A scoping review of implications of Climate Change-related Heatwaves and Urban Heat Islands on Health

A Capstone project submitted to

Johns Hopkins Bloomberg School of Public Health & IIHMR University

in partial fulfillment of the requirements for

the award of the degree of

Master of Public Health

By

Shrutika Rane

MPH

Cohort XI (2023-25)

Under the guidance of

Dr. Seema Mehta

October 2024

ABSTRACT

Nations worldwide are experiencing lethal summers each consecutive year due to climate change. The intense heat impacts the environment and health and is generally followed by other natural hazards such as flash floods, cyclones, and tornados. Urban residents are at a greater risk of heat health-related morbidity and mortality due to the integrated impact of the Urban Heat Island (UHI) and heat waves on the air quality, health, and eventually the health service demand in these regions. The study aims to analyze and develop a conceptual framework to understand the interrelationship between UHI, heatwaves, health, and the environment on the health service system demand. The paper has assessed global studies from various peer-reviewed databases, eminent newspapers, and articles from organizations contributing to climate change crises, focusing on the last decade to streamline the literature available, adding to the limited interdisciplinary body of work in this field. Future multidisciplinary research must be undertaken to understand the broader impact on health and environmental factors such as air, water quality, and health systems. With this study, we conclude that there is a need for a holistic approach to the existing heat action plans to include inputs from relevant stakeholders to reduce the contributory impact of UHI on global warming.

Acknowledgment

I want to convey a heartfelt thank you to **Dr. Seema Mehta** for her constant support and guidance while preparing the capstone. Her expertise and encouragement has made me a better public health professional and researcher today.

I would also like to thank **Johns Hopkins Bloomberg School of Public Health** and **IIHMR University** for creating an enriching and transformative teaching environment for the students.

I am extremely grateful to my parents, siblings, and partner, who stood by me with unwavering support throughout the year.

A big thank you to my close friends and colleagues from Cohort XI and the teaching and non-teaching faculty who motivated and helped me improve my academic journey.

Dr. Shrutika Rane

Cohort XI

TABLE OF CONTENTS

Abstract……...2

Acknowledgment…….....3

List of abbreviations……....5

List of figures.....6

Why heatwaves?…….....7

Why Urban Heat Islands?.....8

What is an Urban Heat Island?.....9

Rationale for study…….....13

Research Question…….....13

Objectives…….....13

Methodology…….....14

- Factors contributing to UHI formation…….....…….....17
- Compounding effect of heatwaves on UHI…….....…….....19
- Implications on the environment……..…….....…...21
  - Energy Utilization …….....21
  - Air pollution…….....22
- Implications on human health…..…….....23
  - Thermal comfort…….....23
  - Sleep…….....24
  - Mental health…….....24
  - Mortality and morbidity…….....26
- Impact on health service systems…….....…….....29
- Proposed Framework based on Actor-Network theory.....30

Discussion……..….....……...….....32

References…….....……..….....33

Appendix.....38

LIST OF ABBREVIATIONS

CSI- Climate Shift Index

DSH- Direct Solar Heat

HHWS- Heat-Health Warning Systems

HVAC- Heating, Ventilation, and Air Conditioning

IMD- Indian Meteorological Department

IPCC- Intergovernmental Panel on Climate Change

ISH- Indirect Solar Heat

PET- Physiological Equivalent Temperature

UAP- Urban Air Pollution

UHI- Urban heat island

UHII- Urban Heat Island Index

UHC- Universal Health Coverage

UNDRR- United Nations Disaster Risk Response

UNICEF- United Nations Children's Fund

WHO- World Health Organization

WMO- World Meteorological Organization

WPR- Western Pacific Region

LIST OF FIGURES

SR. NO	DESCRIPTION	PAGE NUMBER
1	WHO's outline for climate change and the exposure and vulnerability factors that affect health outcomes	8
2	An illustration of the variation in temperature as per land utilization	9
3	UHI clusters in Singapore	10
4	UHI clusters in the USA	10
5	UHI clusters in Japan	11
6	UHI clusters in the UK	11
7	Line graph representing the trend of studies undertaken in the field of UHI and its implications on health.	14
8	Treemap chart indicating the geographical distribution of articles based on the search strategy on the Web of Science	15
9	Treemap chart indicating the distribution of fields of the articles based on the search strategy on Web of Science	15
10	Documents on Scopus by subject area based on the search strategy	16
11	Highest temperature differences recorded between urban and rural areas internationally	18
12	Proposed Framework based on Actor-Network theory	31

Why heat waves?

From Denver to Delhi, every continent is experiencing higher-than-normal temperatures lasting unusually long durations. This occurs due to climate change which earlier emerged naturally but since the 18th century due to the rise in anthropogenic activities and emission of greenhouse gases has led to global warming. A climate action report by the United Nations defines climate change as "*long-term shifts in temperatures and weather patterns.*"[40] In 2010 Russia experienced a 44-day heatwave resulting in 56,000 more deaths.[1] In 2022, China experienced a heatwave lasting more than 70 days.[2] Indian Meteorological Department (IMD) revealed that in 2024 India had heatwaves lasting 24 days across various parts of the country. Temperatures were recorded as high as 50°C by day and 37°C at night. Making this year the longest hot spell documented so far.[3] These high thermal levels at night prevent the body from recovering from the physiological stresses experienced during the daytime. Soaring temperatures are also attained earlier during the day in such scorching circumstances. This intense heat poses an economic risk and health-related risks to humans and the environment. It increases the risk of natural disasters such as droughts, and forest fires which consecutively increase human morbidity and mortality.[2] Contrary to other natural disasters such as cyclones, and tornados which occur in specific geographical locations. Heatwaves occur in large areas due to their diffusive nature. Thereby affecting large populations.[4]

There is no universal definition of heatwaves as it is geographic climate-based. The World Meteorological Organization (WMO) defines it as *"a period where local excess heat accumulates over a sequence of unusually hot days and nights."*[2] WHO reported heatwaves as the major cause of meteorological-related deaths, accounting for 489,000 heat-related deaths between 2000 and 2019. Of these 45% occurred in Asia alone. With further global warming, it is expected that there will be a rise in the severity, regularity, and period of heat waves.[5] During 2018, over 220 million people were exposed to heat waves.[2] However, as per

Climate Central's report, in 2024 five billion people were exposed to heatwaves due to climate change over 9 days in June alone.[6] Heatwaves can have an amplifying effect on the human body. It can particularly affect children, the elderly population with pre-existing conditions, vulnerable and marginalized communities, and persons employed in manual labor.[5]

These intensely high temperatures have physiological and psychological impacts on human beings. Studies suggest an association between pre-existing mental health conditions and the likelihood of such individuals experiencing new or exacerbation of existing symptoms due to extreme temperatures. It also revealed an increased risk of interpersonal violence by 4% and intergroup violence by 14%.[7]

Why Urban Heat Islands?

WHO provides an outline of the exposure and vulnerable elements for global warming-induced heatwaves and their effect on health outcomes and systems.[8] On further studying the exposure pathway, it was found that more than fifty percent of the world's population inhabits urban areas. These regions hold 57% of Asia's population. In India, a large population and growing urbanization, has led to the formation of heavily crowded metropolitan cities.[9] Research has shown that heat waves are more prominent in extensive metropolitan areas due to the urban heat island (UHI) effect.[4] UHI has a compounding impact on heatwaves amplifying their intensity in urban areas.[10] Countries define "urban" areas based on an integration of two or more criteria of population size, concentration, trade systems, and structural properties. Half the countries in the world define urban areas based on the minimal population limit of 5000 residents.[41]

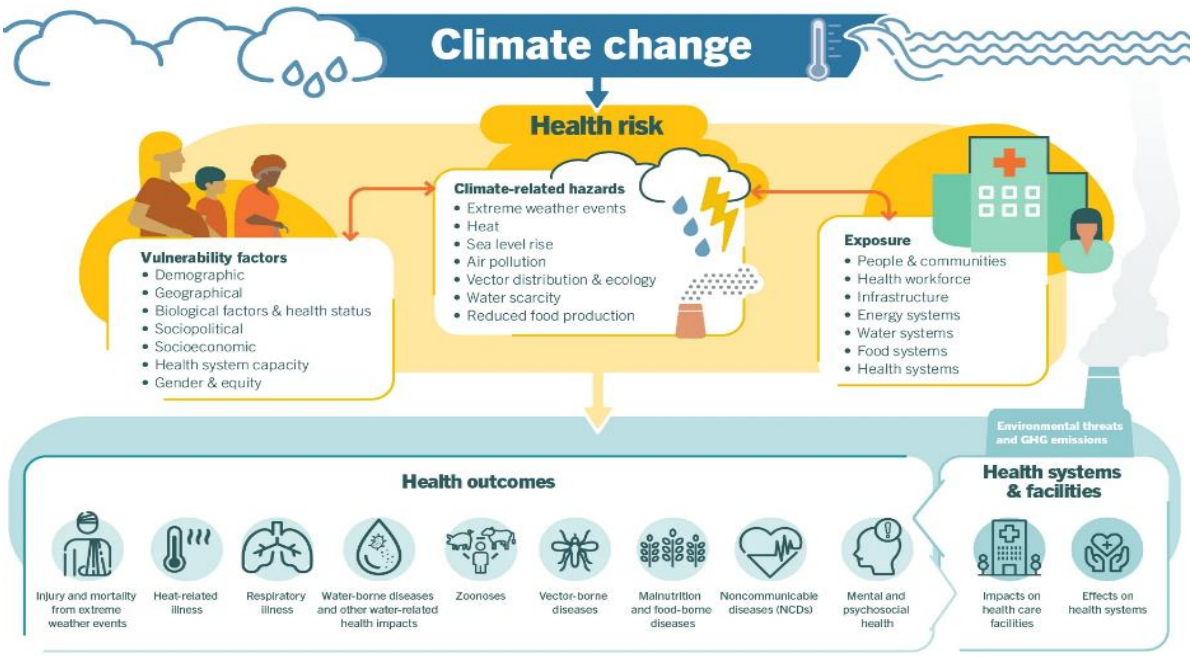

Figure 1: WHO's outline for climate change and the exposure and vulnerability factors that affect health outcomes [8]

What are Urban Heat Islands?

An UHI is a city that has elevated thermal temperatures as compared to its rural or peri-urban counterparts. They are geographical pockets of highly concentrated areas with structures made of asphalt, concrete, steel, brick, and increased human activity. These materials absorb the light radiated from the sun and store it, which is then converted into heat, making the urban surfaces warmer than the surrounding suburban and rural infrastructures. These built structures are impermeable i.e. they do not absorb water. Thereby, prohibiting the cycle of water flow and evaporation and hindering the cooling of such surfaces. As these structures are more commonly found in the urban areas of the country with limited vegetation to combat its effects, these pockets are more readily formed.[11]

U.S. Environmental Protection Agency defines the UHI effect as *"a measurable increase in ambient urban air temperatures resulting primarily from the replacement of vegetation with buildings, roads, and other heat-absorbing infrastructure. The heat island effect can result in significant temperature differences between rural and urban areas."*[11]. UHI's are a classic example of how human influences can change our environment.

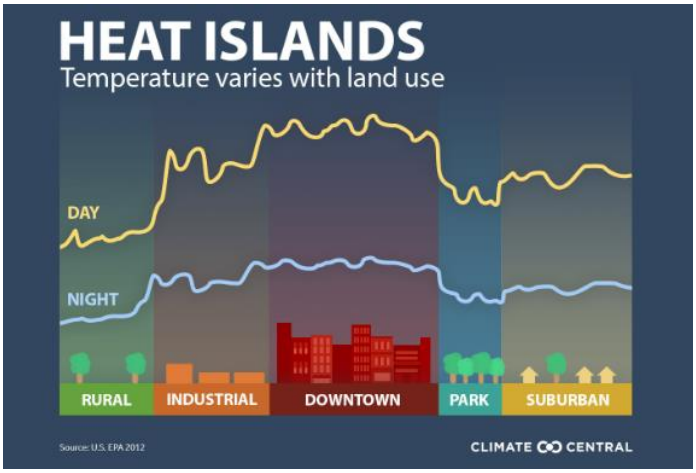

Figure 2: An illustration of the variation in temperature as per land utilization.[12]

UHI effects vary according to the land use within the region. Certain parts of the city record higher temperatures than others. This is due to the higher thermal uptake by urban infrastructures such as buildings, streets, and industries in these areas. Whereas other localities within the same city, remain cooler due to the presence of vegetation cover, ponds, and spaced-out residences which absorb lower levels of the sun's radiation.[11] The rapid conversion of vegetative cover to a concrete jungle in an unplanned manner poses an economic and health risk to urban populations by affecting their ability to work and the quality of air, and water, exacerbating pre-existing illnesses, and leading to increased morbidity and mortality.[9]

Figure 3: UHI clusters in Singapore, 2020 [39]

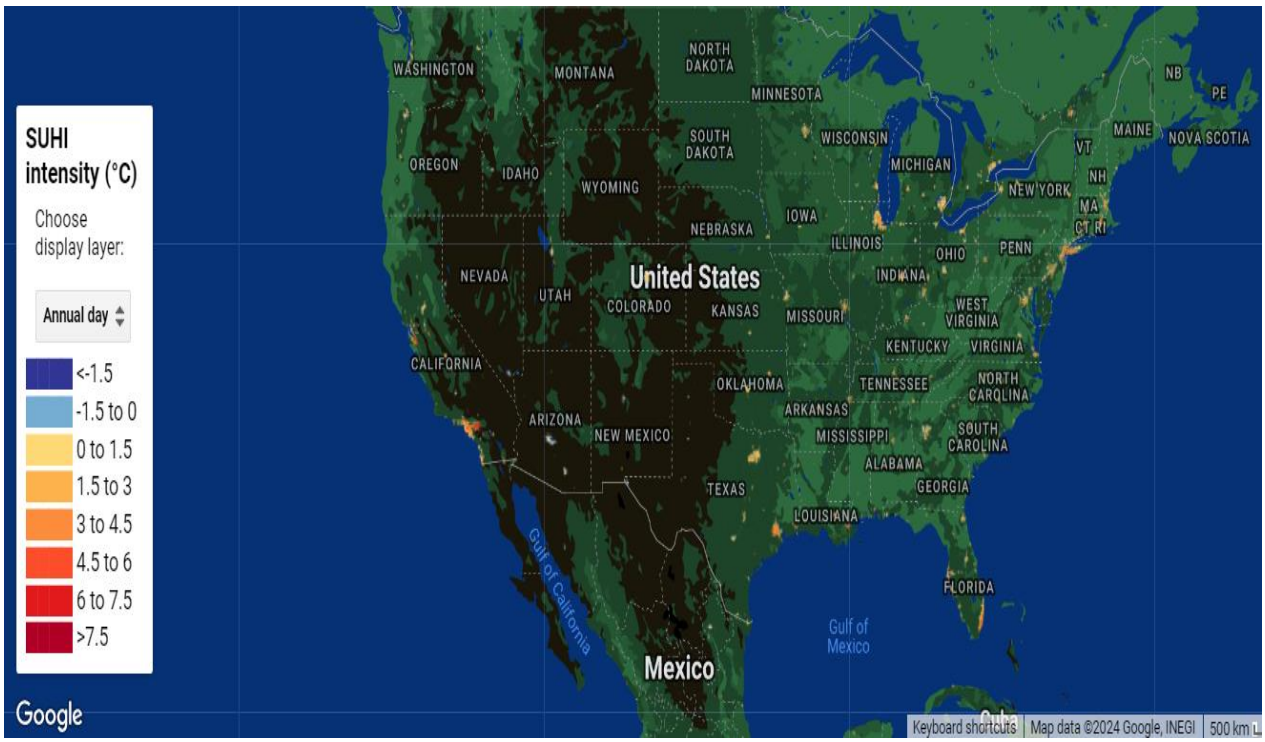

Figure 4: UHI clusters in the USA, 2020 [39]

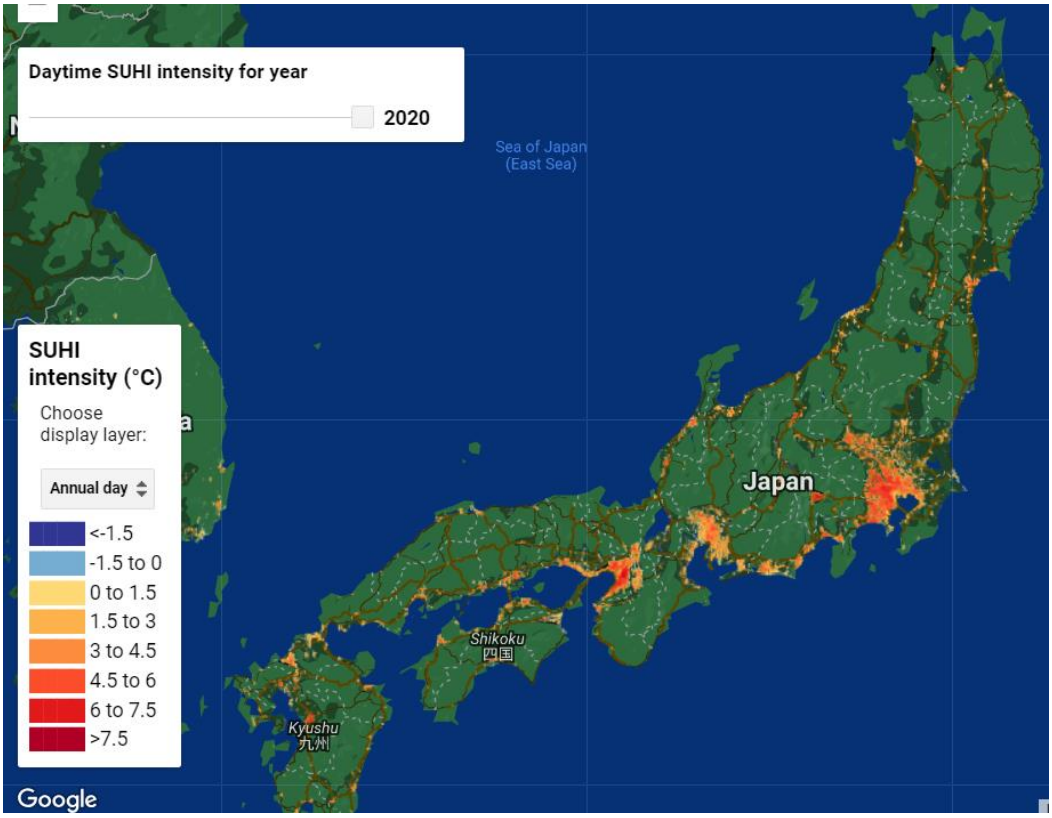

Figure 5: UHI clusters in Japan, 2020 [39]

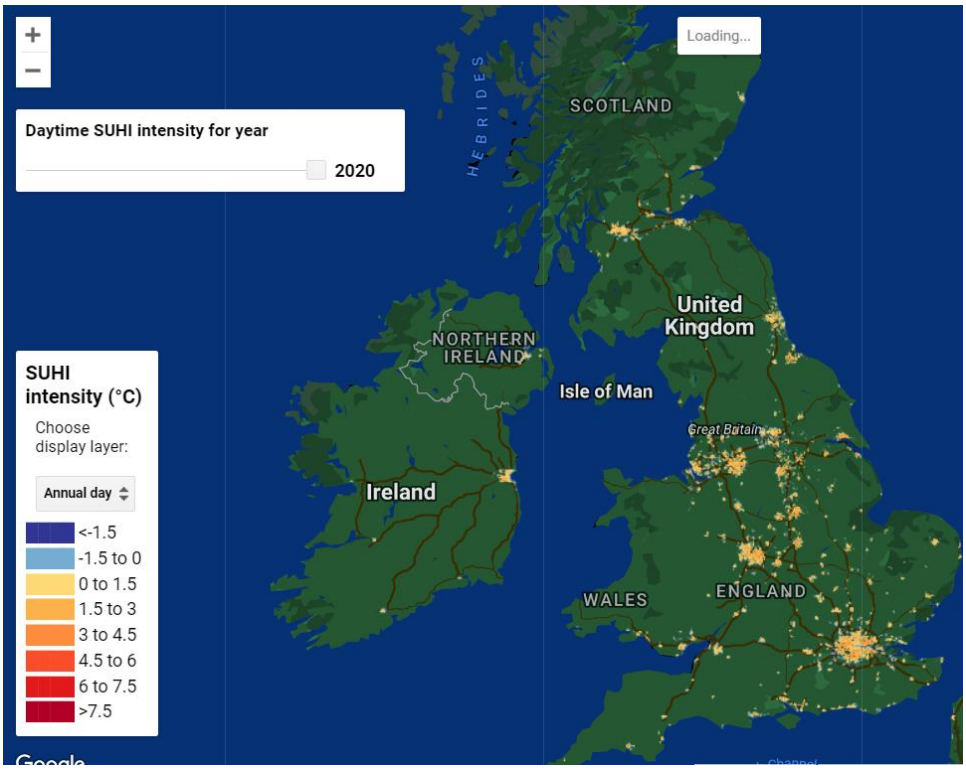

Figure 6: UHI clusters in the UK [39]

Rationale for the study

Climate change-related disasters are observed at an increasing frequency all across the globe. Unplanned urbanization, high population density, increased anthropogenic activities, and rapid migration of individuals to urban areas make these regions highly prone to heat stress. Urban residents are at a higher risk of negative impacts from the UHI effect and global warming-related morbidity and mortality. A search of databases will provide limited information on the compounding impact of UHI on heatwaves and its implications on environmental health and the health of the urban population.

This study aims to understand, summarise, and streamline all the existing literature to comprehend the dynamicity of climate change and heat health outcomes from 2014-2024 on UHI and its compounding effect on heat waves. As well as to gain a deeper understanding of the implications the two have on the environmental, physical, and mental health of those inhabiting cities for planning future heat action policies.

Research Question

1. Does UHI exert a compounding effect on the global climate change-related heat waves? How does this synergy affect the urban environment?
2. What are the associated health risks in the urban population?

Objectives

1. To study the amplification of heatwaves due to UHI
2. To study the effect of UHI and heatwaves on the Environment
3. To study the effect of UHI and Heatwaves on Health

Methodology

A scoping review was conducted to assess the presence of current interdisciplinary literature studying the relationship between Climate change and heat health. Before identifying the databases to be used, we started with a primary manual search on Google to identify the organizations and readily available journals and articles for the topic. In doing so, we were able to scope out peer-reviewed articles, reputed journals, and organizations dedicated to the field of climate change. After reviewing these articles, a comprehensive search strategy was made, and databases such as PubMed, Scopus, Springer Link, ProQuest, Web of Science, and Google Scholar were searched. Various articles and journals ranging from architectural, and meteorological studies to numerical modelling and mitigation frameworks appeared. An inclusion and exclusion criteria were developed only to include articles relevant to the research question. The review comprises 36 relevant articles, books, reports, and journals.

Study setting: An urban global context was identified as the study setting.

Data Collection: A thorough literature search was done across various databases such as Scopus, PubMed, Web of Science, Springer Link, ProQuest, and Google Scholar. A manual search was also done to scope through articles published by international organizations in climate crisis and health. Relevant peer-reviewed journals, books, and articles from eminent newspapers such as the Times of India, and Economic Times, along with articles from organizations such as WHO, WMO, Copernicus, Gavi, and Climate Central were considered.

Inclusion criteria: The inclusion criteria for this study focuses on the implications of UHI and heat waves on the environment and human health in urban setups. We started with the articles that were published between 2014-2024 and used the keywords “Urban heat island” OR “UHI” and “Heatwaves” OR “Heat stress” AND “Health” OR “Public health” AND

"Environment". Studies were included if they explored the consequences of UHI and heat waves on health and the environment.

Exclusion criteria: Studies were excluded if they analyzed heatwave trends, architectural studies, landscape studies, meteorological assessments, UHI, and heatwave grading and intensity as the scope of this review is limited to health impacts due to UHI. Studies that investigated past heat wave events were also excluded due to the changing nature of climate change-related weather events. All studies before 2014 and papers that were presented at conferences were also excluded.

Ethical considerations: No ethical approval was needed for the study as the review is based on publicly available peer-reviewed articles on databases with stringent ethical review processes.

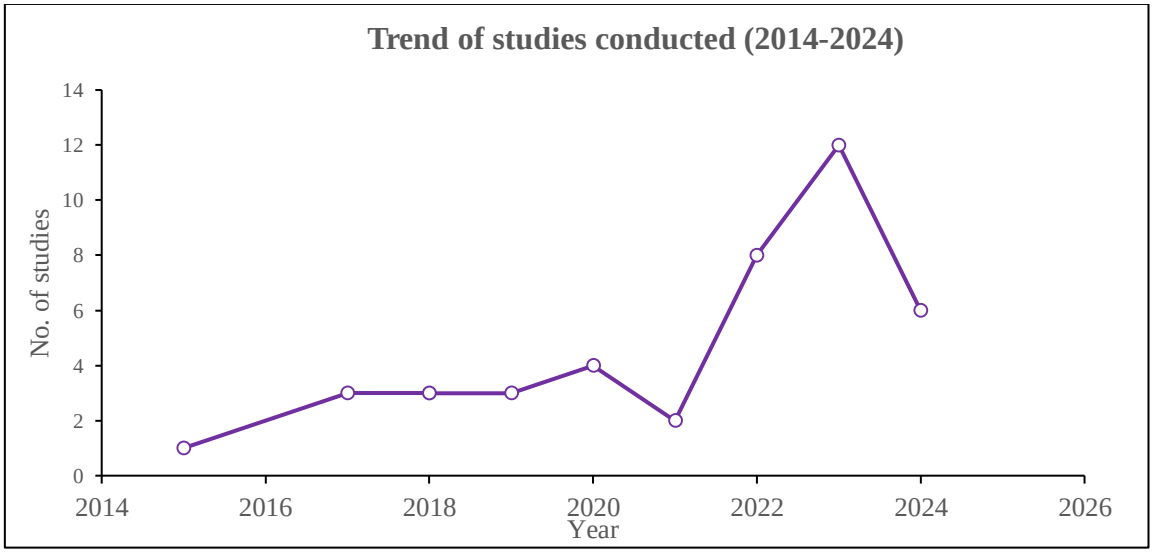

Figure 7: Line graph representing the trend of studies undertaken in the field of UHI and its implications on health.

Figure 8: Treemap chart indicating the geographical distribution of articles based on the search strategy on Web of Science[13]

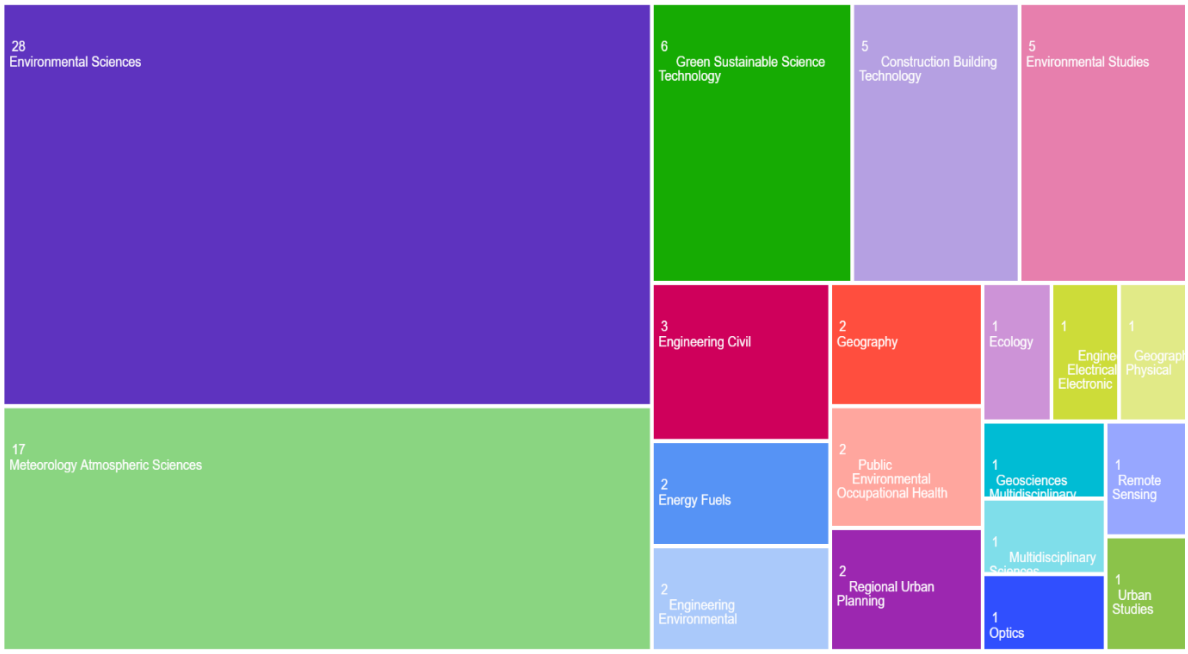

Figure 9: Treemap chart indicating the distribution of fields of the articles based on the search strategy on Web of Science[13]

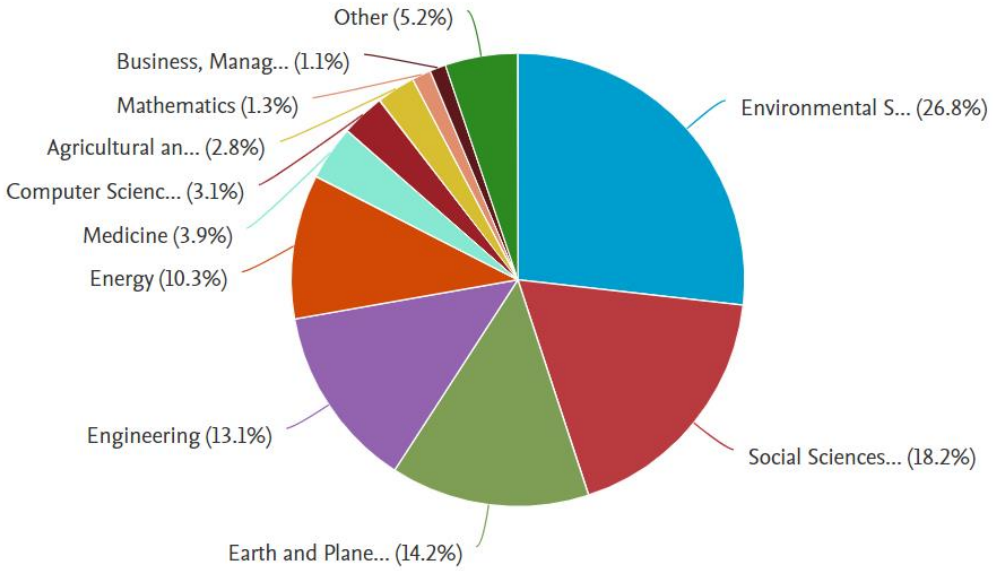

Figure 10: Documents on Scopus by subject area based on the search strategy.[14]

1. Factors contributing to UHI formation

A study by Kotharkar et. al, summarizes that the changing urban microclimate leads to an apparent UHI effect in South Asian cities which was evident at night. UHI formation is attributed to the variation in land use, increase in anthropogenic activity, and population density. It also concluded that coastal cities such as Chennai and Mumbai recorded a temperature variation in the town. Throughout the day, warmer temperatures were documented in the city's interior and cooler temperatures towards the coast. The contrary occurred at night. Thus, whatever positive effect water bodies have on UHI in waterfront cities during the day is negated at night. [10] Per a study by Piracha et. al, this occurs due to the contribution of Direct Solar Heat (DSH) and Indirect Solar Heat (ISH) towards the UHI phenomenon. DSH is the exposure of the urban infrastructure to the sun's radiation which is then stored as heat within these surfaces during the day, whereas ISH is the heat released from the urban fabric at night. The study finds that DSH remains constant in both urban and

rural areas during the day. However, the difference in ISH and heat created due to human activity is responsible for UHI formation.[15]

Heaveside et al. postulates that the difference in the urban infrastructure material and geometry is a factor for the disequilibrium in the surface energy in cities than its rural counterparts. The paper also suggests that UHI formation majorly affects larger cities due to the dual effect of the rise in anthropogenic activities and the absence of humidity in these regions. [16] However, the influence is not limited to large cities as small towns with a high population density and close settlements can also experience heat island effects.[34] The absence of humidity occurs due to the reduction of green infrastructure in urban regions and impacts the process of evapotranspiration.[16] Pyrgou et. al, also found that the lack of greenery in metropolises prevents temperature reduction by altering evapotranspiration, awning, and wind characteristics. Thereby, making lack of vegetation a major contributor to UHI formation.[17]

Singh et. al, attribute UHI formation to the entrapment of longwave electromagnetic radiation due to the formation of street canyons which reduces the visibility of the sky also known as the Sky View Factor (SVF). This entrapment leads to an increase in the thermal state in these regions. The other contributing factors are the replacement rate of vegetation with concrete, the rise in anthropogenic activity, and urban expansion which cancel the positive effects of the urban oasis.[18] Ligsay et al also support the argument that although cities occupy only 3% of the land globally, they produce 60% of total CO2 emissions. This is ascribed to an increase in UHI intensity due to factors such as urban morphology, built area density, and type as well as the growing population density which is expected to increase to 70% by 2050 from 50%.[19]

However, Pyrgou et. al, found that a critical component of urban morphology leading to UHI is the street placement and the SVF which influences the energy exchange between the urban canopy and the environment over the day's course. The urban infrastructure absorbs solar radiation during the day but positively affects its surrounding structures through the shading effect and keeps these structures cooler during daylight hours.[17]

Figure 12: Highest temperature differences recorded among urban and rural areas internationally [29]

2. Compounding effect of heatwaves on UHI

Damaging effects of UHI are studied largely during summers due to the ideal conditions of clear skies, increased solar radiation, and low wind speed. Such circumstances persist during a heatwave.[16] In a study, Jamei et al. reported that cities such as Athens, Sydney, Seoul, and major cities in China reported higher UHI temperature differences up to 3.5 °C during heatwaves, leading to increased morbidity rates.[20] Over the last century, Tokyo reported an increase of 3 °C per the Japan Meteorological Agency. Cities in developing parts of the world also face the brunt of this effect with Southeast Asia reporting one of the longest and brutal heatwaves in 2024. In Asia, dense cities and global warming are accelerating the characteristics of heatwaves making the region hotter by 2°C while increasing the probability by 30 times for heatwaves.[36] However, this effect is not equally distributed within the city. Variations occur due to age, gender, occupation, socioeconomic factors, disease profile, and education status. [21]

Mika et al, argue that the UHI effect is minimally affected due to climate change-related heatwaves. Major contributors to UHI intensification are anthropogenic activity and geographic enlargement of urban areas. Hence, a dense city will experience more damaging effects of the heatwaves than its sparse counterparts.[22] Climate Copernicus reported, that although temperatures are rising due to climate change, increased urban migration, and population density within the cities aid in the worsening of UHI. In the summer of 2023, London recorded a temperature difference of 7°C from its rural analog Vilnius in Lithuania. This occurs due to the synergistic effect of both macro and microclimatic changes.[23] Heaveside in her paper states that these recorded temperatures are underestimated since meteorological stations are located away from the city surrounded by relatively higher greenery than the hot spots of the metropolis.[34] Lee et. al, also found that heatwaves, although large climatological events, put the urban population at a higher risk due to the preexisting UHI effect.[24]

Ngarambe et. al, using regression and clustering models studied the association between UHI and heatwave-related deaths in Seoul and concluded that UHI and heatwaves share a dysfunctional relationship. UHII is enhanced due to urban expansion. This leads to changes in the local meteorological mechanisms such as alterations in wind behavior and simultaneously transforms the large-scale atmospheric dynamics, deteriorating regional climate processes. However, in the presence of heatwaves, UHI effects are amplified, further worsening the heatwaves. This puts the urban residents in a brutal cycle. The phenomenon was reported by the Ministry of Climate Change, Pakistan in 2015 amidst the heatwave in Southern Pakistan.[25]

Jamei et. al asserts the UHI effect is compounded in catastrophic heat events due to the lack of heat dissipation at night contributing to higher heat stress fatalities. In Australia, heatwaves account for the highest weather-related deaths at 55%. Heatwaves are invisible and

the level of destruction cannot be visualized. It impacts every house, but the vulnerable population is most compromised by its effects.[20]

3. Implications on the environment:

a. Energy Utilization

During summer, there is an increased demand for cooling systems due to heat discomfort. This discomfort leads to a rise in indoor energy utilization.[10] In Athens, due to the amplifying nature of heatwaves and UHI, it was found that the cooling appliances operated at a reduced capacity, resulting in increased pressure on the infrastructure's HVAC system, further increasing the power load by three times.[31] Energy utilization is a double-edged sword. Due to increased energy demand, more and more greenhouse gases are emitted. These emissions lead to extreme climatic changes in the local and regional environment. Such extreme heat events further cause an increase in indoor air conditioning, leading to a vicious cycle that puts urban residents at a greater risk for health hazards.[10]

b. Air Pollution

Globally, nearly 4.2 million mortalities occur due to outdoor air pollution, particularly in areas where the air quality index is higher than WHO-recommended levels. A majority of this mortality load is experienced by Southeast Asia and Western Pacific nations.[18] Rapid, unplanned urbanization and increasing population density are major contributors to air pollution as they alter the composition of atmospheric pollutants. These factors and anthropogenic activity contribute to 70% of the total carbon emissions.[20] However, Piracha et al. derive that air pollutants' origin differs based on the country's development. In emerging economies, the primary source of air pollution is from cooking and industries. Whereas, in advanced economies, the source is motor vehicles.[15]

Three main pollutants of significant health concern are particulate matter, tropospheric ozone, and nitrogen oxide. The increased atmospheric presence of greenhouse gases leads to the formation of tropospheric ozone through photochemical reactions in the environment resulting in organic and inorganic aerosols. These aerosols contribute to the haze effect commonly seen in big cities. The presence of tall infrastructure prevents the dissipation of greenhouse gases and leads to accumulation in the cities. In summer, energy demand is high due to the synergistic effect of UHI and heat waves. The emitted gases prevent the dissipation of solar radiation and absorb them. Releasing these harmful radiational waves further warms the atmospheric temperatures. This facilitates reactions for ozone formation and causes ozone-related mortality, particularly cardiovascular and respiratory diseases.[18]

UHI accelerates the incidence and strength of climate change-related weather events. This leads to an increase in natural hazards such as floods, forest fires, and tempests. A rise in wildland fires increased the accumulation of air pollutants primarily particulate matter in the air exacerbating respiratory and cardiovascular illnesses. Poor air quality also induces allergic diseases like asthma, bronchitis, rhinitis, and conjunctivitis. Thus, reducing the quality of life of individuals. The majority of metropolises are located near the shore. A surge in flash floods and heavy rains leads to crop destruction. Global warming-related weather crises and increased natural disasters influence the reemergence of organisms that can also cause crop destruction.[16] In India, in 2022, due to heatwaves followed by drought wheat production declined by 3%. A similar phenomenon was seen in Pakistan the same year resulting in a 15% drop in wheat production.[36] Thereby, causing food insecurity. Urban citizens are stuck in this complicated climate change-air contamination-UHI loop which is catastrophic to human health and well-being.[16]

4. Implications for health

a. Thermal comfort

Thermal comfort is a state in which individuals are at ease with the environmental temperature and can conduct their day-to-day activities. Such ideal conditions in summer are experienced at temperatures between 22 and 27° C with a humidity of 30 to 60%. Pyrgou et. al, found amongst other variables high population density and dense urban morphology influenced urban airflow and thermal comfort outdoors. In normal weather conditions, the human body copes with high temperature variations through sweating which is a cooling down mechanism. However, the regulation fails in extreme and prolonged heat events, and thermal distress is experienced. This failure puts an individual at a higher risk of hyperthermia.[24] A study in Melbourne found that the elderly population is more susceptible to thermal discomfort due to lower blood pressure which affects this thermoregulation mechanism of vaporization, conductive heat transfer, and fluid circulation.[20]

Kotharkar et. al, in their systematic review, studied outdoor human thermal comfort indices such as Physiologically Equivalent Temperature, Temperature-Humidity Index, and Relative Strain Index.[10] They concluded urban morphology plays an important part in thermal comfort. The discomfort was higher in areas with low vegetation canopy, broad streets, and compact structures. Whereas, increased thermal comfort was experienced in areas with high-rise structures, tight roads, more vegetative cover, and the presence of water bodies. In Chennai, during heatwaves and due to the UHI effect 100% of the urban residents experienced thermal discomfort.[10] Ponraj et al, explore the interrelationship between exposure to the urban fabric and thermal comfort. The higher the exposure to these urban infrastructures during extreme heat events higher the thermal discomfort.[24]

b. Sleep

The thermal environment plays a critical role in the sleep quality that an individual receives. Kassomenos, et. al in their systematic review studied the impact of urban overheating on multiple variables one of them being sleep. The review concluded that apart from the thermal environment, humidity is also an important factor in attaining quality sleep as this impacts the REM stages leading to fatigue. High nighttime temperatures negatively affect restorative sleep in individuals who do not suffer from sleeping disorders as the thermal environment is closely related to the body's circadian cycle. This disruption prevents urban residents from performing their day-to-day activities efficiently especially, in energy-poor regions of the world. Individuals with low access to air conditioning were reported to be more likely to depend on an increased dose of sleeping pills than those with access to such energy-consuming appliances.[21]

Aghamohammadi, et. al, studied the association of urban overheating and physical, psychosomatic, and psychological symptoms in Kuala Lumpur through the Physiological Equivalent Temperature (PET) index maintained by the local meteorological station to record the degree of urban heat. A cross-sectional survey reported high PET was significantly associated with psychosomatic symptoms of disturbed sleep, lack of hunger, and lethargy.[26] A study in Sydney found, that with every degree increase in temperature, the quality of sleep was reduced by 1.04%. Physicians in Japan attribute increasing temperatures to the rising rates of poor restful sleep in its urban residents.[37]

c. Mental health

The impact of weather-hazardous events on physical well-being is widely understood, but heat stress also significantly influences individuals' mental health. Mika et. al, state that

mental disturbance occurs in individuals suffering from the aftermath of a destructive climatic event due to heatwaves. However, people suffering from a pre-existing mental illness on medications are highly susceptible to heat stress as these drugs hamper the thermoregulation mechanism of the body which is crucial to cope with such temperatures.[22] Kassomenos et. al, assess the literature on the effects of urban heat on disease and state that apart from the negative effects of these mood stabilizers in extreme heat events. These temperatures also affect the intellectual performance of the individual as far as 3 days.[21] Jamei et. al, conclude the vulnerability of these individuals to their asocial behavior due to their illness and poor access to cooling units.[20]

Kassomenos et. al, find that urban heat stress is associated with mood and behavior disorders. There exists a direct relationship between extreme heat and suicide and homicide rates. A 1 °C increase in temperature caused a surge of 0.7% and 2.1% in suicide rates in the USA and Mexico. Residents in Kuala Lumpur also reported experiencing psychological and psychosomatic symptoms during heatwave events. With the expansion of the city limits, Tianjin residents experienced a higher level of emotional distress particularly when the temperatures surpassed 32 °C.[20] The relation between PET and psychological symptoms as per the review by Aghamohammadi, et. al reveals a negative relationship between PET and despondent symptoms in individuals which is more likely due to the increased energy utilization of the body for internal temperature regulation. However, there was no significant association between PET and clinical depression among urban residents. This result can be due to the low understanding of depression by the study participants.[26]

Liu et. al studied the association of mental health crises reported in hospitals during heatwaves in Jinan, China. The study revealed that during heatwaves there was a rise of 18.3% in the diagnosis of mental illness incidents which mainly included behaviour and mood disorders up to 5 days after the heatwave event. This data supported prior studies in

this field further strengthening the association of urban heat stress on mental illnesses.[27] Heatwaves also play a role in increasing criminal activity and conflicts. As per a study by the United States Institute of Peace, there was a 9% increase in hostilities during heatwaves, whereas a 23% rise was seen during weather-related disasters in ethnically diverse countries.[36]

d. Morbidity and Mortality

Rapid urbanization, global warming, and changing population demographics put urban residents at a higher risk for heat-related morbidity and mortality which range from aggravation of pre-existing illnesses to a greater likelihood of hospital care and in some cases death. This burden is experienced at a higher rate by children, women, the obese, elderly, pregnant women, outdoor workers, individuals with pre-existing diseases, displaced persons, unhoused, and those living alone.[21,16] In large cities of the USA such as Phoenix it is estimated that mortality rates will double in the elderly population particularly due to daytime exposure to extreme heat events in the upcoming decade.[22] Heaveside et. al, in their review, comment on the significant relationship between the socio-economic profile and its association with UHI effects particularly in the socio-economically disadvantaged, limited formal education, and minority populations. Neighbourhoods occupied by wealthy individuals were at a lower risk of these negative effects due to tree canopy coverage, and air conditioning. However, low-income localities that are deficient in vegetation and the necessary infrastructure to cope with these extreme temperatures are at a higher risk of the UHI effect.

Jamei et. al hypothesizes this difference is due to the poor interpretation of manuals to utilize energy appliances as well as challenges in the comprehension of government

guidelines.[20] Studies using Bayesian modelling techniques in the UK reviewed hospital records during heatwaves and found there was a notable association between heat-related morbidity and mortality in crowded and socio-economically disadvantaged areas. Similarly, mapping studies in Philadelphia, USA found higher deaths during the heatwaves in the urban poor population. However, a study in Massachusetts, USA using kriging techniques found that there was a significant association between the socio-demographic factors and heat-related health effects irrespective of the stage of urban development.[16] Mika et. al found that the existing population is more susceptible to global warming-related health effects due to the integrating effect of UHI and air pollution causing higher upper and lower respiratory disorders. This is attributed to the presence of nitrogen oxides and reactive oxygen due to air pollution which affects defense mechanisms while enabling advanced aging and cell degeneration.[22] Heatwaves also caused a 48% rise in COPD deaths in Nanjing, China.[37] During heatwaves in Nicosia, for every degree rise above the daily average temperature there were 24% more deaths, and a 5 °C rise in temperature experienced a 133% increase in mortality.[17]

Heat-related deaths are difficult to quantify as they are not directly documented as the cause of death but contribute majorly towards mortality, especially during heat waves.[15] An assessment of UHI on mortality reported 1.1 deaths for each million individuals in the US. However, the data collected were death certificates clearly stating heat as the primary cause of death which underestimates the mortality rates.[34] Singh et. al postulate that the risk for mortality increases above 40°C and hyperthermia contributes to 40-64% of deaths.[18] According to Jamei et. al risk of mortality increases with the rise in temperature beyond 24°C. In Adelaide, Australia, 32.4% more deaths occurred due to heatwaves.[20] Whereas in Europe, the synergistic effect of heatwaves and UHI contributed to 40% increased deaths.[15] Ho et. al, studied the mortality risk due to UHI in Hong Kong and established that each

degree rise in temperature above 29 °C mortality rates surged by 4.1%. [33] The presence of pre-existing illnesses and elderly age affects the thermoregulatory mechanism to cope with these events. Also, low cardiac functioning in the advanced population puts them at a greater risk with each degree increase in temperature elevating the blood pressure by 0.6mmHg, particularly in residences with a higher household temperature.[18]

Correspondingly, hyperpnea due to heat puts a strain on the respiratory system causing pulmonary trauma.[15] Increased exposure to heat changes the blood consistency resulting in the formation of blood clots which cause ischemia. During a heatwave in Cyprus, more women died in the age group 75-85 due to cardiovascular and respiratory causes. Thus, heatwaves affect women more than men.[17] However, in Adelaide heatwaves affected individuals aged 64 and above.[20] Lo, et. al in their systematic review found diversity in emergency cardiovascular diseases between cities within South Korea. This may be due to the difference in the cardiac health status of the population as well as the location.[37] Besides cardiac and respiratory illnesses, extreme heat events can lead to low blood volume due to the loss of fluid through sweating causing electrolyte dysfunction, and hypoperfusion to the brain and kidneys. Heat strokes can also impact cerebral and analytical functioning leading to disorientation and loss of perception.[18]

Kassomenos et. al in their study apart from other health effects found that the rate of kidney-related hospitalization increased during heatwaves.[21] Tewari et. al explore the relationship between UHI and stroke. It is found that brain temperature is elevated before and after a cerebral stroke. This is due to the neuronal death in the brain which generates heat. Heat and stroke are closely linked to the increased rates of stroke in the urban population as higher temperatures predispose an individual to a stroke. The increased heat exposure to the brain can affect the limbic system leading to an Alzheimer ’s-like disease in the urban population. The author also comments on the association of UHI with the development of

Parkinson's disease due to the presence of free radicals in the brain formed by neuroinflammation after prolonged heat exposure.[28] Lee et. al stated that there is a 46.9% increased risk of mortality due to cardiovascular diseases, and a 51.3% increased risk of mortality due to stroke.[24] There is also an established relationship between the effect of high temperatures on pregnancy and its outcomes, facilitated by air pollution and climatic change. High temperatures play a contributing factor in premature birth outcomes.[31] In Brisbane, pregnant women exposed to heatwaves after the first trimester were 1.13 times more likely to deliver prematurely. Exposure to heat events in the later stages of pregnancy is also associated with stillbirth.[37]

Apart from chronic diseases, Ligsay et. al, emphasize the burden of vector-borne diseases due to the growing urban population, UHI, and climate change. A third of the total malaria cases originate from cities globally. These vectors are also rapidly adapting to the changing urban fabric by depositing their larvae in open containers which previously were found commonly in open waters.[19] Thus, UHI not only increases the burden of non-communicable diseases but also increases the incidence of infectious diseases. The duration and intensity of heatwaves also matter. During prolonged and high-intensity heatwaves there were three times more deaths as per a study by Piticar et.al.[30]

5. Impact on health service systems

WHO estimates weather-related disasters to have increased by threefold in the last half-century. Intense heatwave events are occurring throughout the world increasing the burden of morbidity within the population and causing death during these extreme events. Such events put high pressure on the urban health service systems.[38,21] In South Korea, visits to the hospital increased by 1.1% with each degree rise in temperature for hypotension. Whereas a

subsequent 1.9% increase in hospital visits was seen after heatwave events lasting up to 7 days in the younger population and a 2% increase was seen in those aged 65 years and above. Emergency visits also increased by 5% in France during such events. In California, emergency rooms saw a spike of 12.7% for hypotension and an approximately 2% rise for cardiovascular diseases. Ambulance services recorded a surge of 29% in Canada for every degree increase above the ambient temperature. Hospital admissions due to cardiovascular ailments increased by 6% during heatwaves.[21] The rise in health service demand ranges from minor heat-related illnesses such as dehydration, and cramps to life-threatening conditions such as acute myocardial infarction, and stroke.

In Tokyo, a rise in ambient temperature was associated with an increase in paediatric asthma visits to the emergency room.[37] The relationship between heat-related morbidity and mortality and health service demand is associated with several vulnerability factors with the rise in demand seen mainly in urban poor, marginalized, and areas with subpar infrastructure to cope with heat stress. The financial burden of heat-related health events is expected to rise approximately to 130 million AUD in Perth, Australia. More research-based planned actions need to be taken to meet these future demands by the health systems.[38]

Proposed Framework based on Actor-Network theory

As established in the study, climate change and health don't occur linearly. There exists an interrelationship between multiple factors that eventually affect health and burden the health service systems. There is a need to understand climate change and its impacts in a multidisciplinary manner to take a holistic approach towards heat health policymaking. In this study, we have proposed a conceptual framework for understanding the interrelation between climate change, heat waves, UHI, environment, health, and health service systems.

The framework is based on the ideology of the Actor-Network Theory developed by a French philosopher, Bruno Latour to rationalize how innovations occur in scientific situations. It is a social theory that justifies the universe as a network of ever-changing relationships. These relationships are between human and non-human elements in the social and natural world. Where each object plays a key role in creating an impact on society.[42]

Heatwaves are an expression of climate change and UHI is an independent phenomenon regardless of the growing occurrence of climate change. Due to rapid urbanization, anthropogenic activities, and the increased probability of heatwaves the temperatures in these regions are high due to the synergistic effect of the two phenomena. This impacts the quality of air and has implications for health ranging from mild dehydration to heat strokes to increased morbidity and mortality, especially in vulnerable populations. Energy utilization is a moderating variable. Due to the emission of greenhouse gases which further warm the air and increase the UHI temperatures at the same time, these gases also reduce the air quality.

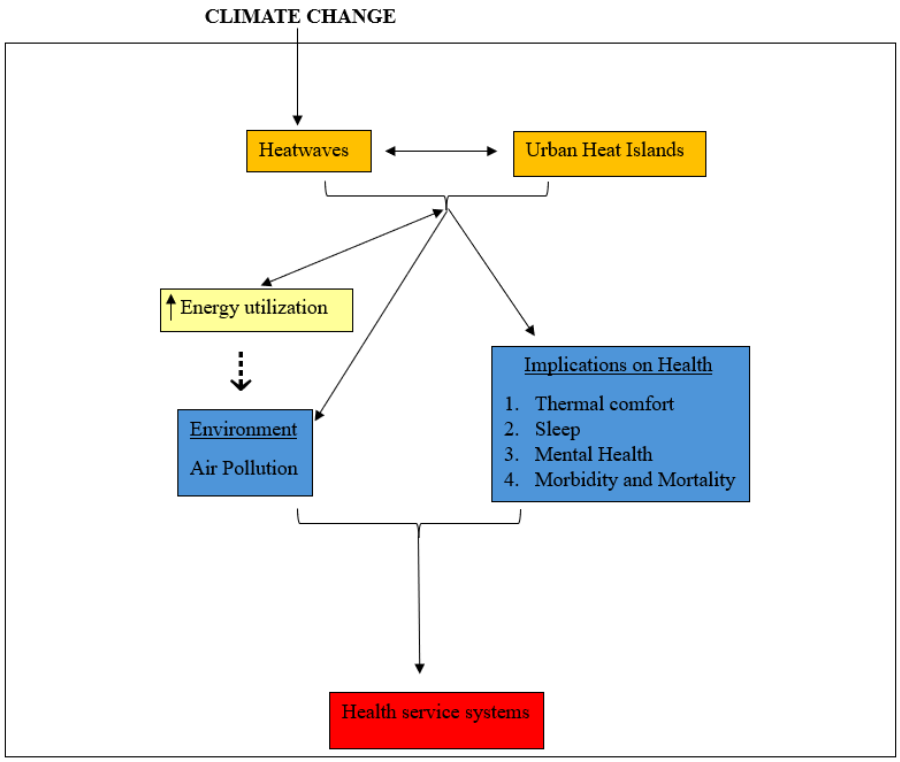

Figure 11: Conceptual framework of the study

Discussion

Heatwaves are amongst the most lethal climate change disasters. Unlike other natural hazards, individuals experiencing deadly heatwaves are not evacuated and the repercussions on health are understated as they can have immediate as well as long-lasting effects on the health and the environment. As forecasted by WMO, heatwaves will occur more frequently and with higher intensity affecting urban populations more than their rural analogues. Within the urban setting, the effect is unequal too impacting those that are vulnerable.[2] Heat mortality risks have increased by 85% for the population aged 65 years and above, from 2000 to 2021.[5] Climate change-related hazards will add a quarter of a million more deaths due to both infectious and non-infectious diseases.[8] Urban fabric with the rising global warming crisis adds fuel to the fire and makes matters worse for its residents by affecting the air and water quality. Subsequent natural disasters following heatwaves also impact the food security of this population.

This study has assessed the implication of heatwaves and UHI on the environment as well as on the heat health risks to the urban population adding to the limited interdisciplinary literature available on this topic. More longitudinal, regional studies need to be undertaken to understand the long-term impact of UHI on the physical, emotional, and mental health of the community. Hospital admissions for pulmonary disorders are projected to rise 2 to 6 times in the coming century compared to the beginning of the century.[35] Heat action plans should also involve better planning and capacity building of health systems to prevent the future burden on healthcare services requirements during these extreme events, particularly from the urban poor and susceptible individuals. Implementing context-based preventive measures across countries backed by research will be fruitful to get the most success in limiting the impact of such catastrophes.

References

1. Gavi the vaccine alliance. (June 17th, 2022) Deadly heatwaves: How high temperatures affect the body. Retrieved August 2nd, 2024, from https://www.gavi.org/vaccineswork/deadly-heatwaves-how-high-temperatures-affect-body
2. World Meteorological Organization. *Heatwave.* Retrieved August 2nd, 2024, from https://wmo.int/topics/heatwave
3. The Economic Time (June 10, 2024) India's heat waves longest ever, worse to come. Retrieved August 2nd, 2024, from https://economictimes.indiatimes.com/news/india/indias-heatwave-longest-ever-worse-to-come/articleshow/110867100.cms
4. World Meteorological Organization and World Health Organization (2015) *Heatwaves and Health*. Retrieved August 2nd, 2024, from https://library.wmo.int/records/item/54600-heatwaves-and-health
5. World Health Organization (2024, May 28) *Heat and health*. Retrieved August 2nd, 2024, from https://www.who.int/news-room/fact-sheets/detail/climate-change-heat-and-health
6. Climate Central (June 27, 2024) *Analysis: Global extreme heat in June 2024 strongly linked to climate change* Retrieved August 2nd, 2024, from https://www.climatecentral.org/report/global-heat-review-june-2024
7. Rony, M. K. K., & Alamgir, H. M. (2023). High temperatures on mental health: Recognizing the association and the need for proactive strategies- A perspective. *Health science reports*, *6*(12), e1729. https://doi.org/10.1002/hsr2.1729

8. World Health Organization (October 12, 2023) *Climate change*. Retrieved August 2nd, 2024, from https://www.who.int/news-room/fact-sheets/detail/climate-change-and-health
9. Goyal, M.K., Singh, S. & Jain, V. (2023) Heat waves characteristics intensification across Indian smart cities. *Sci Rep* **13**, 14786. https://doi.org/10.1038/s41598-023-41968-8
10. Rajashree Kotharkar, Aparna Ramesh, Anurag Bagade. *Urban Heat Island studies in South Asia: A critical review*, Urban Climate, Volume 24, 2018, Pages 1011-1026, ISSN 2212-0955, https://doi.org/10.1016/j.uclim.2017.12.006.
11. United States Environmental Protection Agency. Heat Island Effect. Retrieved August 2nd, 2024, from https://www.epa.gov/heatislands
12. Climate Central (July 26th, 2023) Urban Heat Hot Spots. Retrieved August 2nd, 2024, from https://www.climatecentral.org/climate-matters/urban-heat-islands-2023
13. Web of Science. *Analyze Results*. Retrieved August 16th, 2024, from https://www-webofscience-com.proxy1.library.jhu.edu/wos/woscc/analyze-results/fe6d64d8-66de-4582-8909-59a75b5e8932-010228e04d
14. Scopus. Analyze Results. Retrieved August 17th, 2024, from https://www.scopus.com/term/analyzer
15. Piracha, A., & Chaudhary, M. T. (2022). Urban Air Pollution, Urban Heat Island and Human Health: A Review of the Literature. *Sustainability, 14*(15), 9234. https://doi.org/10.3390/su14159234
16. Heaviside, C., Macintyre, H., & Vardoulakis, S. (2017). The Urban Heat Island: Implications for Health in a Changing environment. *Current Environmental Health Reports, 4*(3), 296–305. https://doi.org/10.1007/s40572-017-0150-3

17. Pyrgou, A., & Santamouris, M. (2018). Increasing Probability of Heat-Related Mortality in a Mediterranean City Due to Urban Warming. *International Journal of Environmental Research and Public Health, 15(8), 1571.* https://doi.org/10.3390/ijerph15081571

18. Singh, N., Singh, S., & Mall, R. (2020). Urban ecology and human health: implications of urban heat island, air pollution and climate change nexus. In *Elsevier eBooks* (pp. 317–334). https://doi.org/10.1016/b978-0-12-820730-7.00017-3

19. Ligsay, A., Telle, O., & Paul, R. (2021). Challenges to Mitigating the Urban Health Burden of Mosquito-Borne Diseases in the Face of Climate Change. *International Journal of Environmental Research and Public Health, 18*(9), 5035. https://doi.org/10.3390/ijerph18095035

20. Jamei, E., & Tapper, N. (2022). Urban overheating and the impact on health in Melbourne. In *Advances in sustainability science and technology* (pp. 233–248). https://doi.org/10.1007/978-981-19-4707-0_12

21. Kassomenos, P., & Begou, P. (2022). The impact of urban overheating on Heat-Related Morbidity. In *Advances in sustainability science and technology* (pp. 39–80). https://doi.org/10.1007/978-981-19-4707-0_3

22. Mika, J., Forgo, P., Lakatos, L., Olah, A. B., Rapi, S., & Utasi, Z. (2018). Impact of 1.5 K global warming on urban air pollution and heat island with outlook on human health effects. *Current Opinion in Environmental Sustainability*, *30*, 151–159. https://doi.org/10.1016/j.cosust.2018.05.013

23. *Extreme weather and human health*. (n.d.). Copernicus. Retrieved August 18th, 2024, from https://climate.copernicus.eu/esotc/2023/extreme-weather-and-human-health

24. Ponraj, M., Lee, Y. Y., Din, M. F. M., Noor, Z. Z., Iwao, K., & Chelliapan, S. (2017). OVERVIEW OF URBAN HEAT ISLAND (UHI) PHENOMENON TOWARDS

HUMAN THERMAL COMFORT. *Environmental Engineering and Management Journal*, *16*(9), 2097–2111. https://doi.org/10.30638/eemj.2017.217

25. Ngarambe, J., Santamouris, M., & Yun, G. Y. (2022). The impact of urban warming on the mortality of vulnerable populations in Seoul. *Sustainability*, *14*(20), 13452. https://doi.org/10.3390/su142013452
26. Aghamohammadi, N., Fong, C. S., Idrus, M. H. M., Ramakreshnan, L., & Sulaiman, N. M. (2021). Environmental heat-related health symptoms among community in a tropical city. *The Science of the Total Environment*, *782*, 146611. https://doi.org/10.1016/j.scitotenv.2021.146611
27. Liu, X., Liu, H., Fan, H., Liu, Y., & Ding, G. (2018). Influence of Heat Waves on Daily Hospital Visits for Mental Illness in Jinan, China-A Case-Crossover Study. *International journal of environmental research and public health*, *16*(1), 87. https://doi.org/10.3390/ijerph16010087
28. Tewari, K., Tewari, M., & Niyogi, D. (2023). Need for considering urban climate change factors on stroke, neurodegenerative diseases, and mood disorders studies. Computational Urban Science, 3(1), 4. https://doi.org/10.1007/s43762-023-00079-w
29. Aboulnaga, M., Trombadore, A., Mostafa, M., & Abouaiana, A. (2024). Understanding Urban Heat Island Effect: causes, impacts, factors, and strategies for better livability and climate change mitigation and adaptation. In *Springer eBooks* (pp. 283–366). https://doi.org/10.1007/978-3-031-51220-9_2
30. Piticar, A., Cheval, S., & Frighenciu, M. (2019). A review of recent studies on heat wave definitions, mechanisms, changes, and impact on mortality. *Forum Geografic*, *XVIII*(2), 96–114. https://doi.org/10.5775/fg.2019.019.d
31. Aboulnaga, M., Trombadore, A., Mostafa, M., & Abouaiana, A. (2024b). Understanding Urban Heat Island Effect: causes, impacts, factors, and strategies for

better livability and climate change mitigation and adaptation. In Springer eBooks (pp. 283–366). https://doi.org/10.1007/978-3-031-51220-9_2

32. Kuehn L, McCormick S. Heat exposure and maternal health in the face of climate change. *International Journal of Environmental Research and Public Health*. 2017;14(8):853. https://www.proquest.com/scholarly-journals/heat-exposure-maternal-health-face-climate-change/docview/1939922440/se-2. doi: https://doi.org/10.3390/ijerph14080853
33. Ho, J. Y., Shi, Y., Lau, K. K., Ng, E. Y., Ren, C., & Goggins, W. B. (2023). Urban heat island effect-related mortality under extreme heat and non-extreme heat scenarios: A 2010–2019 case study in Hong Kong. *The Science of the Total Environment*, *858*, 159791. https://doi.org/10.1016/j.scitotenv.2022.159791
34. Oxford University Press. (n.d.). *Urban Heat Islands and their Associated Impacts on Health - UCL Discovery*. Retrieved September 16th, 2024, from https://discovery.ucl.ac.uk/id/eprint/10106446/
35. Arsad, F. S., Hod, R., Ahmad, N., Ismail, R., Mohamed, N., Baharom, M., Osman, Y., Radi, M. F. M., & Tangang, F. (2022). The impact of heatwaves on mortality and morbidity and the associated vulnerability Factors: a Systematic review. *International Journal of Environmental Research and Public Health*, *19*(23), 16356. https://doi.org/10.3390/ijerph192316356
36. *How heat waves are destabilizing Asia*. (n.d.). United States Institute of Peace. Retrieved September 18th, 2024 from https://www.usip.org/publications/2023/06/how-heat-waves-are-destabilizing-asia
37. Lo, Y., Vosper, E., Higgins, J. P., & Howard, G. (2023). Heat impacts on human health in the Western Pacific Region: an umbrella review. *The Lancet Regional Health - Western Pacific*, *42*, 100952. https://doi.org/10.1016/j.lanwpc.2023.100952

38. Mason, H., King, J. C., Peden, A. E., & Franklin, R. C. (2022). Systematic review of the impact of heatwaves on health service demand in Australia. *BMC Health Services Research*, *22*(1). https://doi.org/10.1186/s12913-022-08341-3

39. *Global_Surface_UHI_Explorer*. (n.d.). Retrieved on September 23rd, 2024, from, https://yceo.users.earthengine.app/view/uhimap

40. United Nations. (n.d.). *Climate change | United Nations*. Retrieved September 23rd, 2024, from, https://www.un.org/en/global-issues/climate-change

41. Deuskar, C. (2024b, March 16). What does "urban" mean? *World Bank Blogs*. Retrieved on September 23rd, 2024, from, https://blogs.worldbank.org/en/sustainablecities/what-does-urban-mean

42. Cresswell, K. M., Worth, A., & Sheikh, A. (2010). Actor-Network Theory and its role in understanding the implementation of information technology developments in healthcare. BMC Medical Informatics and Decision Making, 10(1). https://doi.org/10.1186/1472-6947-10-67

Appendix

Table 1: Summary of literature review

Author	Year	Title	Purpose	Type of source	Summary
World Meteorological Organization and World Health Organization [4]	2015	Heatwaves and Health: Guidance on Warning- System Development	To understand the interdisciplinary facets of heat	Document-WMO	The development of HHWS can prove to be useful in controlling heat-related impact on health and requires an interdisciplinary approach
Kuehn, et al[32]	2017	Heat Exposure and Maternal Health in the Face of Climate Change		Journal-International Journal of Environmental	

				Research and Public Health, Volume 14, Issue 8	
Ponraj, et al[24]	2017	Overview of Urban Heat Island (UHI) phenomenon towards human thermal comfort phenomenon	To investigate the features, factors, and impact of UHI and evaluate human health and safety	Journal- Environmental Engineering and Management Journal Volume 16	With an increase in climate change, heat-related illnesses are increasing. Rapid and unplanned urbanization has led to UHI which has a devastating impact on human health.
Heaviside, et al[16]	2017	The Urban Heat Island: Implications for Health in a Changing Environment	To quantify UHI health impacts and estimate the benefits of mitigation measures	Journal- Built Environment and Health Volume 4 Pages 296-305	Health impacts due to UHI are significant and mitigating strategies should consider multiple factors to maximize health benefits.
Mika et al[22]	2018	Impact of 1.5 K global warming on urban air pollution and heat island with outlook on human health effects	To understand the impact of a 1.5 K rise in temperature on UHI and UAP and its effects on human health	Journal- Current Opinion in Environmental Sustainability Volume 30 Pages 151-159	Forecasted temperature rise due to global warming, influences UHI and UAP properties which in turn affects urban population health.
Rajashree Kotharkar, et al[10]	2018	Urban Heat Island studies in South Asia: A critical review	To review the existing literature systematically on UHI in South Asia and assess their practical implications	Journal- Urban Climate Volume 24 Pages 1011-1026	The rapid environmental decline of South Asian cities makes them vulnerable to climate change phenomena such as UHI. Few studies show significant implications of UHI on energy use and management, human health, air pollution, and urban land use planning.

Pyrgou, et al[17]	2018	Increasing Probability of Heat-Related Mortality in a Mediterranean City Due to Urban Warming		Journal- International Journal of Environmental Research and Public Health, Volume 15, Issue 8	
Liu, et al[27]	2019	Influence of Heat Waves on Daily Hospital Visits for Mental Illness in Jinan, China—A Case-Crossover Study		Journal- International Journal of Environmental Research and Public Health, Volume 16, Issue 1	
Piticar, et al[30]	2019	A review of recent studies on heat wave definitions, mechanisms, changes, and impact on mortality	To define heatwaves, study the driving factors and their impact on mortality	Journal- Forum Geografic, Volume 18, Issue 2	Heatwaves have a significant impact on some continents and with time this impact will only amplify
Singh, et al[18]	2020	Urban ecology and human health: implications of urban heat island, air pollution and climate change nexus	Highlights public health implications of urbanization	Book- Urban Ecology Chapter 17 Pages 317-334	Rapid and unplanned urbanization has led to deterioration of urban ecology due to UHI and poor urban air quality leading to an increase in morbidity and mortality.
Dr. Clare Heaviside[34]	2020	Urban Heat Islands and their Associated Impacts on Health	To understand the compounding impact of UHI on heatwaves and its effect on morbidity and mortality		The UHI effect is more pronounced during a heatwave due to reduced wind speed. It affects morbidity and mortality directly.
World Meteorological Organization[2]	2020	Heatwave	To understand heatwaves and their impact on human, and environmental health	Article- WMO	Heatwaves are worsening year after year and have implications on human health and productivity, agricultural

					productivity, wildlife, and water quality.
Ligsay, et al[19]	2021	Challenges to Mitigating the Urban Health Burden of Mosquito-Borne Diseases in the Face of Climate Change		Journal- International Journal of Environmental Research and Public Health, Volume 18, Issue 9	
Aghamohammadi, et al[26]	2021	Environmental heat-related health symptoms among community in a tropical city		Journal- Science of the Total Environment, Volume 782	
Pavlos Kassomenos, et al[21]	2022	The Impact of Urban Overheating on Heat-Related Morbidity	To provide a comprehensive review of the existing literature with an emphasis on the impact of over-heating on heat-related morbidity	Book- Urban Overheating: Heat Mitigation and the Impact on Health, Pages 39-80	Extreme heat affects human health and well-being. Anthropogenic factors play a role in UHI formation while climate change-related heatwaves lead to exacerbation of this effect in urban areas. Impacting sleep, cardiorespiratory, and cardiovascular diseases.
Linda Geddes[1]	2022	Deadly heatwaves: How high temperatures affect the body	To understand the mechanism and effects of extreme heat on morbidity and mortality	Article- Gavi	Extreme heat events have varied effects on the human body such as exacerbation of pre-existing illnesses. The old and young populations along with marginalized communities are more at risk.
Ngarambe, et al[25]	2022	The Impact of Urban Warming on the Mortality of Vulnerable Populations in Seoul		Journal- Sustainability, Volume 14, Issue 20	

Piracha, et al[15]	2022	Urban Air Pollution, Urban Heat Island and Human Health: A Review of the Literature	To understand the cumulative impact of UHI on UAP and human health	Journal- Sustainability Volume 14, Issue 15	Understanding UHI, UAP and its impact requires an interdisciplinary approach. UAP is exaggerated due to the UHI effect
Mason, et al	2022	Systematic review of the impact of heatwaves on health service demand in Australia	To investigate an increase in health service demand during heatwaves in Australia	Article- BMC Health Services Research	Heatwaves harm health which consequently increases demand for health services. Individuals with chronic conditions and belonging to vulnerable groups are most susceptible.
Arsad, et al[35]	2022	The Impact of Heatwaves on Mortality and Morbidity and the Associated Vulnerability Factors: A Systematic Review	To investigate the recent impact of extreme heat on mortality and morbidity	Journal- International Journal of Environmental Research and Public Health, Volume 19, Issue 23	Mortality and morbidity increase due to heat waves. Socioeconomic, demographic, and geographic factors presented a higher vulnerability towards heat-related illnesses and deaths.
Jamei, et al[20]	2022	Urban Overheating and the Impact on Health in Melbourne	To investigate the factors that contribute towards the l vulnerability towards heat-related deaths due to UHI in Victoria	Book- Urban Overheating: Heat Mitigation and the Impact on Health, Pages 233-248	Climate change-related impacts are seen indirectly due to the developed infrastructure in Victoria. The morbidity is mainly attributed to vulnerability factors such as socioeconomic status.
Goyal, et al [9]	2023	Heat wave characteristics intensification across Indian smart cities	To assist policymakers in planning and heatwave adaptation while improving urban well-being	Article- Scientific reports	

Kayly Ober[36]	2023	How Heat Waves Are Destabilizing Asia	To understand the compounding effect of the climate crisis on heatwaves and its impact on human health.	Article- United States Institute of Peace	Heatwaves are 30 times more likely in Asia due to the exaggeration by the climate change crisis. This has a devastating impact on human health, agriculture, and food security in the region.
World Health Organization[8]	2023	Climate change	To assess the impact of climate change on health, environment, and health systems	Article- WHO	Climate change poses a risk to human and environmental health. It obstructs UHC by impacting health systems.
Copernicus[23]	2023	Extreme weather and human health	To understand the adverse effects of extreme weather on health	Article- Copernicus	The negative health effects of extreme weather have been rising and the ongoing strategies will be inadequate soon
Lo, et al[37]	2023	Heat impacts on human health in the Western Pacific Region: an umbrella review	To address the health impacts of heat in the WPR	Journal- The Lancet Journals, Volume 42	Heat-related morbidity is widely studied in high-income countries. More studies need to be conducted in the WPR.
Climate Central[12]	2023	Urban Heat Spots	To study the variation of UHI within 44 metropolitan cities in the USA	Report- Climate matters, Climate Central	Heatwaves are amplified due to UHIE. Of all the factors albedo has the largest impact on the UHI index
Rony, et al[7]	2023	High temperatures on mental health: Recognizing the association and the need for proactive strategies—A perspective	To investigate the effects of extreme heat on mental health and identify mitigation strategies	Journal- Health Science Report, Volume 6	Extreme heat results in exacerbated mental health symptoms. It puts vulnerable populations and individuals with chronic mental conditions most at risk.
Jy, et al[33]	2023	Urban Heat Island effect-related		Journal-	

		mortality under extreme heat and non-extreme heat scenarios: A 2010-2019 case study in Hong Kong		Science of the Total Environment, Volume 658, Part 1	
Tewari, et al[28]	2023	Need for considering urban climate change factors on stroke, neurodegenerative diseases, and mood disorders studies		Journal- Computational Urban Science, Volume 3, Issue 1	
World Health Organization[5]	2024	Heat and health	To understand the implications of heat on health	Article- WHO	Heat is an environmental and occupational hazard. Heat related deaths are increasing with the increase intensity of heatwaves.
Aboulnaga, et al[31]	2024	Understanding Urban Heat Island Effect: Causes, Impacts, Factors, and Strategies for Better Livability and Climate Change Mitigation and Adaptation	To examine the interrelationship of UHIE and climate change	Book- Livable Cities, Pages 283-366	UHIE extremity depends on various factors. Its impact on health can be due to three factors i.e. heat exposure, vulnerability to extreme heat, and behavioral exposure
Climate Central[6]	2024	Analysis: Global extreme heat in June 2024 strongly linked to climate change	To understand the role of climate change in global extreme heat and quantify the number of people exposed to these extreme temperatures	Report- Climate Central	Heatwaves are made stronger and more frequent every year due to human-caused climate change. Nearly 5 billion people were exposed to extreme heat reaching a CSI level of at least 3.
The Economic Times[3]	2024	India's heatwave longest ever, worse to come	To highlight the increasing intensity and duration of heatwaves in India	Newspaper article- The Economic Times	If preventive measures are not taken to reduce greenhouse emissions, heatwaves will be more frequent and intense in the future.

United States Environmental Protection Agency[11]		Heat Island Effect	To understand, strategize, and take measures for UHIE	Article- Environmental Protection Agency	Heat islands impact health due to the urban infrastructure, anthropogenic activity, and air pollution.
World Meteorological Organization [2]		Heatwaves	To understand the implications of heatwaves on morbidity and mortality	Article- WHO	Out of all natural disasters heatwaves rarely get noticed due to the lack of direct mortality rates. They harm urban dwellers due to the UHI effect and put a strain on the health systems.