{MM}$  was highest in the southern parts of France [35].

In Australia, pooled data show that the relative risk of mortality started to increase around the 95th percentile of temperature, increased sharply at the 97th percentile and rose alarmingly at the 99th percentile. These researchers think that tiered health risk-based metrics should be performed to define a heat wave [36].

A study about infant mortality in California showed that the excess mortality risk was 4.4% per 5.6°C increase for average of same day and a previous 3-day apparent temperature. The associations for apparent temperature were highest for black infants. This study suggested that infants were also a vulnerable subgroup to heat exposure [37].

### 3.1. Cardiovascular disease and mortality

In China, strong associations between daily maximum temperature and daily mortality from cardiovascular causes were observed in different geographical cities, with increases in 4.6–7.5% with each 1°C increase in the daily maximum temperature over the threshold [29].

In Beijing, people with hypertensive disease were susceptible to both extremely low and high temperatures, and in Shanghai, people with ischemic heart disease showed greater susceptibility to extremely cold days [38]. Some studies have documented an association between mean temperature and humidity variations, and the number of visits to the emergency departments for atrial fibrillation [10].

In East Asia, heat waves had the strongest effects on cardiovascular deaths, which was (8.8, 95% CI: 5.5–12.2) [27]. In Washington State, statistically significant results were found for circulatory (9%) and cerebrovascular (40%) deaths and heat in all ages [30] and stratifying by age, and statistically significant increases in mortality risk on hot days were found for the 65–84 age group, in cerebrovascular (37%), and in the 85+ age group, in circulatory (18%), cardiovascular (17%), and cerebrovascular (53%) mortality [30].

In China per capita years of education (as an indicator of economic status), percentage of population over 65 years and percentage of women had direct impact on cold-related cardiovascular mortality in populations. Also number of hospital beds (as an indicator of the availability of medical resources), percentage of population engaged in industrial occupations, and percentage of women showed direct impact on heat-related cardiovascular mortality [39],



which confirms that socioeconomic factors can alter the effect of climate variables on cardiovascular mortality.

Gender also shows a different impact at low and high temperatures. Men tend to have a higher risk at low temperatures, whereas women tend to have higher risk at high temperatures [39].

A study from Kerman, Iran, showed increases in daily mortality from cardiovascular diseases as temperature decreased. Also significant correlations were observed between cardiovascular mortality and temperature, and the maximum correlations for cardiovascular deaths were on lag 0–lag 3. For each 1°C decrease in temperature, cardiovascular deaths showed a 0.6% increase [40], but no increase in cardiovascular mortality was detected with increased temperature, which is probably related to acclimatization. In Shiraz, Iran, the minimum number of cardiovascular deaths happened at 20°C. Drops in mean monthly temperature were significantly associated with increased 18- to 60-year-old cardiovascular deaths that happened one month later [41].

### 3.2. Respiratory disease and mortality

There is epidemiological evidence that shows influenza-related morbidity and mortality peaks 2–3 weeks after falls in AH. Also, *in vitro* experiments have shown improved survival of the influenza virus at lower AH levels [6]. Extremes can be hazardous for health in many other indirect ways as well. Prolonged droughts fuel bush fires that release hazardous respiratory pollutants [3].

In Korea, above a threshold temperature of 29.5°C, a rise in temperature of 1°C resulted in an increase in death from respiratory conditions (RR 1.02; 95% CI: 1–1.04). There was also an increased risk of death from asthma (RR 1.05, 95% CI: 1.01–1.11) [24].

In Hong Kong, cold temperature and rainfall was associated with most influenza epidemics; but, relative humidity and absolute humidity did not show much contribution to epidemics [42]. This effect may be due to prolonged survival of viral particles under colder conditions or enhance crowding and indoor activities that would increase contact, aerosol and droplet transmission [42].

Some studies have shown that rainfall could be a predictor to forecast influenza infection for subtropical and tropical regions, but not in all temperate regions. One plausible mechanism is that rainfall could increase indoor activities, and therefore influence the number of contacts and the risk of exposure to infected individuals [42].

A study from Turkey reported that some meteorological parameters such as wind direction, air temperature and atmospheric pressure were related to the incidence of pulmonary embolism. But no relation was found between unprovoked pulmonary embolism (PE) cases' monthly distribution and pressure, humidity or temperature. However, there was a statistically significant positive correlation between provoked PE cases and air temperature [43]. The relation between PE and hot temperature may be related to dehydration or people traveling in cars for longer distances [43]. In a study about temperature and infant mortality, white infants had an elevated risk for deaths from respiratory causes [37].

Climate-related events including heat waves and extreme meteorological events can increase the frequency of acute cardiorespiratory events due to higher concentrations of ground level ozone, changes in particle pollution, altered spatial and temporal distribution of allergens (pollens, molds, and mites), and some infectious disease vectors. These events will not only aggravate the condition of those with current respiratory disease and asthma but also increase the incidence and prevalence of allergic respiratory conditions [44].

Weather can affect asthma directly, by acting on airways, or indirectly, by influencing airborne allergens and pollutant levels. Cold air temperature can aggravate asthmatic symptoms [44]. There is evidence that, during pollen season, thunderstorms can be associated with asthma outbreaks or acute respiratory disease outbreaks [44, 45].

Some studies have reported higher barometric pressure, more hours of sunshine and lower humidity in winter to be associated with an increase in chronic obstructive pulmonary disease (COPD) exacerbations, implying that warm and dry high pressure systems were associated with COPD anomalies. Studies from Trinidad showed that in warm, wet climates incidence of asthma increased with higher relative humidity in the wet season. Conversely, a study from Japan demonstrated an association between low relative humidity and hospital admissions for pediatric asthma. The other indirect effects of humidity in respiratory disease include its role in promoting the increasing mold and mites [5]

In many world countries, low humidity levels were found to precede the onset of increased winter time influenza-related mortality by several weeks. Low humidity probably impacts on virus stability and viability, host susceptibility and human behavior [5].

A study from Australia about pediatric emergency department visits showed that high temperatures had a significant impact on pediatric diseases, including chronic lower respiratory diseases. Low temperatures were also significantly associated with respiratory diseases [46].

A study from Kerman, Iran, showed increases in daily mortality from respiratory diseases as temperature decreased. This relation reached a maximum after a 26-day lag. In this study, for each 1°C decrease in temperature, respiratory deaths showed an average of 2.5% increase [40]. In Shiraz, Iran, the minimum number of respiratory deaths happened in 25°C. Mean monthly temperature was inversely and significantly associated with total and female respiratory deaths on the same month and with total, male and female respiratory deaths that happened one month later [41].

#### **4. Premature delivery**

In the United States, ambient temperature was significantly associated with preterm birth, and regardless of their maternal demographic characteristics or baby gender, each 5.6°C (10° F) increase in weekly average apparent temperature (with lags up to one week), caused an 8.6% increase (95% confidence interval: 6.0, 11.3) in preterm delivery. Preterm delivery has many etiologies, but one possible explanation for its relation with heat is increased dehydration with

heat exposure, which may decrease uterine blood flow and increase pituitary oxytocin to induce labor [47].

In Spain, when maximum apparent temperature exceeded the 90th percentile, the risk of preterm birth increased up to 20% after 2 days, and when minimum temperature rose to the 90th percentile, it increased by 5% after a week [48]. Exposure to moderately high temperatures during late pregnancy might be associated with an increase in risk of preterm birth [49].

In Rome and Barcelona, increase in maximum apparent temperature (MAT), especially in the second half of the second trimester, increased the risk of preterm and particularly early preterm births [50].

## **5. Diabetes, endocrine and metabolic diseases**

Some researchers have suggested that climate change may be related to increase in type 2 diabetes [51].

Studies have reported significant associations between increases in daily endocrine and metabolic diseases mortality with increase in the daily maximum temperature above the threshold. Mortalities for diabetes were also significantly associated with temperature. The increased mortality for every 1°C increase in the daily maximum temperature over the threshold for endocrine and metabolic outcomes, and particularly diabetes, was 12.5–31.9% and 14.7–29.2% [29]. Statistically significant increases in post-heat exposure diabetes-related mortality in the 45–64 age group in the United States suggests that underlying health status may contribute to these risks [30].

In a study about pediatric emergency department visits in Australia, high temperatures had a significant impact on endocrine and metabolic pediatric diseases, whereas low temperatures were also significantly associated with endocrine, nutritional and metabolic diseases [46].

Although congenital hypothyroidism was reported to have a seasonal pattern in some parts of the world, a recent study did not find a significant pattern [52].

## **6. Mental diseases**

Extremes of temperature and rainfall, such as heat waves, floods and drought, have both direct immediate effects such as mortality, and indirect longer term effects. For example, populations that have survived severe floods and drought may suffer from sustained increases in common mental disorders [2].

In a study about the effects of extreme heat in mortality in the United States, statistically significant results were found for mortality related to mental disorders which showed a 43% increased risk [30].

## 7. Injuries and trauma deaths

Extreme events such as floods can cause injuries, deaths and other sequelae [11]. A study from Iran showed that the overall mortality caused by trauma was higher in the warm season, and the highest significant correlation between unintentional trauma deaths and temperature was seen in ages over 60 years ( $r = 0.301$ ). Also, an inverse significant correlation was observed between the unintentional trauma deaths and humidity and was again highest in the over 60-year age group ( $r = -0.336$ ). The authors think these results may be attributed to increase in activity or travelling in warm seasons and increased risk of unintentional injuries, such as traffic accidents, falls, drowning and heat exhaustion. Also, older people tolerate hot environments less than others [53].

Some studies have shown a peak in suicide rates during the spring season, and attributed it to increased temperatures; and others showed no relation between suicide and temperature. Some authors have regarded pollen as an important seasonal aeroallergen that may act as trigger for suicide [53]. However, suicide can be related to many other important socio-economic factors that have to be considered in these studies. Some researchers have commented that suicide is a complex, phenomenon driven by not only biological factors but also interactions between individuals and their environments, and weather variables may only increase the risk [53].

In a study about the effects of extreme heat on mortality in the United States, statistically significant results were found for accidental deaths [30].

## 8. Parkinson's disease

In Spain, a study about the effect of heat waves on Parkinson's disease (PD) mortality and morbidity showed that at a maximum daily temperature of 30°C, PD-related admissions were at a minimum. But starting at a temperature of 34°C, the number of admissions increases with temperature. Researchers concluded that suffering from PD is a risk factor for excess morbidity and mortality associated with high temperatures [54].

## 9. Multiple sclerosis

A study from Kerman, Iran, showed that the highest number of hospital admissions for multiple sclerosis happened in spring and winter, and this seasonal pattern was more pronounced in women. Researchers think that the seasonal-related hospital admissions are probably related to climate variables or seasonal infectious diseases [55].

Other researchers have found that the disease prevalence is lower in warmer climates, which enjoy more sunshine; also as latitude and distance from the equator increases, the prevalence of MS increases as well. Others have shown that the prevalence is less in people with sun burns

or those who have high levels of vitamin D [55]. However, more research about the role of climate variables in the incidence of MS is needed as some studies have not shown these relations.

## 10. Allergic diseases

Climate change may change the timing and duration of the pollen and spore seasons and the geographic scope of these aeroallergens, affecting allergic disorders such as hay fever and asthma [11].

Meteorological events can alter the onset, spatial and temporal distribution and the duration and intensity of allergens such as pollens, molds and mites. Therefore, the onset, duration and intensity of the pollen may also vary from year to year. Weather variables are among the main factors affecting phenology and pollen production by plants [44].

Different climate variables influence the daily fluctuations in the amount of pollen. The more important variables are temperature, rainfall and duration of sunshine. At least 10 weather elements are thought to affect the concentration of pollen, which are temperature, rainfall, average wind speed, relative humidity, maximum temperature, minimum temperature, temperature range, continued rainfall hours, accumulated sunshine hours and accumulated mean temperature [44].

When conditions are good for pollination (ripe anthers, low humidity and warm temperature), anthers open and release pollen. If the favorable weather conditions arrive early, ripe anthers will release less ripe pollen with less allergen. Otherwise, if weather is non-favorable and anthers do not open until later, riper pollen with more allergens are released [44].

These events can increase the incidence and prevalence of allergic-related conditions [44]. Thunderstorms can also induce attacks of severe asthma and are a common cause of epidemics of asthma attacks requiring Emergency Department visits [44]. Thunderstorm-related asthma has happened in England, Canada, Mexico, Australia, Italy [44] and Iran [45].

## 11. Renal problems

A US study on older adults showed that risks of hospitalization for fluid and electrolyte disorders, renal failure, urinary tract infection, septicemia and heat stroke were statistically significantly higher on heat wave days. For fluid and electrolyte disorders and heat stroke, the risk of hospitalization increased during more intense and longer lasting heat wave periods. Risks were generally highest on the heat wave day but remained elevated for up to five subsequent days [56].

Another US study showed statistically significant increased mortality risk associated with extreme heat from nephritis and nephrotic syndromes [30]. In South Korea, a significant heat-

associated increase in the RR of mortality from genitourinary conditions was observed. This shows that patients with preexisting chronic conditions may be more susceptible to high ambient temperatures [24].

Kidney stones have also been inversely linked to relative humidity in a few studies [5]. A study showed that extraterrestrial radiation, isothermality, annual mean temperature (AMT) and precipitation seasonality were significant predictors of urolithiasis prevalence in Iran, and urolithiasis is more prevalent in the south of Iran, which has a warmer climate. High temperatures can result in increased urinary concentration and low urinary volume due to excessive sweating, which can increase in the concentration of relatively insoluble salts that turn into stones. Some authors have indicated a strong relationship between annual mean temperature (AMT) and stone prevalence and predicted that cases of nephrolithiasis will increase due to the global warming [57].

## 12. Environmental toxins

Studies about climate change have found out that ocean warming around the Faroe Islands has facilitated the methylation of mercury and its subsequent uptake by fish. Researchers think that methyl mercury concentrations in fish will increase by 3–5% for a 1°C rise in water temperature. Eating methyl mercury-contaminated fish has harmful effects for humans and also impairs fetal/infant neurocognitive development [11, 58].

The severe effects of climate change and global warming on human populations suggest that actions should be taken to reduce its burden on human populations. All populations will be affected by climate change, but some are more vulnerable than others. Countries with weak health infrastructure, mostly in developing countries will be the least able to cope with climate change [1].

Many policies have the potential to reduce greenhouse gas emissions. For example, promoting clean energy, the safe use of public transportation and physical activity can reduce carbon emissions [1]. Carbon taxation has also been implemented in some developed countries.

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