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Health impact of urban green spaces: a systematic review of heat-related morbidity and mortality

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ABSTRACT

Objectives The objective of this review was to scrutinise the impact of urban green spaces on heat-related morbidity and mortality.

Design This systematic review was meticulously carried out following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines

Data sources A comprehensive search was conducted across PubMed, Scopus and Google Scholar including studies from January 2000 to December 2022.

Eligibility criteria Studies that examined the influence of urban green spaces on heat-related morbidity and mortality, including randomised controlled trials, observational and modelling studies, were included.

Data extraction and synthesis A total of 3301 publications were initially identified, out of which 12 studies met the inclusion criteria and were selected for analysis. The selected studies were predominantly from high-income and upper-middle-income nations (95%).

Results The research points towards a pattern where regions abundant in green spaces report lower rates of heat-related morbidity and mortality in contrast to those with sparse greenery. Additionally, urban vegetation appears to exert a positive influence on mental health and well-being, potentially aiding in offsetting the adverse health repercussions of high temperatures.

Conclusion Urban green spaces play a vital role in mitigating heat-related health risks, offering a potential strategy for urban planning to address climate change and enhance public health. Additional research is required to thoroughly comprehend the magnitude of urban greenery's impact on heat-related morbidity and mortality, as well as its interplay with other variables, including air pollution, socioeconomic status, among others.

STRENGTHS AND LIMITATIONS OF THIS STUDY

⇒ The study conducted a rigorous and comprehensive literature review, drawing from multiple well-established databases, ensuring a comprehensive and representative overview of the existing research.

⇒ The study employed well-defined inclusion and exclusion criteria to select relevant research, enhancing the precision and quality of the included studies.

⇒ Prior to selection, each paper underwent a systematic quality assessment using the CHecklist for critical Appraisal and data extraction for systematic Reviews of prediction Modelling Studies checklist, ensuring a rigorous approach to data inclusion.

⇒ While the study evaluates associations between green spaces and health outcomes, it does not establish causal relationships. Causality between these variables may require further research using experimental methods.

⇒ The study may be susceptible to publication bias, as it relies on published research. Unpublished studies or those with negative results may not be represented in the review, potentially affecting the comprehensiveness of the findings.

INTRODUCTION

As consequences of urbanisation and climate change, environmental alterations such as the urban heat island effect and other extreme weather phenomena are increasingly evident. Compounding these issues are escalating temperatures, primarily fuelled by rapid urbanisation.[1] Counteracting these global challenges—encompassing climate change, health inequity and sustainable urbanisation—green areas or urban vegetation are deemed critical. In this vein, the United Nations Sustainable Development Goal 11 target 7 stipulates the provision of universal access to secure, inclusive, and accessible green and public spaces, especially for vulnerable populations, by 2030.[2]

The health implications of high temperatures are profound, posing substantial risks to individuals across all age groups. If untreated, persistent exposure to elevated temperatures can escalate into heat exhaustion and potentially prove lethal. A multitude of studies have endeavoured to comprehend the toll exerted by high temperatures on human health.[3] Vulnerable demographics, including children, the elderly and individuals with pre-existing medical conditions, are especially at risk from the adverse effects of high temperatures. Children's developing bodies, older adults' decreased physiological resilience and compromised health status of those with chronic conditions make these groups particularly susceptible to heat stress and heat-related illnesses. The exacerbated

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vulnerability of these populations highlights the critical need for targeted urban planning and public health strategies. Urban green spaces, by mitigating urban heat, offer a protective buffer that can reduce the incidence of heat-related morbidity and mortality among these sensitive groups, underscoring the importance of accessible and well-maintained green infrastructure as part of comprehensive climate adaptation and health equity efforts.[4]

Urban green areas have emerged as a potential counter to heat, demonstrated by research evidencing their critical role in thermal mitigation.[1 5] For instance, a study in China underscored the efficient cooling effect of green spaces.[1] Vegetation, through its added shading effect, significantly cools night-time temperatures in urban regions while trees contribute to daytime temperature regulation.[6] Green spaces have also been linked to mental well-being, with their health advantages attributed to community cohesion, physical activity enhancement and mental well-being improvement.[6] Furthermore, they offer environmental benefits such as reductions in environmental exposures (air and noise pollution), cooling effects and flood risk reduction. Such evidence is invaluable in informing public health policy and providing recommendations for safeguarding public health during periods of extreme heat.[7]

Despite ample research elucidating the overall health impacts of green spaces, their effect on heat-related health risks remains inadequately understood. This review, therefore, seeks to investigate the impact of vegetation or green areas within urban settings on heat-related mortality and morbidity.

Review question

What is the effect (positive, negative or none) of green zones on health-related mortality and morbidity in urban areas across the globe?

METHODS

This systematic review has been duly registered at Figshare (https://doi.org/10.6084/m9.figshare.23744553.v1) and access to protocol can be requested from the corresponding author. This review aims to explore the worldwide influence of urban green spaces on heat-related morbidity and mortality. This systematic review was meticulously carried out following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines.[8]

In this study, 'morbidity' refers to the incidence or levels of health conditions and illnesses related to or exacerbated by exposure to heat stress within urban environments, particularly focusing on how urban green spaces can mitigate these health impacts.

Study selection criteria

All studies that examined the influence of urban green spaces on heat-related morbidity and mortality including randomised controlled trials, observational and modelling studies were included to encapsulate the entirety of the available evidence. We included peer-reviewed journal articles in English, published from January 2000 to December 2022. We have specifically chosen articles focused on urban settings, as the impact of green spaces can vary across urban, rural and other contexts. We have excluded commentaries, conference abstracts, book reviews, conference and editorial articles, and those articles that do not delve into heat-related health outcomes.

Search strategy

To identify the relevant literature, three databases including PubMed, Scopus and Google Scholar were searched from 2000 to 2022 using the search terms and strings provided in online supplemental table S1.

Screening and data extraction

Microsoft Excel and Rayyan Software for Systematic Reviews were used to perform screening and extraction of data. All results from each database were exported to Rayyan and screening for duplicated articles was performed. After the duplicates were removed, two researchers (AN and KA) independently screened all titles and abstracts as per the eligibility criteria. Any conflicts were resolved on the basis of detailed discussion and mutual consensus. Articles that fulfilled the eligibility criteria were undertaken for full-text screening, independently by the two researchers (AN and KA), for final inclusion in the review.

Once the list of eligible articles was finalised, data extraction for descriptive parameters was independently performed by the two researchers (AN and KA) who undertook screening procedures. A standardised charting form was developed for data extraction and categorisation. The form included sections on author details, publication details, and year of study, study design, participants/population, health outcomes, results, and interpretations. Both extraction files were compared, and any conflicts were resolved through mutual discussion.

Risk of bias assessment

The rigorous evaluation of the quality of selected studies is an integral part of this systematic review, ensuring the robustness and reliability of the findings. This was performed by using the Checklist for Critical Appraisal and Data Extraction for Systematic Reviews of Prediction Modelling Studies (CHARMS) Checklist.[9] The following items of CHARMS checklist were handled: study participants and characteristics, outcome to be predicted, sample size, missing data, model development and evaluation and result interpretation. Each study was scored for the risk of bias as low if bias is unlikely, moderate if there are no essential shortcomings, but not all criteria were satisfied, and high if bias was likely due to errors in one or more domains. Applicability refers to the extent to which the study matches the review question. Each study was independently assessed by two researchers (AN and

KA), and any discrepancies in their evaluations were resolved through discussion until a consensus was reached. Studies were not excluded based on their quality score; instead, the quality assessment was used to critically interpret and discuss the findings of the review.

Data synthesis and analysis

Measures of heat-related diseases, hospital admissions, death rates and other health effects were retrieved from outcome data relating to morbidity and mortality brought on by the summer heat. Data were taken from all relevant research, including observational, modelling and randomised controlled trials. We retrieved and synthesised any pertinent data from several heat-related outcome metrics. A quantitative meta-analysis was not possible due to the heterogeneity, complexity and variation in the studies' variables and results. The results from the included studies were instead critically analysed and synthesised using a narrative synthesis. This narrative synthesis used a thematic method to group data into categories based on important topics including the kind of urban green spaces, geography, population demographics and particular heat-related health outcomes.

The narrative synthesis offered an interpretive analysis of the data, showcasing patterns and discrepancies and bringing together the results from diverse research types. This method made it possible to thoroughly examine many context-specific ways that urban green spaces may affect heat-related illness and death.

Patient and public involvement

No patient is involved.

RESULTS

Study characteristics

A total of 3301 publications were identified from selected databases (figure 1). Title and abstract screening resulted in the inclusion of 28 potentially relevant articles. After full-text screening, 12 articles met the inclusion criteria. Table 1 summarises the characteristics of all 12 studies conducted between 2014 and 2022.[10–21] These studies focused on the impact of green spaces on heat-related mortality and health outcomes across various countries including Hong Kong,[10] Australia,[11 15 16 21] Vietnam,[12] the USA,[13 19 20] South Korea,[14] Portugal[17] and Japan.[18] The research methodologies range from epidemiological studies,[10 12 14 16 17] modelling and simulation,[11 13] experimental research,[18] to quantitative analyses.[19–21] Most studies have used meteorological data, census and mortality data.

Risk of bias assessment

Table 2 provides a critical appraisal of studies related to the impact of green spaces on heat-related mortality and morbidity. The majority of the studies (9 out of 13) were evaluated with a low risk of bias, suggesting a reliable and robust methodology. Four studies were found to have a medium risk of bias. All studies demonstrated applicability to our review question, reflecting relevance to the

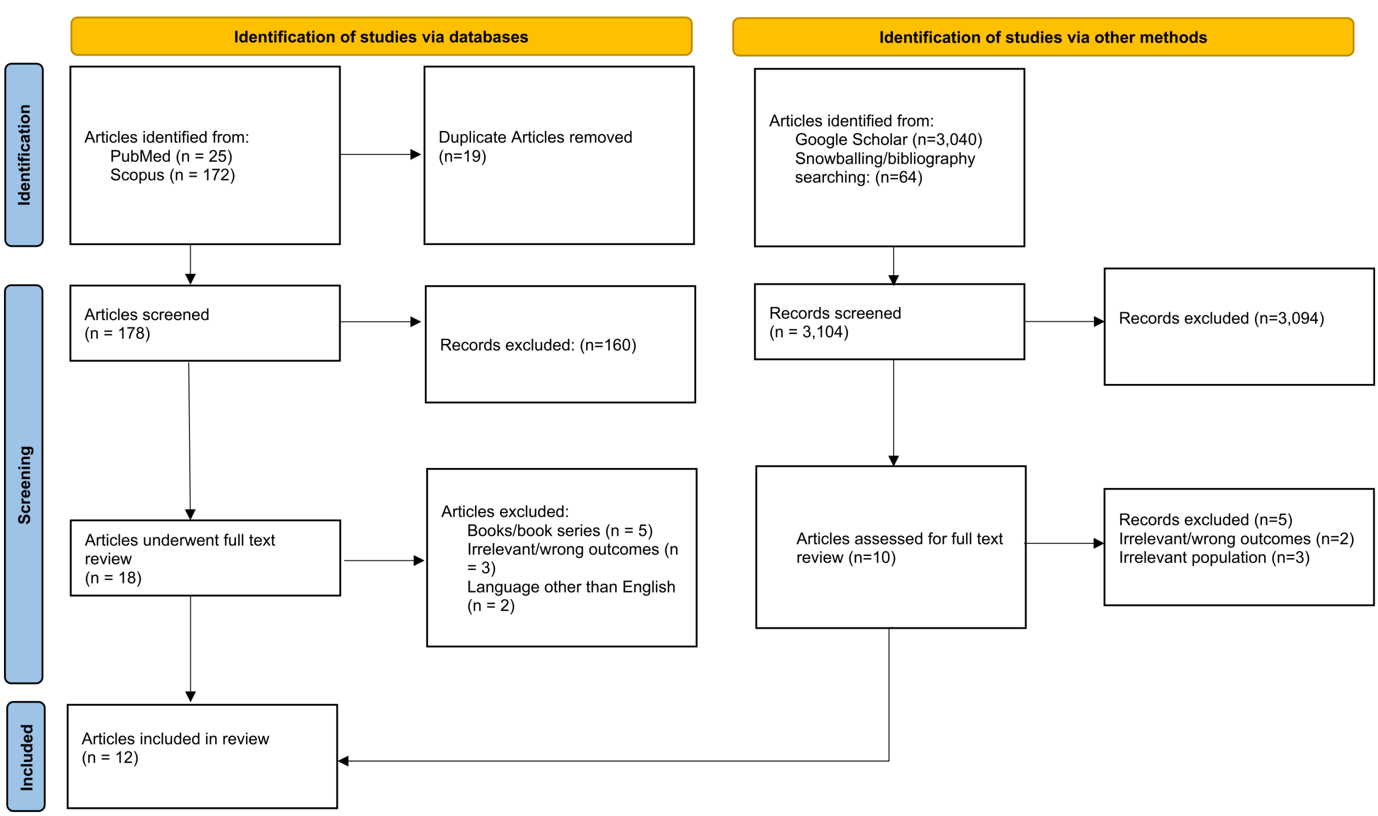

Figure 1 Flow chart.

Table 1 Description of studies

Author (year)	Location	Characteristics	Study duration	Exposure variable	Outcome variable
Song *et al*[10] (2022)	Hong Kong, China	Daily mortality and meteorological data were analysed, using the Normalised Difference Vegetation Index (NDVI) and distance to coast as proxies for green and blue space exposure, respectively.	2008–2017	Green space (measured by NDVI) and blue space (proximity to coast)	Heat-related mortality
Chen *et al*[11] (2014)	Melbourne, Australia	Mortality data were analysed. The study considered population by sex and by two age groups (0–75 and 75+).	1988–2007	Urban vegetation schemes	Heat-related mortality rate
Nguyen *et al*[12] (2022)	Hanoi, Vietnam	Used hospital admission records from three national hospitals in Hanoi. Daily meteorological data and satellite images for green space measurement were used.	2010–2014	Green space	Heat-related respiratory hospitalisation among children under 5 years of age.
Kalkstein *et al*[13] (2022)	Los Angeles, California, USA	Used historical weather data and mortality data. Mortality data were assessed to estimate excess deaths during extreme heat events.	1985–2010	Tree canopy and albedo modifications	Heat-related mortality reduction
Son *et al*[14] (2016)	Seoul, Korea	Mortality data and NDVI data from MODIS satellite images were used to assess urban vegetation.	2000–2009	Urban vegetation measured by NDVI	Heat-related mortality.
Chaston *et al*[15] (2022)	Sydney, Australia	Mortality records, census population data, weather observations and climate change projections.	1997–2018 and projected data up to 2100.	Urban Heat Island effect and tree cover	Heatwave-attributable excess deaths
Wang *et al*[16] (2015)	Brisbane, Melbourne and Sydney, Australia	Daily climate variables and mortality data were assessed. It focused on non-accidental and circulatory mortality.	1988–2011	Heatwaves are defined consistently across the cities.	Non-accidental (heart attacks and strokes) and circulatory mortality.
Burkart *et al*[17] (2015)	Lisbon, Portugal	Mortality data, remotely sensed data for urban vegetation and proximity to water bodies were assessed.	1998–2008	Urban green (vegetation) and urban blue (proximity to water bodies)	Heat-related all-cause natural excess mortality.
Kusaka *et al*[18] (2022)	Tsukuba, Ibaraki, Japan	Thermal comfort of healthy individuals was assessed under wisteria trellises and tents, compared with direct sunlight.	Specific dates in August and September 2017	Shade provided by wisteria trellises and tents	Subjective thermal comfort and physiological responses.
Sinha *et al*[19] (2021)	Baltimore, Maryland, USA	Mortality data, census population data, weather observations and climate change projections were assessed.	2007–2017	Urban green space coverage	Reductions in mortality attributable to extreme heat events
McDonald *et al*[20] (2019)	USA (97 cities)	Analysed tree cover and developed land-cover information across 97 US cities.	2011 National Land Cover Database	Urban green space coverage	Heat-related mortality, morbidity
Sadeghi *et al*[21] (2021)	Sydney, Australia	Used weather stations across, calculating average hourly Universal Thermal Climate Index (UTCI).	2017	Urban greening infrastructure	Reduction in daily average UTCI and heat-attributable deaths.

MODIS, Moderate Resolution Imaging Spectroradiometer.

Table 2 Critical appraisal of included studies

Title	Risk of bias	Applicability
Effect modifications of green space and blue space on heat–mortality association in Hong Kong, 2008–2017[10]	Low	Yes
Urban vegetation for reducing heat related mortality[11]	Low	Yes
The protective effect of green space on heat related respiratory hospitalization among children under 5 years of age in Hanoi, Vietnam[12]	Low	Yes
Increasing trees and high-albedo surfaces decreases heat impacts and mortality in Los Angeles, CA[13]	Medium	Yes
Urban vegetation and heat-related mortality in Seoul, Korea[14]	Low	Yes
Mortality Burden of Heatwaves in Sydney, Australia Is Exacerbated by the Urban Heat Island and Climate Change: Can Tree Cover Help Mitigate the Health Impacts?[15]	Medium	Yes
The Impacts of Heatwaves on Mortality Differ with Different Study Periods: A MultiCity Time Series Investigation[16]	Low	Yes
Modification of Heat-Related Mortality in an Elderly Urban Population by Vegetation (Urban Green) and Proximity to Water (Urban Blue): Evidence from Lisbon, Portugal[17]	Low	Yes
Wisteria trellises and tents as tools for improved thermal comfort and heat stress mitigation: Meteorological, physiological and psychological analyses considering the relaxation effect of greenery[18]	Medium	Yes
Modeling lives saved from extreme heat by urban tree cover[19]	Low	Yes
The Value of US Urban Tree Cover for Reducing Heat-Related Health Impacts and Electricity Consumption[20]	Low	Yes
The health benefits of greening strategies to cool urban environments—A heat health impact method[21]	Low	Yes

investigation of urban green spaces and their influence on heat-related mortality and morbidity.

Main findings

Effect on the vulnerable

As documented in table 3, green spaces have the potential to improve health of urban residents, particularly of specific vulnerable groups such as the elderly and children. In the study conducted in Hanoi the capital city of Vietnam, researchers examined the protective effect of green space in urban areas heat-treated respiratory hospitalisation of children under 5.[10] They used a two-stage model, including a distributed non-linear model coupled with multivariate meta-analysis. Hospitalisation in the central districts which are hotter and crowded increased significantly at temperatures >34°C. Heat significantly increased the risk of hospitalisation among children under 5.[12] In another study conducted in Lisbon, authors emphasised on the relevance of urban green on heat mitigation. Heat and mortality had a significant association in the elderly. Researchers used remote senses data and geographic information to determine the urban spaces. They conclude that urban green has a mitigation effect on heat-related mortality in elderly population.[17]

Positive effect on heat-related mortality /morbidity

Interestingly, three studies included in this review were conducted in Australia. Chen *et al* used two scale modelling approach to quantify the effect of the urban vegetation schemes on current 2009 and future climates in 2030–2050. Results showed that the average summer temperatures can be reduced in the range of around 0.5 and 2 C. If Melbourne Central Business District (CBD) were replaced by vegetated suburbs and planted parklands, it would result in significant changes to the city's urban landscape, environment, and potentially its socioeconomic structure.[11] Another study found the benefit of urban vegetation in reducing heat-related mortality. Mortality records (2006–2018) were linked with weather observations (1997–2016), census population data and climate change projections to 2100. Heat wave attributable deaths were calculated based on risk estimates from published study of Australia. High-resolution satellite observations of green cover and air temperature excesses were used to determine the associated effects on heat-related mortality.[15] Moreover, the heatwave–mortality relationship was assessed using different study periods in the three largest cities in Australia (Brisbane, Sydney and Melbourne). The study has implications for developing approaches to evaluate heatwave–mortality relationship and setting up heat health warning systems.[16] In Seoul, Korea, a study showed high mortality effect of high temperatures with low vegetation. Poisson generalised liner model was used to assess the effect modification of mortality temperature association by urban vegetation.[14] Another study claims that roughly one in four lives currently lost during heat waves could be saved. They propose a climate change-induced warming could be delayed approximately 40–70 years under

Table 3 Comparison of results and interpretation

Author (year)	Results and interpretation
Song *et al*[10] (2022)	No significant effect modifications of green and blue spaces on heat-related mortality risk.
Chen *et al*[11] (2014)	Simulation revealed the average seasonal summer temperatures can be reduced in the range of around 0.5 and 2 C if the region is replaced by vegetated suburbs and planted parklands, respectively.
Nguyen *et al*[12] (2022)	This study confirmed the protective effect of green space on heat risk on respiratory hospitalisation among children under 5
Kalkstein *et al*[13] (2022)	Roughly one in four lives currently lost during heat waves could be saved. Climate change-induced warming could be delayed approximately 40–70 years.
Son *et al*[14] (2016)	Findings suggest a higher mortality effect of high temperature in areas with lower vegetation in Seoul, Korea
Chaston *et al*[15] (2022)	Study found that tree canopy reduces urban heat, and that widespread tree planting could offset the increases in heat-attributable deaths as climate warming progresses.
Wang *et al*[16] (2015)	Non-accidental and circulatory mortality significantly increased during heatwaves across the three cities even with different heatwave definitions and study periods. Using the summer data resulted in the largest increase in effect estimates compared with those using the warm season or the whole year data.
Burkart *et al*[17] (2015)	Urban green and blue appeared to have a mitigating effect on heat-related mortality in the elderly population in Lisbon. Increasing the amount of vegetation may be a good strategy to counteract the adverse effects of heat in urban areas.
Kusaka *et al*[18] (2022)	The thermal environment under a wisteria trellis showed significantly lower heat stress compared with a tent or direct sunlight. This reduction is largely due to lower black-globe temperatures. Subjects under the trellis also perceived the environment as cooler and more comfortable, with significant reduction in pulse rate.
Sinha *et al*[19] (2021)	Existing tree cover reduced annual mortality by 543 deaths compared with a 0% tree cover scenario. Increasing tree cover by 10% reduced baseline annual mortality by 83–247 deaths. The benefits were greater for individuals over 65 years and for regions with greater tree cover.
McDonald *et al*[20] (2019)	The research found urban tree cover helps avoid 245–346 deaths annually and provides heat-reduction services estimated to be worth US\$5.3–US\$12.1 billion annually for the entire US urban population.
Sadeghi *et al*[21] (2021)	Greening interventions reduced the daily average UTCI by −0.2°C to −1.7°C, decreasing heat-attributable deaths by up to 11.7 per day. This emphasises the health benefits of urban greening in mitigating heatwave effects.

UTCI, Universal Thermal Climate Index.

business-as-usual and moderate mitigation scenarios, respectively.[13]

The research conducted in Japan found that wisteria trellises provided a more effective means of improving thermal comfort and mitigating heat stress compared with tents.[18] These findings are further reinforced by Sinha *et al*,[19] revealing that existing tree cover significantly contributes to reducing mortality from extreme heat, particularly among the most vulnerable elderly population. Another Australian study revealed that urban greening infrastructure reduced heat-related deaths, highlighting the significant health benefits of implementing greening infrastructure.[21]

Interestingly, our review found that increasing urban spaces is not only an effective way to reduce urban ambient temperatures, but it may also be associated with economic value.[20]

No significant effect on heat-related mortality/morbidity

The study conducted in Hong Kong did not show any significant effect of green spaces on heat-related mortality for the whole population or any specific gender and age. The findings challenge existing evidence on the role of vegetation in mitigating heat-related mortality risk.[10]

DISCUSSION

There was heterogeneity in studies, this could be due to a variety of reasons such as differences in study design, population characteristics and exposure assessment methods. Some studies focused on a specific subgroup of population, such as children under 5 years and elderly. The study conducted in Hong Kong did not show any significant effect of green and blue spaces on heat-related mortality risk, unlike other studies included in this review. These findings challenge existing evidence on the role of urban green spaces in mitigating heat-related mortality risk. This could perhaps be due to the difference in study design and population.

Interestingly, research conducted in various settings further shed light on the importance of green spaces. For instance, in Japan, experimental study on the usefulness of wisteria trellises found that they offered a more effective means of reducing thermal discomfort and preventing heat stress compared with tents, even demonstrating psychological relaxation effects.[18] In the USA, urban tree canopy has been significantly associated with decreased heat-related mortality, accentuating the significance of maintaining and expanding urban green spaces.[19 20] A study in Australia has also emphasised the health benefits of greening infrastructure, possibly reducing heat-attributable mortality by up to 11.7 per day in the Sydney region.[21] These results accentuate the palpable impact of urban green spaces on temperature control and health outcomes, underpinning the need for targeted efforts in urban planning and infrastructure development.

Almost all studies that are published on assessing the effect of green vegetation on heat-related mortality and morbidity are from high-income countries. However, people living in low-middle-income countries face higher heat-related health issues due to poverty, lack of access to air conditioning and inadequate infrastructure for dealing with extreme heat events.[22] Moreover, people living in low-resource settings are particularly susceptible, as outdoor manual labour is more common and adaptation to climate change is costly. Moreover, they are at a higher risk from heat waves due to shortages of electricity during summer months, this further disadvantage those who cannot afford alternative sources of power. In 2015, Karachi Pakistan, 65 000 people were taken to the hospital with heat related or lack of access to air conditioning symptoms.[23] Heat-related deaths are also reported in countries such as India and Bangladesh where people are exposed to extreme heat from climate change and heat island effects. Furthermore, it is important for countries to generate local evidence to understand the impact of heat on population.

There is a wide range of international commitment and international agreements and support to establish green spaces in urban settings, however, there is a gap in literature on the assessments of green space accessibility and its impact on health. Such data would enable urban planners and local authorities to establish planning decisions. Interventions for urban green space should be planned and designed with the local community and intended green space users. Moreover, such interventions need to be considered as long-term investments and should be integrated in national developmental strategies, for example, housing regulations, urban masterplans, transport policies, etc. This requires a general understanding that urban green go beyond ecological or environmental objectives and deliver health benefits that increase well-being of urban residents and improves quality of life.

It is also important to accurately measure accessibility to green spaces, for this, we propose a multidimensional approach that considers not only the physical proximity but also the quality and usability of these spaces. This includes factors like maintenance, safety and availability of facilities. In economically developed countries, integrating geographical information systems with social demographic data can provide insights into equitable access. We also suggest incorporating community engagement metrics to understand the perceived value and actual use of green spaces, thereby offering a holistic measure of accessibility.

The limitation of this review is that we could not examine studies for the size, location and accessibility of green spaces that can have a significant effect on heat-related health outcomes and the potential to mitigate heat exposure. Second, our analysis acknowledges the diverse time span of studies reviewed, spanning nearly a decade. This range allows for a broader understanding of urban green spaces' impacts over time, including changing urbanisation patterns and climate change effects. However, it also introduces variability in data due to evolving environmental policies, green space management practices and socioeconomic factors. We discuss the methodological approaches to mitigate these challenges, such as standardising outcome measures and adjusting for confounding factors, providing a comprehensive view of the accumulated evidence.

CONCLUSION

A review of urban greenery and its effect on heat-related morbidity and mortality suggests that urban green spaces, such as parks and trees, can have a positive impact on reducing the negative health effects associated with high temperatures. Studies have found that areas with more green space have lower rates of heat-related morbidity and mortality compared with areas with less green space. Moreover, urban greenery can also have a positive impact on mental health and well-being, which can also contribute to reducing the negative health effects of high temperatures. However, it is important to note that more research is needed to fully understand the extent of the impact of urban greenery on heat-related morbidity and mortality, and how it interacts with other factors such as air pollution, socioeconomic status and others.

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