PUBLIC HEALTH RESEARCH

Identifying Vulnerable Population in Urban Heat Island: A Literature Review

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ABSTRACT

Introduction	The term "urban heat island" refers to a phenomenon that occurs when temperatures in urban areas are higher than those in the areas that surround them (suburban area).
Methods	The urban heat island phenomenon can result in increase of energy consumption, increase of air pollution, decrease of water quality, and increase of greenhouse gas emissions, all of which have the potential to negatively impact people in a variety of ways.
Results	In this review we identified certain groups such as elderly, children, woman, pregnant woman, single person, and minority communities, who are living in dense area or in high rise building, low education level, low income, work in outdoor environment and had pre-existing illnesses may face health issues or insufficient resources to cope with the heat in urban area. There were more susceptible to heat-related illnesses and mortality, particularly during extreme heat events.
Conclusions	Recognising these vulnerable populations is crucial to develop effective strategies to mitigate the effects of urban heat islands and protect them. This can aid policy makers and urban planners to implement targeted interventions to address these issues.
Keywords	Urban heat island - UHI - Vulnerable population - Heat exposure.

Article history:
Received: 5 February 2023
Accepted: 3 July 2023
Published: 1 September 2023

INTRODUCTION

Increased urbanisation and industrialisation will devastate the urban environment, causing the cities to develop without a proper planned and regulated development policy. The expansion of cities has led to an increase demand for public services and infrastructure, which has made it to be challenging for governments to keep up with the growing needs.[1] Unplanned urbanisation may result in adverse effects, including overcrowding, the emergence of slums, higher living expenses, elevated crime rates, pollution, impersonal relationships, and stress.[2–5] Moreover, the rapid development of cities may have a negative impact on the environment, causing temperature fluctuations and imbalances, particularly in urban areas.[6] This will lead to an effects known as Urban Heat Island (UHI).[7] UHI is believed to be caused by an increase in temperature in urban areas compared to their surroundings. The buildings in the urban or city area are mostly built using the hard surface material such as concrete, which will trap the heat. Lack of green space will worsen the condition as the evaporation rate will decrease and indirectly increase the heat. This has a direct impact on the average air temperature throughout the urban area. This causes the area to become warmer than the surrounding countryside (Figure 1)

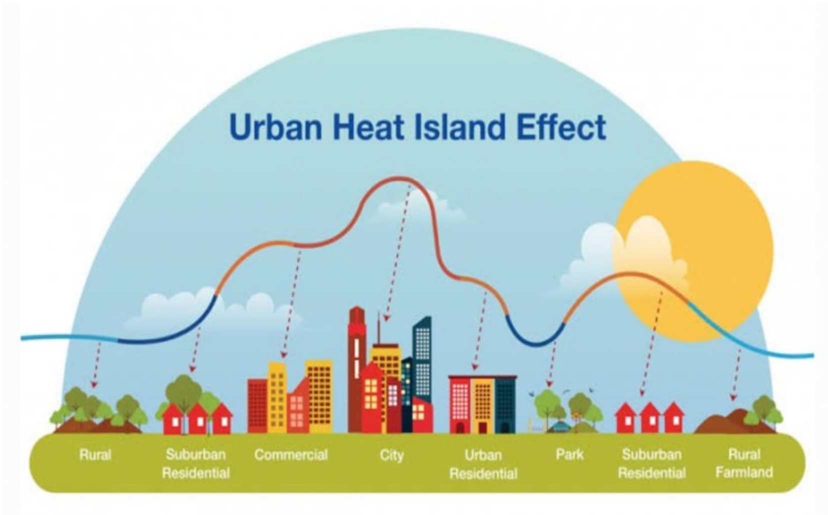

Figure 1 Urban heat island formation
Source:https://www.insightsonindia.com

Luke Howard discovered the UHI phenomenon in the 1980s, noticing temperature differences in London at night and during the day compared to the surrounding city area.[8] The UHI can be affected by various factors such as time, location, geography, meteorological parameters, and wind speeds.[9–11] The intensity of UHI is higher in densely populated areas, and it also varies hourly and seasonally.[12] Moreover, the geographical location of the area affects the intensity of UHI.[13] Urban areas located in higher latitudes will have colder temperatures, which could reduce the burden of global warming.[13] This variation is observed in urban areas located in lower or middle latitudes, where UHI effect is stronger and temperatures are slightly warmer, causing discomfort to the residents. This, in turn, leads to an increase in the usage of air conditioning units which further increases the surrounding temperature due to the increase in greenhouse gases.[14]

UHI phenomenon can have both environmental and health implication. Study conducted in Italy, had shown that UHI led to a significant increase in energy consumption.[15] Other research, such as study by Su et al,[16] had validated the relationship between UHI intensity and monthly cooling energy consumption, which can range from 0.17 kWh/m^2 to 1.84 kWh/m^2. Furthermore, studies conducted in Singapore during 2016 and 2017 had shown that UHI can lead to an increase in cooling energy consumption ranging from 4% to 12%.[17,18] However, while these studies provide evidence for the impact of UHI on energy consumption, it is important to note that UHI also has an impact on the economy. Increase energy consumption and demands for cooling will lead to increased cost for individuals and bussinesses. However, the economic impact of the UHI extends beyond just increased energy costs.[19] Studies have shown that it can also result in decreased productivity due to heat-related illnesses, decreased property values, and increased infrastructure costs for cooling systems.

UHI have additional environmental effects, including increased air pollution and greenhouse gas emissions. UHI worsens air quality due to higher fossil fuel consumption, resulting in the production of carbon dioxide (CO^2) and other pollutants like sulphur dioxide (SO^2) and nitrogen oxides (NO^x), which contribute to the greenhouse effect. Yuanyuan et al[20] conducted a study in China, investigating the relationship between UHI and air pollutants such as carbon monoxide (CO), nitrogen dioxide (NO^2), ozone (O^3), fine particulate matter (PM2.5), coarse particulate matter (PM10), and sulfur dioxide (SO^2) They found that factors like land surface temperature, vegetation coverage, and economic development influenced these situations.[20] Another study demonstrated that UHI increased air pollution emissions, which indirectly increased hospital admissions.[21] UHI can lead to deteriorated water quality. One of the causes are the accumulation of warm rainwater in sewers, which subsequently flow to rivers and surrounding water sources. Consequently, it can cause the river to become warmer, which may indirectly impact aquatic life.[22] Moreover, the rise in air pollution caused by UHI will result in an increase in acid rain.[23] The plants and soils will absorb acidic precipitation and its components. In addition, a part of the acidic water will flow to the surrounding water supply. Consequently, both animal and human health will be affected.[24]

Heat islands amplify heat waves' severity, especially in cities, which can have potentially fatal effects. Heat waves are extended episodes of extremely hot weather that can be dangerous, especially for the elderly and people with chronic conditions. During heat waves, temperatures in metropolitan regions with urbanisation, which are characterised by densely inhabited cities and widely impervious surfaces, are frequently to have higher degrees than in nearby rural areas. This dangerous conditions are exacerbated the additional heat, raising the risk of heat-related diseases and fatalities. On the other hand, non-urban locations with more natural elements, such as vegetation, typically have cooler temperatures, providing some relief during heat waves. The heat waves and UHI work together to cause health problems, such as general discomfort, respiratory disorders, heat cramps, heat exhaustion, and heat stroke.

During the occurrence of UHI, certain groups are at higher risk of experiencing adverse health effects due to exposure to high temperatures. These vulnerable groups include the elderly, young children, pregnant women, outdoor workers, people with chronic illnesses, and those living in poverty or without access to cooling infrastructure. These groups may have underlying health issues or may have insufficient resources to protect themselves from the heat, such as air conditioning, proper hydration, or shelter. As a result, they are more prone to experience heat-related illnesses and fatalities, particularly during extreme heat conditions like heat waves. Therefore, it is crucial to identify these vulnerable populations in order to develop suitable strategies to mitigate the effects of UHI and protect them from heat-related illnesses and mortality. This identification of vulnerable populations can aid policy makers and urban planners in implementing targeted interventions to address these issues.

METHODS

This narrative literature review utilised databases such as PubMed, Web of Science, and Google Scholar using the keywords such as “vulnerable group” OR “vulnerable population” OR “at-risk group” OR “ at-risk population” AND “urban heat island” OR “ UHI” OR “ heat island” were used. In addition to the above-mentioned databases, the search was conducted using the "snowballing" technique, which involved referrals from the initial search strategy. All study types, including observational studies, clinical trial, and review studies, were included in this review. Only studies in English language and published in year 2005 till 2022 were included in the articles. The documents that met the criteria were retrieved and imported into the Mendeley reference manager.

RESULTS

This study focused on vulnerable populations in UHI and 27 relevant articles were identified via the search strategy. The summary of findings was presented in Table 1. Of those articles, eight were from the United States, four from India, three from Hong Kong, two from France and Malaysia, and one each from Sweden, Italy, Europe, South Korea, China, and the Philippines (Table 1). The literature review was categorised into two themes: sociodemographic and socioeconomic factors. Within each of these themes, there were subthemes such as age, gender, citizenship, ethnicity, marital status, education, occupation, household income, living location, and health status. Out of the included studies, 26 discussed sociodemographic themes, with ten focusing on age, nine on gender, three on ethnicity, and four on marital status. Additionally, 20 studies discussed socioeconomic factors, with four focusing on education, three on occupation, four on income status, four on living conditions, four on health status, and one on social status (Table 2).

Table 1: Summary of the findings

Author/Year		Study Design	Findings
Hsu et al. 2021 [25]	United States of America	Cross sectional	○ In 86% of the cities in the United States, individuals who were over the age of 65 tended to have lower exposure to the UHI effect compared to those who are under the age of 65. ○ Individuals from racial and ethnic minority groups in every age group were exposed to noticeably higher levels of heat compared to their white counterparts.
Robine et al. 2008 [40]	Europe	Ecological	○ During the period of high mortality, there was a notable difference in the gender distribution of deaths. Specifically, on August 12th in France and August 13th in Italy, there was a significant increase in the proportion of female deaths, with a 21% increase in France and a 14% increase in Italy.
Fouillet et al. 2006 [42]	France	Ecological	○ As age increased, particularly among those 65 years old and above, there was a higher incidence of mortality. ○ The risk of mortality increased with age. ○ For those aged 45 and older, mortality was 15% higher in women compared to men of the same age ○ Widowed, single, and divorced individuals had a higher mortality rate than married individuals. ○ Cardiovascular diseases, respiratory diseases, nervous system diseases, and other ill-defined morbid disorders also contributed significantly to higher mortality
Kakkad et al. 2014 [26]	India	Retrospective Cross-sectional	○ When the temperature reached 42 degrees Celsius or higher, there was a 43% increase in the number of new-borns who required intensive care unit (ICU) admission due to heat-related issues.
Alonso et al. 2020 [50]	France	Ecological	○ People aged 75 years and over was the most vulnerable category to heat waves ○ Women aged 45–74 were slightly vulnerable (54%) than men (46%) in the same age group ○ Women aged 75 and over were just as sensitive (52%) as men (48%)
Rocklov et al. 2014 [47]	Sweden	Ecological	○ Heat waves had a stronger effect on mortality rates among younger individuals, as well as in regions with lower socio-economic status. ○ Individuals aged over 80 years old were also more susceptible. ○ Women below the age of 65 but with history of mental health hospitalisations, and individuals with prior cardiovascular disease were at a higher risk of mortality. ○ Rising summer temperatures were associated with mortality in those under 65

			years old with previous heart attacks and chronic obstructive pulmonary disease (COPD).
Ellena et al. 2020 [27]	Italy	Ecological	o The risk of mortality was greater in older individuals (2.13; 95% CI = 1.94, 2.33) during the heat events. o The risk of mortality was greater in women (1.88; 95% CI = 1.77, 2.00) and in older individuals (2.13; 95% CI = 1.94, 2.33). o The risk of mortality showed a significant association with education levels, men had a higher risk with higher education levels (1.66; 95% CI = 1.38, 1.99), and women had a higher risk with lower education levels (1.93; 95% CI = 1.79, 2.08). o There was a higher risk of all-cause mortality among widowed men (1.66; 95% CI = 1.38, 2.00) and separated or divorced women (2.11; 95% CI = 1.51, 2.94). Men who lived alone have a stronger association with mortality risk (1.61; 95% CI = 1.39, 1.86), while for women, the results were similar for both groups, who lived alone and not.
Vaidyanathan et al. 2017 [55]	United States of America	Ecological	o Individual aged ≥ 65 years had the highest rate of heat-related deaths (0.7 per 100,000 population). o 70% of heat-related deaths occurred in males excepts for infants aged <1 year. o Non-Hispanic American Indian/Alaska Natives had the highest rate of heat-related deaths (0.6 per 100,000 population). o Non-Hispanic blacks had the second-highest number of heat-related deaths (1,965) and rate (0.3 per 100,000 population).
Ngarambe et al. 2022 [45]	South Korea	Ecological	o The effect of rising temperatures on mortality was more pronounced among males and individuals who were ≥ 65 years old.
Huang et al. 2015 [46]	China	Ecological	o Individual factors that increased susceptibility to the effects of heat included elderly, female, died outside of a hospital setting, died of respiratory diseases, and had a lower level of education.
Chan et al. 2012 [28]	Hong Kong	Ecological	o Women were more vulnerable to heat-related mortality. o Married people were more vulnerable to heat-related mortality. o High temperatures had a greater effect on non-cancer related causes of death, such as cardiovascular and respiratory infections. o People lived in low socioeconomic districts, were more vulnerable to heat-related mortality. o High temperatures had a greater effect on non-cancer related causes of death, such as cardiovascular and respiratory infections.

Jesdale et al. 2013 [56]	United States of America	Ecological	o Non-Hispanic blacks were 52% more likelihood (95% CI: 37%, 69%) to live in areas with heat-risk related conditions than non-Hispanic whites. o Non-Hispanic Asians had a 32% higher likelihood (95% CI: 18%, 47%), while Hispanics had a 21% higher likelihood (95% CI: 8%, 35%) of living in such areas compared to non-Hispanic whites.
Wong et al. 2016 [60]	Hong Kong	Ecological	o The risk of being exposed to intense urban heat island effect was higher for individuals who were widowed, divorced, or separated. o Individuals who were 60 years or older, had lower levels of education, were widow, divorced, or separated and had low or middle incomes, were at a higher risk of being exposed to intense urban heat island effect. o People who have low or middle incomes, were at a higher risk of being exposed to intense UHI effect.
Benz et al. 2021 [63]	United States of America	Ecological	o 76% of counties in the United States had a higher burden of urban heating on individuals with lower income and education levels.
Voelkel et al. 2018 [64]	United States of America	Ecological	o There were strong links between exposure to heat and populations who had minimal education or had limited English proficiency. o There was a notable correlation between low-income populations and their susceptibility to the effects of heat exposure.
Sett et al. 2013 [54]	India	Cross sectional	o The intense summer heat in brickfields led to physiological strain among female workers making them more susceptible to UHI phenomenon.
Wong et al. 2017 [29]	Malaysia	Cross sectional	o Indoor workers affected by UHI experienced various heat-related illnesses, with respiratory problems was being the most common (90%), followed by heat exhaustion, heat cramps, and heat stroke.
Harshad et al. 2006 [30]	India	Cross sectional	o Among firefighters, 20% reported experiencing significant occurrences of heat exhaustion, while 5% reported heat syncope, pyrexia, and cramps.
Barnett et al. 2014 [75]	United States of America	Ecological	o High-risk areas for extreme heat were associated with a low number of high-income earners and a higher population density.
Zander et al. 2018 [81]	Philippines	Cross-sectional	o Population density was positively associated with the level of heat stress experienced by respondents. Those who felt little heat stress lived in areas with lower population density (less than 1467 people/km2), while those with higher levels of heat stress lived in areas with higher population density (up to 41,500 people/km2 in Manila City).

Elsayed et al. 2012 [82]	Malaysia	Case study	○ The study found that the UHI in Kuala Lumpur reached an intensity of 5.5 ºC on December 26, 2004. This was higher than the intensity of 4.0 ºC recorded in 1985, according to previous studies.
Mallick et al. 2012 [83]	India	Ecological	○ The highest surface temperatures were observed in the central and eastern parts of the India, specifically in the areas dominated by commercial activities with low vegetation cover and high population density. ○ These areas included Chandni Chowk, Mangolpuri, Uttam Nagar, Okhla Phase I, Shahdara, Lakshminagar, Mayapuri Industrial Area and Narela Industrial Area, where temperatures ranged from 34°C to 40°C.
Taylor et al. 2018 [91]	United States of America	Cross-sectional	○ Heat-related deaths were more common among non-US citizens compared to US citizens, accounting 2.23% and 0.02% of deaths, respectively. The risk was 3.4 times higher for non-US citizens, with the highest risk observed among Hispanic non-US citizens and those aged 18 to 24 years
Sun et al. 2016 [62]	Hong Kong	Cross-sectional	○ Elders with pre-existing health conditions were more vulnerable to mortality risk to hot and/or cold temperature.

Table 2: Themes and subthemes of the included studies.

Theme	Subtheme	Author/Year
Sociodemographic	Age	Hsu et al. 2021 [25] Robine et al. 2008 [40] Fouillet et al. 2006 [42] Kakkad et al. 2014 [26] Alonso et al. 2020 [50] Rocklov et al. 2014 [47] Ellena et al. 2020 [27] Vaidyanathan et al. 2017 [55] Wong et al. 2016 [60] Ngarambe et al. 2022 [45]
	Gender	Ngarambe et al. 2022 [45] Huang et al. 2015 [46] Rocklov et al. 2014 [47] Alonso et al. 2020 [50] Robine et al. 2008 [40] Chan et al. 2012 [28] Ellena et al. 2020 [27] Fouillet et al. 2006 [42] Vaidyanathan et al. 2017 [55]
	Citizenship	Taylor et al. 2018 [91]
	Ethnicity	Hsu et al. 2021 [25] Vaidyanathan et al. 2017 [55] Jesdale et al. 2013 [56]
	Marital status	Wong et al. 2016 [60] Ellena et al. 2020 [27] Chan et al. 2012 [28] Fouillet et al. 2006 [42]

Socioeconomic	Education	Wong et al. 2016 [60] Ellena et al. 2020 [27] Benz et al. 2021 [63] Voelkel et al. 2018 [64]
	Occupation	Sett et al. 2013 [54] Wong et al. 2017 [29] Harshad et al. 2006 [30]
	Income	Barnett et al. 2014 [75] Voelkel et al. 2018 [64] Chan et al. 2012 [28] Wong et al. 2016 [60]
	Living area	Zander et al. 2018 [81] Elsayed et al. 2012 [82] Mallick et al. 2012 [83] Barnett et al. 2014 [75]
	Health status	Chan et al. 2012 [28] Sun et al. 2016 [62] Fouillet et al. 2006 [42] Rocklov et al. 2014 [47]

Sociodemographic

Age

Studies from various countries, including Europe, South Korea, and Hong Kong, had indicated that individuals aged 65 years or above were at higher risk of experiencing heat-related mortality.[40,45,60] Similar findings were reported in studies conducted in France by Fouillet et al[42] and Alonso et al[50], where the risk of mortality increased with age, particularly for those aged 75 years or above. In Sweden, a study found that individuals over the age of 80 were particularly vulnerable to heat-related mortality.[47] Another study supported this finding, indicating that the risk of mortality was twice as high in older individuals compared to younger age groups.[27] According to a study conducted in the United States of America, the elderly (aged 65 years or above) and young children (below 5 years of age) were the most susceptible to the effects of UHI.[25,55] While in India, heat-related illnesses led to an increase in the number of new-borns requiring ICU.[26]

Gender

In various studies, female was more susceptible to heat related mortality and morbidity.[27,28,40,42,45,47,55] This postulated by study in Italy, where women had two times higher risk to get heat related mortality.[27]

Citizenship

According to a study conducted by Taylor et al[91], non-citizens had a significantly higher risk of heat-related mortality, approximately three times greater than that of citizens.

Ethnicity

The majority of studies had demonstrated that ethnic minority groups experienced higher rates of heat related mortality and morbidity compared to the dominant ethnic groups, such as the non-Hispanic population.[25,55,56]

Marital status

Prominent studies consistently indicated that individuals who were widowed, single, or divorced face a greater risk of heat-related mortality and morbidity due to increased exposure to UHI.[27,42,60] However a contrasting perspective was presented in a study conducted by Chan et al[28], which found that married individuals were more susceptible to heat-related deaths.

Socioeconomic

Education

Multiple studies had demonstrated that individuals with lower educational attainment were disproportionately exposed to UHI, leading to a higher incidence of heat-related morbidity and mortality.[27,60,63,64]

Occupation

According to studies conducted by Hershad et al[30] and Sett et al,[54] outdoor workers such as brick workers and firefighters were considered more susceptible to the effects of UHI. However, Wong et al's[29] study presented a contrasting viewpoint, suggesting that even indoor workers can be at higher risk for UHI exposure, resulting in various heat-related health issues.

Income

Multiple studies had suggested that individuals residing in low-income households were particularly susceptible to heat exposure and the intensity of UHI, thereby increasing their vulnerability to heat-related mortality.[28,60,64,75]

Living location

Multiple studies suggested that residing in densely populated areas increased the likelihood of experiencing UHI effects, which in turn rose the risk of heat-related illnesses and fatalities of UHI effect such as heat-related morbidity and mortality.[75,81,82,83]

Health status

The majority of studies indicated that individuals with pre-existing chronic conditions, such as cardiovascular and respiratory diseases, were at a higher risk of experiencing heat-related mortality due to their vulnerability to high temperatures and the effects of urban heat islands.[28,42,47, 62]

DISCUSSION

This review highlighted the vulnerability of certain groups in UHI. These groups include young children, elderly individuals, predominantly females, single or widowed individuals, minority ethnicities, non-citizens, those with lower education levels, and those live in low-income households. Additionally, individuals reside in high population density areas and those with pre-existing chronic diseases, such as cardiorespiratory conditions, are at higher risk of experiencing the impacts of UHI, which can lead to increased morbidity and mortality which are associated with heat.

Sociodemographic

Age

In this review, both older and younger age groups particularly children had been identified as vulnerable populations impacted by UHI. The vulnerability of the older population to heat was intensified by their reduced capacity to cope with high temperature.[31,32] These physiological changes occurring in the elderly may render them to be more susceptible to heat-related issues compared to other age groups. It is believed that older, frailer persons have a reduced heat tolerance, and contributing factor, such as immobility, exacerbates their susceptibility.[33] Factors such as hemodynamic instability (involving arterial blood pressure and organ perfusion) and a diminished ability to regulate body temperature contribute to the development of thermal vulnerability during the aging process.[34] Sustaining a proper equilibrium of body fluids plays a vital role in preserving hemodynamic stability and adequate intravascular volume when heat is dissipated. Heat exposure can lead to considerable dehydration due to heightened perspiration rates that can reach up to 0.3 L/h.[35,36]

Age-related factors during heat waves can impact the body fluid regulation of the elderly. One notable factor is that older individuals tend to have a reduced thirst response compared to younger generations.[37] This is because older individuals have a diminished response to changes in plasma osmolality and reduced baroreflex activity in their bodies.[38–40] Therefore, it can be inferred that the elderly are more susceptible to dehydration during a significant rise in temperature, which can contribute to higher rates of mortality and morbidity. In addition, it is important to note that many older adults may have existing health conditions or is taking medications that can exacerbate their sensitivity to heat.[41] Certain medications, such as diuretics or beta-blockers, can disrupt fluid balance or hinder the body's ability to cope with high temperatures. Furthermore, chronic health conditions like cardiovascular disease, diabetes, or respiratory disorders can further increase their susceptibility to the negative effects of elevated temperatures.[41]

Children are more vulnerable to the impacts of UHI due to several factors. Children have a bigger body surface area compared to adults which allow to absorb heat quicker and have harder time to regulate their body temperature. As a result, they are more prone to dehydration, heat stress and heat related illnesses.[26] Moreover, children’s physiological systems such as cardiovascular and respiratory systems are still developing. These makes more challenging for them to adapt to extreme heat conditions. Air pollution level is typically higher in urban areas which exacerbates the UHI effects. Children who live in urban areas is particularly vulnerable to the adverse effects of air pollution as their developing respiratory system are more sensitive to pollutants. In addition, rapid breathing rates, time spent outdoors, and their developing respiratory systems aggravate asthma and other lung diseases are caused by the air pollution, which usually increases during heat waves.[43] In a separate study, Salthammer et al. (2016) found that children experienced lethargic when exposed to higher temperatures in school environments.[44] This finding serves as evidence of their vulnerability to the heat as the temperature rises.

Gender

The vulnerability to UHI effects is significantly influenced by gender, as evidenced by the findings of this review, which indicates that females are more susceptible than males. The varying physiological responses to heat exposure between men and women can be attributed to differences in their regulatory mechanisms.[48,49] Women have higher body insulation during vasoconstriction however due to greater body fat, lower strength and muscle mass, and smaller circulating blood volume compared to men, they require greater physiological effort to maintain heat balance.[48] When expose to higher ambient temperature, women tend to experience more peripheral blood pooling, increased heart rates, lower perspiration rates, higher body heat storage, and difficulties in maintaining adequate blood volume circulation, which can contribute to a greater risk of dehydration.[48] Contrary to the majority finding in this review, recent studies conducted in Italy and Hong Kong found no substantial disparity in susceptibility to rising temperatures between women and men.[50 51] The variations in the findings across these studies may be attributed to the influence of climatic conditions at the respective study sites, which could have contributed to the discrepancies in the results.

Additionally, pregnant women are more susceptible to the adverse effects of heat exposure. The association between ambient heat exposure and pregnancy complications, such as pre-term birth and low birthweight, suggests that pregnant women are at higher risk in extreme heat condition. This heightened vulnerability may be attributed to specific thermoregulatory changes that occur during pregnancy in response to heat exposure.[52] This accordance to recent systematic review which postulated that pregnant women can posed multiple adverse health outcomes when they exposed to extreme heat; such as hypercoagubility, trigger of uterine contraction and increase of oxytocin level which then lead to the pre-term delivery, reduction of blood flow to uterine which will disturbed the growth of the foetus, and might lead to maternal fever.[53]

Citizenship status

Citizenship can influence and individual's vulnerability to heat exposure and indirectly impact their susceptibility to the effects of UHI. In this review, we found a study stated that non-citizens were more vulnerable to the effects of rising temperatures. Migrants, as defined by the International Organization for Migration (IOM), are people who move from their usual place of residence, whether within a country or across borders, either temporarily or permanently, for various reasons. This includes different legal categories such as migrant workers, individuals with specific legal definitions like smuggled migrants, and those who do not have a specific international legal status, such as international students.[88] Migrants face multiple challenges due to the nature of their work and the circumstances they encounter in their host countries. These challenges include a lack of information, documentation, family support, and language barriers, which make them more vulnerable to exploitation. They also struggle to access education, employment, housing, and healthcare services. Economic disparities between their home and host countries can hinder the transferability of their skills and experiences. Overall, migrants are considered a vulnerable population due to these factors.[89]

Numerous studies have consistently shown that migrants tend to earn lower wages compared to citizens in their host countries. For example, a study on the "Migrant Pay Gap" revealed that low-skilled migrant workers earned 71 percent less than nationals.[90] This financial disparity can contribute to their vulnerability to extreme heat and microclimates, such as UHI. Limited financial resources also act as a barrier to accessing healthcare, further increasing their vulnerability. In addition, language barriers pose a significant challenge for migrants in obtaining information about rising temperatures in their localities and accessing necessary help and healthcare services. Extreme heat stress, which led to an increase in cardiovascular disease mortality among migrants, demonstrated the vulnerability of this group.[92] All of these factors will increase their susceptibility to extreme heat, especially urban heat.

Ethnicity

Some races or ethnicities may appear to be more vulnerable than others. However, only a few researches had been conducted to investigate the relationship between heat vulnerability and ethnicity. In this review, we found that most studies indicated that minority ethnic groups were more vulnerable to heat exposure. Various ethnic groups may exhibit differences in genetic traits and physiological responses to environmental conditions, including extreme temperatures.[58] These genetic variations can influence how individuals from different ethnic backgrounds adapt and acclimatise to heat stress.[58] Factors that contribute to these differences include skin pigmentation, sweat gland density and thermoregulation mechanism. For example, individuals with darker skin tones may have challenges in dissipating heat efficiently. Consequently, certain minority ethnicities may have a higher susceptibility to the adverse effects of intense temperatures. Furthermore, socioeconomic factors and disparities in access to healthcare service can contribute to the vulnerability of minority ethnicities to extreme temperatures.[59] Limited access to air conditioning, inadequate housing conditions, and occupational factors can exacerbate the risks associated with intense heat exposure.[59] Recognising and addressing these disparities are important for protecting minority ethnic groups from the health risks associated with extreme temperatures.

Marital Status

Marital status also contributes to an individual's susceptibility to heat exposure. The findings in the review demonstrated that individuals who were single, widowed or separated were more likely to expose to UHI effects. On the contrary, study by Chan et al[28] demonstrated that married people were more vulnerable. Marital status is always been used as proxy for family structure and social isolation. A recent study demonstrated the positive effects of marriage on the spouses' health.[61] Marriage promotes a healthier lifestyle, lowers risk-taking behaviour, boosts optimism, and improves wellbeing.[62] Those who are single are more vulnerable since marriage has a protective effect that lowers the risk of death, reduces health issues, and improves mental health.

Socioeconomic

Education

Education is widely acknowledged as an important component in acquiring knowledge and skills. It is essential for personal growth, social improvement, and economic growth. Individuals can gain knowledge, broaden their view, and improve critical thinking and problem-solving skills through education. It lays the groundwork for lifelong learning and equips people to make informed decisions and engage meaningfully in society. Therefore, education is regarded as a crucial tool of acquiring information and supporting personal and communal advancement. Our review revealed that individuals with low education were more prone to the effects of UHI, which puts them at higher risk when rising of environmental temperature. As a result, they experienced increased morbidity and mortality related to heat exposure. Research suggested that individuals with higher level of education tend to adopt more effective adaptation mechanisms during periods of heat stress, making them less susceptible to extreme heat events.[65] Conversely, populations with lower levels of education are believed to be more vulnerable to the effects of UHI due to limited knowledge and resources for effective adaptation.

Occupation

When the UHI effects are experienced by the general urban population, it is crucial to specifically consider its impact on workers. The UHI phenomenon, which is primarily caused by increased anthropogenic heat, directly affects the thermal comfort of workers and leads to high energy usage in their work environments.[66] Various health effects had been associated with the increase of heat exposure. Workers exposed to UHI may suffered from discomfort, heat stress, heat cramps, respiratory problems, cardiovascular disease and other condition.[67,68] Finding in this review demonstrated that outdoor worker were more susceptible to the impact of UHI compared to their counterparts who spent most of their time indoors. As we know, the UHI effect, caused by human activities, leads to elevated temperatures in urban areas, posing specific challenges for those who work outdoors. These individuals endure extended periods of intense of heat and direct sunlight, which can adversely affect their overall well-being. The limited availability of shade and cooling options and increased energy expenditure required for physical tasks in hot environments, contribute to their vulnerability. In addition, less water consumption during work hours will further exacerbate dehydration and worsen the condition.[69,70] Exposure to ozone air pollution, which is a consequence of the UHI effect, further contributes to their health deterioration.[71] Moreover, prolonged exposure to high temperatures puts the outdoor workers at an increased risk of heat-related illnesses. This finding emphasises the importance of implementing appropriate measures to protect the health and safety of the outdoor workers.

Household Income

Residents living in low-income areas were impacted by UHI, facing heightened vulnerability to heat-related illnesses and even death as a result of increased temperatures. For instance, these places frequently lack of tree cover and green spaces, which can provide shade and aid in mitigating the UHI effect.[43,72–74] The ambient temperatures in these places can be substantially higher without these natural cooling components. Living quarters in low-income areas are often small and cramped, making it difficult for them to find respite from the heat within their homes. This lead to prolonged exposure to high temperature and increased the risk of heat-related morbidity. Furthermore, individuals with low income may lack of financial resources to adequately cope with extreme heat.[43,72–74] They maybe unable to afford air conditioning systems which could provide the relief during the hot weather.[77,78] In addition, the house condition may have limited ventilation which further exacerbate the indoor heat levels. Low income individuals may face financial constraints that prevent them from seeking alternative shelter, such as staying in hotels during extreme heat events.[77] Therefore, they are less likely to engage in positive adaptive activities that can help protect them from the heat.[77] These will further increase their vulnerability to the negative impacts of the heat events.

Living Area

Living in high-density areas exacerbates the vulnerability of individuals to the impact of UHI. In densely populated areas, there is higher concentration of buildings, roads, and other infrastructure that absorb and retain heat, leading to elevated temperatures. Lack of green places, such as parks and trees reduce natural shade and cooling place. These factors contribute to a thermal imbalance, with densely populated areas experience much higher temperatures than less densely populated areas.[83] Furthermore, the high concentration of human activity in these areas, such as transportation and industrial processes, generates additional heat, exacerbating the UHI effect. In addition, individuals in these areas are more prone to heat-related illnesses, heat exhaustion, and heatstroke.[84] The simultaneous effect of greater temperatures, limited access to cooling measure, and reduced green space cause residents in densely populated places more vulnerable to the negative impacts of UHI.[80]

Health status

The susceptibility of individuals to the effects of urban heat islands and elevated temperature is influenced by their health status. In this review we found that, those with chronic illnesses, disabilities, limited mobility, and taking specific medication, were particularly vulnerable to negative health effects in extreme temperatures. For example, individuals with heart failure may face difficulties in coping with the additional cardiovascular demands caused by heat exposure. This can result in increase of cardiac strain, arrythmias, peripheral edema, and indirectly increase the risk of heat-related mortality in these patients.[76] Additionally, higher temperatures were associated with increased levels of B-type natriuretic peptide and C-reactive protein, which are markers to detect severity and prognosis of heart failure.[76] The underlying mechanism of this disease indicates that individuals with pre-existing conditions, like cardiovascular diseases are more prone to the effects of rising temperature.

CONCLUSION

In conclusion, identifying vulnerable populations in regard to UHI is crucial for effective heat mitigation and adaptation strategies. Through various studies and research, it is evident that certain groups are more susceptible to the adverse effects of UHI. The elderly, children, women and pregnant women, those who live alone (single/separated/widow), non-citizen and minority ethnic are identified as vulnerable populations. Aside from that, people who live in densely populated areas, have low income or wages, work in outdoor environments, and have pre-existing illnesses are more vulnerable when temperature increases. Recognising and understanding these vulnerable populations is essential for implementing targeted interventions and policies that aim to reduce the impact of UHI on public health and well-being. By addressing the specific needs of these people, we can move towards more equitable and resilient urban environments that protects the most vulnerable individuals from the heat-related dangers that is posed by UHI.

ACKNOWLEDGEMENT

We would like to thank the Department of Community Health, Faculty of Medicine, Universiti Kebangsaan Malaysia, for the permission to conduct this study and technical support (JEP-2022-492).

Funding: No funding

Conflict of Interest: The authors declare no conflict of interest.

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