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The Health Impact of Urban Green Spaces: A Systematic Review of Heat-Related Morbidity and Mortality

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The Health Impact of Urban Green Spaces: A Systematic Review of Heat-Related Morbidity and Mortality

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ABSTRACT:

Background: Elevated temperatures present considerable health threats to populations across age groups, warranting the exploration of effective mitigative strategies. The role of enhanced vegetation cover in alleviating heat stress associated with extreme temperatures and air pollution has emerged as a crucial area of research. The objective of this review was to scrutinize the impact of urban green spaces on heat-related morbidity and mortality.

Methodology: A comprehensive search was conducted across PubMed, Scopus, and Google Scholar, following the PRISMA guidelines, including studies from January 2000 to December 2022. All studies that examined the influence of urban green spaces on heat-related morbidity and mortality including randomized controlled trials, observational, and modelling studies were included.

Results: Out of 3,301 publications, 12 studies were selected. Predominantly, 95% of the studies originated from high and upper-middle-income nations. 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, socio-economic status, among others.

Strengths:

1. 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.
2. The study employed well-defined inclusion and exclusion criteria to select relevant research, enhancing the precision and quality of the included studies.
3. Prior to selection, each paper underwent a systematic quality assessment using the CHARMS (CHecklist for critical Appraisal and data extraction for systematic Reviews of prediction Modelling Studies) checklist, ensuring a rigorous approach to data inclusion.

Limitations:

1. 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 utilizing experimental methods.
2. 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.

KEYWORDS: air pollution, global warming, green spaces, heat risk, morbidity and mortality, urban vegetation.

INTRODUCTION

As consequences of urbanization 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 urbanization.[1] Counteracting these global challenges - encompassing climate change, health inequity, and sustainable urbanization - green areas or urban vegetation are deemed critical. In this vein, the United Nations Sustainable Development Goal (SDG) 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 such as children, the elderly, and individuals with pre-existing medical conditions are particularly susceptible to the ramifications of high temperatures. Given the heightened health and mortality risks associated with soaring temperatures, it is crucial to identify mitigating factors in urban environments.[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 author. This review aims to explore the worldwide influence of urban green spaces on heat-related morbidity and mortality. This systematic review, meticulously carried out following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.[8]

Study selection criteria

All studies that examined the influence of urban green spaces on heat-related morbidity and mortality including randomized 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 through 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 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 finalized, data extraction for descriptive parameters was independently performed by the two researchers (AN and KA) who undertook screening procedures. A standardized charting form was developed for data extraction and categorization. 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 domain. 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 the many and context-specific ways that urban green spaces may affect heat-related illness and death.

RESULTS

Study Characteristics

A total of 3,301 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 summarizes the characteristics of all 12 studies conducted between 2014 and 2022. 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], United States[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.

Table 1: Description of studies

Title	Country	Population/Source of data	Duration of study	Outcome to be predicted
Effect modifications of green space and blue spac Chen D e on heat–mortality association in Hong Kong, 2008–2017[10]	Hong Kong	Census data, meteorological and daily mortality data	2008-2017	Mortality risks under moderate heat
Urban vegetation for reducing heat related mortality[11]	Melbourne, Australia	Mortality data	1988-2007	heat-related health burden.
The protective effect of green space on heatrelated respiratory hospitalization among children under 5 years of age in Hanoi, Vietnam[12]	Hanoi, Vietnam	Daily hospital admission records &meteorological data. Satellite data to calculate green space	2010-2014	Health outcomes /hospitalization, heat related health risk

Increasing trees and high-albedo surfaces decreases heat impacts and mortality in Los Angeles, CA[13]	Los Angeles, USA	Meteorological and mortality data		Heat related mortality and morbidity
Urban vegetation and heat-related mortality in Seoul, Korea[14]	Seoul, Korea	Mortality data, census	2000-2009	heat-related health burden.
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]	Sydney, Australia	Mortality data, Data for UHI-related temperature were generated using satellite land surface temperature (LST) measurements over the Sydney GMR	Mortality 2006-2018, weather observation 1997-2016	Heat mortality

The Impacts of Heatwaves on Mortality Differ with Different Study Periods: A MultiCity Time Series Investigation[16]	Australia	Meteorological data Daily data on mortality	1988-2011	Non-accidental and circulatory mortality data
Modification of Heat-Related Mortality in an Elderly Urban Population by Vegetation (Urban Green) and Proximity to Water (Urban Blue): Evidence from	Lisbon, Portugal	Daily age-stratified death counts, meteorological and air pollution data	1998-2008	Deaths above 65 years

Lisbon, Portugal[17]				
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]	Japan	Meteorological measurement (wet-bulb globe temperature (WBGT) for heatstroke risk level) Subjective measurements (physiological temperature, feelings of heat and comfort, pulse rate)	2022	Risk of heatstroke using WBGT, physiological temperature, feelings of heat and comfort, pulse rate
Modeling lives saved from extreme heat by urban tree cover[19]	USA	A model named i-Tree Cool Air, which estimates hourly temperature changes based on different scenarios of urban tree cover across 653 Census Block Groups in	2021	Changes in air temperature, premature mortality rate, associated economic value of changes in mortality rates

		Baltimore City, Maryland		
The Value of US Urban Tree Cover for Reducing Heat-Related Health Impacts and Electricity Consumption[20]	USA	The study uses tree cover and developed land-cover information for 97 US cities, as well as current relationships between temperature and health outcomes.	2020	The study aims to quantify how much current urban tree cover reduces summer air temperatures and associated heat-related mortality, morbidity, and electricity consumption.
The health benefits of greening strategies to cool urban environments – A heat health impact method[21]	Australia	Meteorological data	2017	Urban Cooling Effect (UCE), reduction in heat-attributable deaths per day

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 out review question, reflecting relevance to the investigation of urban green spaces and their influence on heat-related mortality and morbidity.

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

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 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 hospitalization of children under.[10] They used two-stage model, including a distributed non-linear model coupled with multivariate meta-analysis. Hospitalization in the central districts which are hotter and crowded increased significantly at temperatures > 34 °C. Heat significantly increased the risk of hospitalization among children under 5.[12] In another study conducted in Lisbon, authors emphasized on the relevance of urban green on heat mitigation. Heat and mortality had a significant association in 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]

Table 3. Comparison of results and interpretation

Title	**Methods**	**Results and interpretation**
Effect modifications of green space and blue space on heat–mortality association in Hong Kong, 2008–2017[10]	Time-series analyses were performed using fitting generalized linear mixed models	No significant effect modifications of green and blue spaces on heat-related mortality risk were observed in Hong Kong.

Urban vegetation for reducing heat related mortality[11]	A two-scale modelling approach. A meso-scale urban climate model was used to quantify the effects of ten urban vegetation schemes on the current climate in 2009 and future climates in 2030 and 2050.	Simulation results showed that the average seasonal summer temperatures can be reduced in the range of around 0.5 and 2 C if Melbourne CBD were replaced by vegetated suburbs and planted parklands, respectively.
The protective effect of green space on heat-related respiratory hospitalization among children under 5 years of age in Hanoi, Vietnam[12]	Estimated district-specific meteorological conditions from 2010 to 2014 by using a dynamic downscaling approach with a fine-resolution numerical climate model.	This study confirmed the protective effect of green space on heat risk on respiratory hospitalization among children under 5.
Increasing trees and high-albedo surfaces decreases heat impacts and mortality in Los Angeles, CA[13]	Weather Research and Forecasting model was used to explore the effects that tree cover and albedo scenarios would have, correlating the resultant meteorological data with standardized mortality data algorithms to quantify potential reductions in mortality.	The study found that roughly one in four lives currently lost during heat waves could be saved. We also found that climate change–induced warming could be delayed approximately 40–70 years under business-as-usual and moderate mitigation scenarios, respectively.
Urban vegetation and heat-related mortality in Seoul, Korea[14]	Normalized Difference Vegetation Index (NDVI) used to assess the urban vegetation within Seoul. Poisson generalized linear model applied with	Findings suggest a higher mortality effect of high temperature in areas with lower vegetation in Seoul, Korea

	interaction term between temperature and indicator of NDVI group to assess the effect modification of the temperature-mortality association by urban vegetation.	
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]	Modeled interactions between UTCI and average NDVI during June–August. Mortality (2006–2018) records were linked with census population data, weather observations (1997–2016) and climate change projections to 2100.	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.
The Impacts of Heatwaves on Mortality Differ with Different Study Periods: A MultiCity Time Series Investigation[16]	Poisson generalised additive model (GAM) was used to examine the heatwave effects on mortality for each city	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 to those using the warm season or the whole year data.

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]	Poisson generalized additive models were fitted, allowing for the interaction between equivalent temperature [universal thermal climate index (UTCI)] and quartiles of urban greenness [classified using the Normalized Difference Vegetation Index (NDVI)] and proximity to water (≤4km vs. >4km), while adjusting for potential confounders	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 area.
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]	The study used meteorological measurements (temperature, humidity, wind direction/speed, radiation, black-globe temperature) and subject experiments (questionnaires on warmth/comfort sensations) to assess heat stress mitigation of a wisteria trellis, tent, and direct sunlight. Physiological measurements (ear temperature, blood pressure, pulse rate) were taken pre and post exposure. Statistical tests	The thermal environment under a wisteria trellis showed significantly lower heat stress compared to 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.

	were used for data analysis.	
Modeling lives saved from extreme heat by urban tree cover[19]	The study introduced a method for quantifying and valuing changes in premature mortality from extreme heat due to urban tree cover changes in Baltimore City, Maryland. The model i-Tree Cool Air estimated hourly temperature changes based on alternative scenarios of tree cover across 653 Census Block Groups.	Existing tree cover reduced annual mortality by 543 deaths compared to a 0% tree cover scenario. Increasing tree cover by 10% reduced baseline annual mortality by 83 to 247 deaths. The benefits were greater for individuals over 65 years and for regions with greater tree cover.
The Value of US Urban Tree Cover for Reducing Heat-Related Health Impacts and Electricity Consumption[20]	The authors assembled land-cover information for 97 US cities, used regression analysis to study how urban tree cover influences air temperatures, health outcomes, and electricity consumption.	The research found urban tree cover helps avoid 245–346 deaths annually and provides heat-reduction services estimated to be worth $5.3–12.1 billion annually for the entire US urban population.
The health benefits of greening strategies to cool urban environments – A heat health impact method[21]	The Heat Health Impact (HHI) method, based on the Universal Thermal Climate Index (UTCI), was applied to Sydney using 2017 meteorological data from 10 stations. Three	Greening interventions reduced the daily average UTCI by -0.2 to -1.7 °C, decreasing heat-attributable deaths by up to 11.7 per day. This emphasizes the health benefits

	greening intervention scenarios were investigated, calculating the Urban Cooling Effect (UCE) and estimating mortality change.	of urban greening in mitigating heatwave effects.

Positive effect on heat related mortality /morbidity:

Interestingly, three studies included in this review are conducted in Australia. Chen et al. used two scale modelling approach to quantify the effect of then 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 CBD were replaced by vegetated suburbs and planted parklands, respectively.[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 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 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 to 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 to tents, even demonstrating psychological relaxation effects.[18] In the United States, 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 emphasized 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 the 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, 65000 people were taken to the hospital with heat related o lack of access to air conditioning symptoms.[23] Heat related deaths are also reported in countries like 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 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 e.g., 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 wellbeing of urban residents and improves quality of life.

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.

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 to 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's 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, socio-economic status, and others.

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CONTRIBUTION STATEMENT: Dr Ahsana Nazish conceptualized, planned the study, undertook the screening process, data extraction, draft writing, and proofread the manuscript. Dr Kiran

Abbas undertook the data extraction, analysis, interpretation and draft writing. Dr Emmama Sattar did draft writing and proof reading.

DATA AVAILABILITY: All relevant documents including protocol, data extraction form; data extracted from included studies can be requested directly from the corresponding author (AN).

RESEARCH ETHICS APPROVAL: Not applicable

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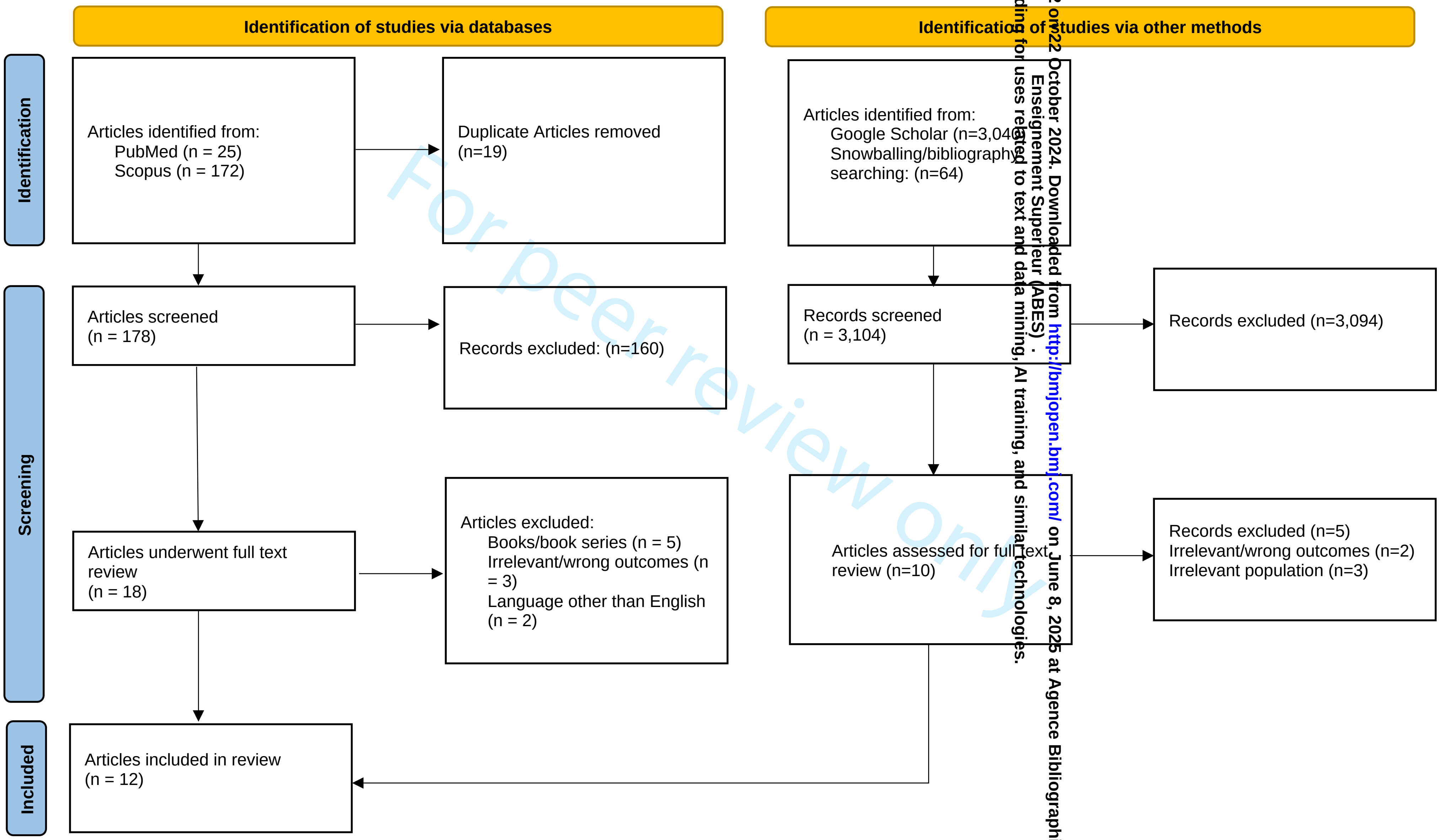
Figure 1: Study search and selection- flow diagram



Supplemental Table S1

Database	Key terms related to 'Urban Green Spaces') AND	Key terms 'Heat-related Morbidity and Mortality'	Combined Keywords
Pubmed	("Urban Green Space"[Title/Abstract] OR "Urban Greenery"[Title/Abstract] OR "Urban Vegetation"[Title/Abstract] OR "Urban Trees"[Title/Abstract] OR "Urban Parks"[Title/Abstract] OR "Urban Green Zones"[Title/Abstract] OR "Green Roofs"[Title/Abstract] OR "Green Infrastructure"[Title/Abstract])	("Heat-related Mortality"[Title/Abstract] OR "Heat-related Morbidity"[Title/Abstract] OR "Heat Stress"[Title/Abstract] OR "Heat Illness"[Title/Abstract] OR "Heat Stroke"[Title/Abstract] OR "Heat Exhaustion"[Title/Abstract] OR "Heat-related Health Outcomes"[Title/Abstract])	("Urban Green Space"[Title/Abstract] OR "Urban Greenery"[Title/Abstract] OR "Urban Vegetation"[Title/Abstract] OR "Urban Trees"[Title/Abstract] OR "Urban Parks"[Title/Abstract] OR "Urban Green Zones"[Title/Abstract] OR "Green Roofs"[Title/Abstract] OR "Green Infrastructure"[Title/Abstract])) AND (("Heat-related Mortality"[Title/Abstract] OR "Heat-related Morbidity"[Title/Abstract] OR "Heat Stress"[Title/Abstract] OR "Heat Illness"[Title/Abstract] OR "Heat Stroke"[Title/Abstract] OR "Heat Exhaustion"[Title/Abstract] OR "Heat-related Health Outcomes"[Title/Abstract])
Scopus	"Urban Green Space" OR "Urban Greenery" OR "Urban Vegetation" OR "Urban Trees" OR "Urban Parks" OR "Urban Green Zones" OR "Green Roofs" OR "Green Infrastructure"	"Heat-related Mortality" OR "Heat-related Morbidity" OR "Heat Stress" OR "Heat Illness" OR "Heat Stroke" OR "Heat Exhaustion" OR "Heat-related Health Outcomes"	"Urban Green Space" OR "Urban Greenery" OR "Urban Vegetation" OR "Urban Trees" OR "Urban Parks" OR "Urban Green Zones" OR "Green Roofs" OR "Green Infrastructure" AND "Heat-related Mortality" OR "Heat-related Morbidity" OR "Heat Stress" OR "Heat Illness" OR "Heat Stroke" OR "Heat Exhaustion" OR "Heat-related Health Outcomes"
Google Scholar	("Urban Green Space" OR "Urban Greenery" OR "Urban Vegetation" OR "Urban Trees" OR "Urban Parks" OR "Urban Green Zones" OR	("Heat-related Mortality" OR "Heat-related Morbidity")	("Urban Green Space" OR "Urban Greenery" OR "Urban Vegetation" OR "Urban Trees" OR "Urban Parks" OR "Urban Green Zones" OR

	"Green Roofs" OR "Green Infrastructure")		"Green Roofs" OR "Green Infrastructure") AND ("Heat-related Mortality" OR "Heat-related Morbidity")

S.No	Title	Link/Source	Publication year	Duration of study	Country	Source of data	Study type	Objectives	Methods	Results	Conclusion
1	Effect modifications of green space and blue space on heat–mortality association in Hong Kong, 2008–2017	https://doi.org/10.1016/j.scitotenv.2022.156127	2022	2008-2017	Hong Kong	Meterological data	Epidemiological study	The primary goal is to understand how green and blue spaces might modify the effects of heat on mortality rates.	Daily mortality and meteorological data from 2008 to 2017 in Hong Kong, China were collected. The Normalized Difference Vegetation Index and distance to coast were used as proxies for green and blue space exposure, respectively. Time-series analyses was performed using fitting generalized linear mixed models with an interaction term between heat and levels of exposure to either green or blue space. Age-, sex-, and heat level-stratified analyses were also conducted.	With a 1 °C increase in temperature above the 90th percentile (29.61 °C), mortality increased by 5.7% (95% confidence interval [CI]: 1.6, 10.1%), 5.4% (1.4, 9.5%), and 4.6% (0.8, 8.9%) for low, medium and high levels of green space exposure, respectively, and by 7.5% (3.9, 11.2%) and 3.5% (0.3, 6.8%) for low and high levels of blue space exposure, respectively. Significant effect modifications of green and blue spaces were not observed for the whole population or any specific age and sex group, either at a moderate heat level or a heat level (Ps > 0.05).	No significant effect modifications of green and blue spaces on heat-related mortality risk were observed in Hong Kong. These findings challenge the existing evidence on the prominent protective role of green and blue spaces in mitigating heat-related mortality risks.
2	Urban vegetation for reducing heat related mortality	https://pubmed.ncbi.nlm.nih.gov/24857047/	2014	1988-2007	Melbourne, Australia	Mortality data	Modeling and simulation-based research	To explore the potential benefits of urban vegetation in reducing heat-related mortality in Melbourne, by considering how different vegetation schemes would affect both outdoor climate and indoor thermal performance.	Urban Climate Modeling (Meso-scale): This model was used to study the effects of ten different urban vegetation schemes on the climate in Melbourne for three time points: the current climate (2009), and future projections for 2030 and 2050. Meso-scale refers to intermediate spatial scales that capture features like weather patterns over a city. Building Simulation Tool: This part of the study focused on simulating the indoor thermal performance of five residential buildings under the various local meso-climates associated with different vegetation schemes. This is crucial to understanding how outdoor changes would translate into indoor living conditions.	Depending on the vegetation scheme, average seasonal summer temperatures could be reduced by approximately 0.5 to 2 °C. The temperature reductions were associated with estimated reductions in heat-related mortality rates. Specifically, doubling the city's vegetation coverage could lead to a 5-28% reduction, while transforming the city into parklands might result in a 37-99% reduction.	The study provides evidence that urban vegetation might play a vital role in mitigating heat-related mortality in Melbourne. By modeling different scenarios, it offers insights into potential urban planning strategies to increase resilience to heat-related risks. It's noteworthy that the study acknowledges its limitations, including the restricted set of buildings and local climates investigated, which would have to be taken into account when applying its conclusions more broadly.
3	The protective effect of green space on heat-related respiratory hospitalization among children under 5 years of age in Hanoi, Vietnam	https://pubmed.ncbi.nlm.nih.gov/35635669/	2022	2010 to 2014	Vietnam	District-specific meteorological conditions estimated using a dynamic downscaling approach with a fine-resolution numerical climate model. Green space in each district calculated using satellite data. Hospitalization data	Epidemiological research	To examine the protective effect of urban green space on heat-related respiratory hospitalization among children under 5 years of age in Hanoi, Vietnam. To understand the spatial distribution of heat and green space and their impact on child health at the district level.	Estimation of meteorological conditions using a dynamic downscaling approach with a numerical climate model. Calculation of green space using satellite data. Estimation of the attributable fraction of heat-related respiratory hospitalization using a two-stage model, including a distributed lag non-linear model (DLNM) coupled with multivariate meta-analysis. Exploration of the association between heat-related respiratory hospitalization and green spaces at the district level using linear regression.	Central districts were more crowded and hotter, with less green space than outer districts. Hospitalizations increased significantly in central districts at temperatures > 34 °C, but were insignificant in outer districts. Extreme heat attributed to 0.33% of citywide hospitalization, 0.35% in the center, and 0.32% in the outer region. A 1% increase in green space fraction was associated with a 3.8% reduction in heat-related respiratory hospitalization risk.	Heat significantly increased the risk of respiratory hospitalization among children under 5 years in Hanoi, Vietnam. The findings support the protective role of green space in reducing this risk. The results are valuable for authorities to consider strategies to protect children's health against the effects of heat, including measures to increase green space in urban areas.
4	Increasing trees and high-albedo surfaces decreases heat impacts and mortality in Los Angeles, CA	https://link.springer.com/article/10.1007/s00484-022-02248-8	2022	Not specified in the given text.	United States (Los Angeles, California)	Meteorological data for historical summer heat waves. Historical mortality data related to heat.	Modeling and simulation-based research, focusing on climate change mitigation and health outcomes related to heat.	To quantify how various tree cover and albedo scenarios would impact heat-related mortality, temperature, humidity, and oppressive air masses in Los Angeles. To quantify the number of years that climate change–induced warming could be delayed in Los Angeles if the interventions were implemented.	Classification of historical summer heat waves into discrete air mass types using synoptic climatology. Analysis of historical mortality data to determine excess heat-related mortality. Utilization of the Weather Research and Forecasting (WRF) model to explore the effects of tree cover and albedo scenarios. Correlation of resultant meteorological data with standardized mortality data algorithms to quantify potential reductions in mortality.	Roughly one in four lives currently lost during heat waves could be saved through the implementation of tree cover and higher albedo surfaces. Climate change–induced warming could be delayed approximately 40–70 years under business-as-usual and moderate mitigation scenarios, respectively.	Increasing trees and high-albedo surfaces in Los Angeles would significantly decrease heat impacts and associated mortality. These interventions could also delay the effects of climate change-induced warming, thereby presenting a valuable strategy to mitigate urban heat and associated health risks.
5	Urban vegetation and heat-related mortality in Seoul, Korea	https://pubmed.ncbi.nlm.nih.gov/27644031/	2016	2000-2009	South Korea (Seoul)	Normalized Difference Vegetation Index (NDVI) to assess urban vegetation. Mortality data related to heat	Epidemiological research	To investigate the effects of urban vegetation on heat-related mortality in Seoul, Korea. To evaluate how different levels of vegetation and individuals' characteristics (such as sex and age) affect the association between temperature and mortality.	Utilization of NDVI to assess urban vegetation levels, categorized into three groups. Application of an overdispersed Poisson generalized linear model with an interaction term between temperature and NDVI group to assess the modification of temperature-mortality association by urban vegetation. Stratified analysis to explore associations based on individual characteristics like sex and age.	The association between total mortality and a 1°C increase in temperature above the 90th percentile (25.1°C) was highest for areas with low NDVI. The heat effect corresponded to a 4.1%, 3.0%, and 2.2% increase in mortality risk for low, medium, and high NDVI groups, respectively. Estimated risks showed similar effects by sex and age.	The findings suggest that higher mortality effects of high temperature are observed in areas with lower vegetation in Seoul, Korea. Urban vegetation might play a protective role against heat-related mortality, and this effect is consistent across different genders and age groups.
6	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?	https://www.mdpi.com/2073-4433/13/5/714	2022	Mortality data from 2006 to 2018, weather observations from 1997 to 2016, and climate change projections to 2100	Australia (Sydney)	Mortality records (2006–2018) Census population data Weather observations (1997–2016) Climate change projections to 2100 High-resolution satellite observations of UHI (Urban Heat Island) air temperature excesses and green cover	Epidemiological and modeling study	To quantify the mortality burden of historical heatwave days in Sydney, Australia. To assess the contribution of the UHI effect. To estimate future health impacts using climate change projection data. To assess the potential for tree cover to mitigate the UHI effect.	Linking mortality records with census population data, weather observations, and climate change projections. Calculating heatwave-attributable excess deaths based on risk estimates from a published heatwave study of Sydney. Utilizing high-resolution satellite observations to determine the effects of UHI air temperature excesses and green cover on heat-related mortality.	More than 90% of heatwave days would not breach heatwave thresholds in Sydney if there were no UHI effect. The number of heatwave days could increase fourfold under the most extreme climate change scenario. Tree canopy was found to reduce urban heat, and widespread tree planting could offset the increases in heat-attributable deaths as climate warming progresses.	Heatwaves are significantly exacerbated by the UHI effect, contributing to increased mortality in Sydney. The projected increase in heatwave days under climate change scenarios could lead to increased mortality risks. Tree canopy and widespread tree planting can reduce the UHI effect and could play a vital role in mitigating increases in heat-related deaths as climate change progresses.
7	The Impacts of Heatwaves on Mortality Differ with Different Study Periods: A Multi-City Time Series Investigation	https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0134233	2015	1988 to 2011	Australia (Brisbane, Melbourne, Sydney).	Daily data on climatic variables and mortality for the three cities, obtained from relevant government agencies.	Epidemiological study	To assess the heatwave-mortality relationship using different study periods in the three largest Australian cities. To understand the comparability and consistency of previous effect estimates in the literature.	A consistent definition of heatwaves was used for the cities. Poisson generalized additive model was fitted to assess the impact of heatwaves on mortality.	Non-accidental and circulatory mortality significantly increased during heatwaves across the three cities, regardless of different heatwave definitions and study periods. Using the summer data resulted in the largest increase in effect estimates compared to those using the warm season or the whole year data.	The findings demonstrate that the impacts of heatwaves on mortality differ with different study periods, and this may have implications for developing standardized approaches to evaluating the heatwave-mortality relationship. The results also highlight the need for advancing heat health warning systems and provide impetus for methodological advancements in assessing climate change-related health consequences.
8	Modification of Heat-Related Mortality in an Elderly Urban Population by Vegetation (Urban Green) and Proximity to Water (Urban Blue): Evidence from Lisbon, Portugal	https://pubmed.ncbi.nlm.nih.gov/26566198/	2016	1998 to 2008	Portugal (Lisbon).	Remotely sensed data and geographic information	Epidemiological study	To investigate the influence of urban green and urban blue on heat-related excess mortality in the elderly population (> 65 years old) in Lisbon.	Amount of urban vegetation and distance to bodies of water determined using the Normalized Difference Vegetation Index (NDVI) and geographic information. Poisson generalized additive models fitted, allowing for interactions between equivalent temperature (universal thermal climate index, UTCI) and quartiles of urban greenness (NDVI) and proximity to water, adjusting for potential confounders.	A stronger association between mortality and a 1°C increase in UTCI in areas with the lowest NDVI quartile (14.7% higher) compared to areas in the highest quartile (3.0%). In areas more than 4 km from water, a 1°C increase in UTCI was associated with a 7.1% increase in mortality, whereas in areas 4 km or less from water, the estimated increase was only 2.1%.	Urban green and blue appeared to mitigate heat-related mortality in the elderly population in Lisbon. Increasing vegetation may be a good strategy to counteract the adverse effects of heat in urban areas, and findings suggest potential benefits of urban blue that may be present several kilometers from a body of water.
9	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	https://rmets.onlinelibrary.wiley.com/doi/10.1002/met.2046	2022	not explicitly mentioned	Japan	Wet-bulb globe temperature (WBGT) measurements under wisteria trellises, under tents, and in direct sunlight, along with subject experiments and questionnaire responses.	Experimental research	To measure and analyze the thermal comfort and heat stress mitigation effects of wisteria trellises and tents, considering both meteorological and psychological factors, such as the relaxation effect of greenery.	Measured WBGT under wisteria trellises, tents, and in direct sunlight. Conducted a subject experiment considering the relaxation effect of greenery. Analyzed the risk of heatstroke and the mitigation effects of different environments, taking into account factors like black-globe temperature and solar radiation. Used questionnaires to gather subjects' feelings of comfort under the different conditions.	The risk of heatstroke under the wisteria trellis was one level lower than that in direct sunlight. The wisteria trellis had a greater mitigation effect than the tent, mostly due to differences in radiation environment. The wisteria trellis blocked most solar radiation, reducing the increase in leaf surface temperature and downward longwave radiation. The tent material allowed more solar radiation and increased the tent surface temperature. The subjects felt cooler and more comfortable under the wisteria trellis than under the tent, with or without a blindfold.	Wisteria trellises provide a more effective means of improving thermal comfort and mitigating heat stress compared to tents. The differences in thermal comfort are primarily due to the varied radiation environment between the trellis and the tent. The wisteria trellis's ability to block solar radiation and the associated psychological relaxation effect make it a preferred option for cooling and comfort.
10	Modeling lives saved from extreme heat by urban tree cove	https://www.sciencedirect.com/science/article/abs/pii/S030438002100123X?via%3Dihub	2021	not explicitly mentioned	USA (Baltimore City, Maryland)	Data was sourced through the model i-Tree Cool Air	Modeling and quantitative analysis	The study aimed to investigate the role of trees in reducing temperature during warm seasons and their associated impacts on human health and well-being. The researchers introduced a method for quantifying and valuing changes in premature mortality from extreme heat due to changes in urban tree cover and applied this method to Baltimore City, Maryland.	Using the model i-Tree Cool Air to estimate hourly changes in air temperature due to various tree cover scenarios across 653 Census Block Groups. Applying changes in temperature to existing temperature–mortality models to estimate changes in health outcomes and associated values.	Existing tree cover in Baltimore is estimated to reduce annual mortality by 543 deaths compared to a 0% tree cover scenario. Increasing tree cover by 10% in each Census Block Group reduced annual mortality by 83 to 247 deaths (valued at \$0.68 –2.0 billion using Value of Statistical Life estimates). Over half of the reduced mortality is from the over 65-year age group. Reductions in air temperature were greatest in downtown Baltimore, but the greatest reductions in mortality occurred in the outskirts where a greater number of vulnerable elderly people reside.	Urban tree cover significantly contributes to reducing mortality from extreme heat, particularly among the most vulnerable elderly population. The quantification and valuation of the health benefits due to increased tree cover can be instrumental for informing climate adaptation and mitigation plans. There's an urgent need for developing effective adaptation strategies to address these issues, especially considering future changing climates and an aging population.
11	The Value of US Urban Tree Cover for Reducing Heat-Related Health Impacts and Electricity Consumption	https://doi.org/10.1007/s10021-019-00395-5	2020	not explicitly mentioned	United States	Tree cover and developed land-cover information for 97 US cities, housing 59 million people, along with regression relationships to analyze the impact of tree cover on temperatures and health outcomes	Quantitative analysis	The study aimed to analyze how current urban tree cover in 97 US cities affects summer air temperatures and associated heat-related mortality, morbidity, and electricity consumption for air conditioning.	Assembling tree cover and developed land-cover information for the cities. Using regression relationships to analyze the impact of tree cover on temperatures and health outcomes.	78% of urban dwellers are in neighborhoods with less than 20% tree cover. 15.0 million people experience a temperature reduction of 0.5–1.0°C from tree cover, and 7.9 million people experience a reduction of greater than 1.0°C. Tree cover helps avoid 245–346 deaths annually. As AC availability increased, the value of tree cover for avoiding heat-related mortality decreased, while the value for reducing electricity consumption likely increased. The total annual economic value of avoided mortality, morbidity, and electricity consumption for the studied cities is estimated at \$1.3–2.9 billion, or \$21–49 annually per capita. Estimated value for the entire US urban population is \$5.3–12.1 billion.	High air temperatures are a significant public health threat in the US, but increasing tree canopy cover can be an effective way to reduce urban air temperatures. Current urban tree cover significantly contributes to reducing summer temperatures, heat-related mortality, morbidity, and electricity consumption. The benefits have shifted over time, with increased AC availability reducing the impact on mortality but likely increasing the value for electricity consumption. The total estimated value of the heat-reduction services provided by urban tree cover across the US is substantial, emphasizing the importance of maintaining and expanding urban tree cover.
12	The health benefits of greening strategies to cool urban environments – A heat health impact method	https://doi.org/10.1016/j.buildenv.2021.108546	2022	2017	Australia (Sydney region)	Meteorological observations from all available weather stations (10) covering the Sydney region, used to calculate average hourly Universal Thermal Climate Index (UTCI).	Quantitative analysis, proof-of-concept exercise.	To develop a new method (Heat Health Impact (HHI) method) to quantify the benefits of urban heat mitigation technologies (such as green infrastructure) on human heat balance and population mortality.	Using the state-of-the-art multi-parameter model UTCI as a base. Calculating average daily UTCI values for each of the 10 observation sites in Sydney. Spatially interpolating these values across the entire Sydney region for a representative heatwave day. Investigating three different greening intervention scenarios and calculating the daily average change in UTCI (ΔUTCI) under each, named Urban Cooling Effect (UCE). Implementing a health impact assessment methodology to estimate the change in attributable mortality due to each greening scenario.	Urban greening infrastructure scenarios reduced the daily average UTCI between −0.2 and −1.7 °C on the heatwave day. The health impact assessment indicated that heat-attributable deaths were reduced up to 11.7 per day across the Sydney Greater Metropolitan Region (GMR) compared to the baseline scenario.	The study highlighted the significant health benefits of implementing greening infrastructure to cool urban environments. By reducing the urban heat effect through greening interventions, cities can reduce the health burden due to heatwaves, indicating the essential role that urban planning and green infrastructure can play in enhancing urban resilience against heat-related health risks.

What is already known on this topic:

- Climate change and urbanization are contributing to high temperatures in urban areas, which pose health risks, particularly to vulnerable groups such as children, the elderly, and those with pre-existing medical conditions.
- Green spaces in urban settings can mitigate these high temperatures and have shown benefits for mental well-being, but their specific effects on heat-related health risks are not fully understood.
- The United Nations Sustainable Development Goal (SDG) 11 target 7 promotes the development of safe, accessible, green public spaces by 2030.

What this study adds:

- This review provides evidence that green spaces in urban areas have the potential to lower heat-related morbidity and mortality, particularly for vulnerable groups.
- A significant heterogeneity in the impact of green spaces on heat-related health risks across various global regions and among different population subgroups is identified.
- The study highlights the need for local evidence to address heat-related health issues in low and middle-income countries and the necessity of incorporating urban green spaces into national developmental strategies.

How this study might affect research, practice, or policy:

- The results suggest that city planning, and policy development should incorporate more green spaces to mitigate health risks associated with high temperatures, especially in regions with high urbanization rates.
- It encourages further research to understand the variability in the impact of green spaces on heat-related health risks among different population subgroups and global regions.
- The study may also influence policy towards improving access to green spaces in low-resource settings and integrating green space development into broader health and environmental policies.

PRISMA 2020 Checklist

Section and Topic	Item #	Checklist item	Location where item is reported
TITLE			
Title	1	Identify the report as a systematic review.	1
ABSTRACT			
Abstract	2	See the PRISMA 2020 for Abstracts checklist.	1
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	2
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	2
METHODS			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	2-3
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	3
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	3, S1
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	3-4
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	3-4
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	3-4
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	3-4
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	3
Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.	4
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	4
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	4
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	4
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	4
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).	N/A
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	N/A
Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	N/A
Certainty	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	N/A

PRISMA 2020 Checklist

Section and Topic	Item #	Checklist item	Location where item is reported
assessment			
RESULTS			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	4
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	Figure 1
Study characteristics	17	Cite each included study and present its characteristics.	4, Table 1,2
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	Table 3, 9-10
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	N/A
Results of syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	4-10
	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	N/A
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	N/A
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	N/A
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	N/A
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	N/A
DISCUSSION			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	16-17
	23b	Discuss any limitations of the evidence included in the review.	16-17
	23c	Discuss any limitations of the review processes used.	17
	23d	Discuss implications of the results for practice, policy, and future research.	17
OTHER INFORMATION			
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	2
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	2
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	N/A
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	18
Competing interests	26	Declare any competing interests of review authors.	18
Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	18

From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi:

PRISMA 2020 Checklist

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The Health Impact of Urban Green Spaces: A Systematic Review of Heat-Related Morbidity and Mortality

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ABSTRACT:

Background: Elevated temperatures present considerable health threats to populations across age groups, warranting the exploration of effective mitigative strategies. The role of enhanced vegetation cover in alleviating heat stress associated with extreme temperatures and air pollution has emerged as a crucial area of research. The objective of this review was to scrutinize the impact of urban green spaces on heat-related morbidity and mortality.

Methodology: A comprehensive search was conducted across PubMed, Scopus, and Google Scholar, following the PRISMA guidelines, including studies from January 2000 to December 2022. All studies that examined the influence of urban green spaces on heat-related morbidity and mortality including randomized controlled trials, observational, and modelling studies were included.

Results: Out of 3,301 publications, 12 studies were selected. Predominantly, 95% of the studies originated from high and upper-middle-income nations. 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, socio-economic status, among others.

Key takeaways:

What is already known on this topic:

- Climate change and urbanization are contributing to high temperatures in urban areas, which pose health risks, particularly to vulnerable groups such as children, the elderly, and those with pre-existing medical conditions.
- Green spaces in urban settings can mitigate these high temperatures and have shown benefits for mental well-being, but their specific effects on heat-related health risks are not fully understood.
- The United Nations Sustainable Development Goal (SDG) 11 target 7 promotes the development of safe, accessible, green public spaces by 2030.

What this study adds:

- This review provides evidence that green spaces in urban areas have the potential to lower heat-related morbidity and mortality, particularly for vulnerable groups.
- A significant heterogeneity in the impact of green spaces on heat-related health risks across various global regions and among different population subgroups is identified.
- The study highlights the need for local evidence to address heat-related health issues in low and middle-income countries and the necessity of incorporating urban green spaces into national developmental strategies.

How this study might affect research, practice, or policy:

- The results suggest that city planning, and policy development should incorporate more green spaces to mitigate health risks associated with high temperatures, especially in regions with high urbanization rates.
- It encourages further research to understand the variability in the impact of green spaces on heat-related health risks among different population subgroups and global regions.
- The study may also influence policy towards improving access to green spaces in low-resource settings and integrating green space development into broader health and environmental policies.

Strengths:

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 CHARMS (CHecklist for critical Appraisal and data extraction for systematic Reviews of prediction Modelling Studies) checklist, ensuring a rigorous approach to data inclusion.

Limitations:

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 utilizing 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.

KEYWORDS: air pollution, global warming, green spaces, heat risk, morbidity and mortality, urban vegetation.

INTRODUCTION

As consequences of urbanization 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 urbanization [1]. Counteracting these global challenges - encompassing climate change, health inequity, and sustainable urbanization - green areas or urban vegetation are deemed critical. In this vein, the United Nations Sustainable Development Goal (SDG) 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 the compromised health status of those with chronic conditions make these groups particularly susceptible to heat stress and heat-related illnesses. The exacerbated 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].

An urban area, is defined as a geographical space characterized by a continuous urban settlement with a population density higher than the surrounding space [5]. Urban green areas have emerged as a potential counter to heat, demonstrated by research evidencing their critical role in thermal mitigation [1]. For instance, a study in China highlighted the efficient cooling effect of green spaces. 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 author. This review aims to explore the worldwide influence of urban green spaces on heat-related morbidity and mortality. This systematic review, meticulously carried out following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 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 randomized 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 through 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 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 finalized, data extraction for descriptive parameters was independently performed by the two researchers (AN and KA) who undertook screening procedures. A standardized charting form was developed for data extraction and categorization. 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 domain. 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 the many and context-specific ways that urban green spaces may affect heat-related illness and death.

Patient and Public Involvement

No patient involved

RESULTS

Study Characteristics

A total of 3,301 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 [10-21]. Table 1 summarizes the characteristics of all 12 studies conducted between 2014 and 2022. 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], United States [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.

Table 1: Description of studies

Author (year of study)	Characteristics (Location, Sample population, Source of data, etc)	Duration	Exposure Variable	Outcome Variable
Song J (2022) [10]	Hong Kong, China; mortality and weather data, using normalized difference vegetation index (NDVI) and coast distance as proxies for green and blue space exposure.	2008-2017	Green space (measured by NDVI) and blue space (proximity to coast)	Heat-related mortality.
Chen D (2014) [11]	Melbourne, Australia; mortality data by sex and age (0-75, 75+) was sourced from the Australian Bureau of Statistics.	1988 to 2007.	Urban vegetation schemes	Heat-related mortality rate
Nguyen (2022) [12]	Hanoi, Vietnam; used hospital data from three Hanoi hospitals and daily weather data for green space measurement.	2010-2014	Green space.	Heat-related respiratory hospitalization among children under 5 years of age.
Kalkstein (2022) [13]	Los Angeles, California, USA; historical weather and mortality data from Los Angeles were used to estimate excess deaths during heatwaves.	1985–2010	Tree canopy and albedo modifications.	Heat-related mortality reduction.
Son (2016) [14]	Seoul, Korea; assessed urban mortality using national data and MODIS satellite NDVI for vegetation.	2000-2009	Urban vegetation measured by Normalized Difference Vegetation	Heat-related mortality.

			Index (NDVI)	
Chaston (2022) [15]	Sydney, Australia; assessed heatwave deaths and UHI effects using 2006–2018 mortality records, weather data, and future climate projections.	1997 to 2018 & up to 2100	Urban Heat Island (UHI) effect and tree cover	Heatwave-attributable excess deaths
Wang (2015) [16]	Brisbane, Melbourne, and Sydney, Australia; Mortality data for Brisbane, Melbourne, and Sydney was used	1988-2011	Heatwaves, defined consistently across the cities.	Non-accidental (heart attacks and strokes) and circulatory mortality.
Burkart (2015) [17]	Lisbon, Portugal; the study focused on the elderly population (>65 years), using mortality data, remotely sensed data for urban vegetation and proximity to water bodies.	1998-2008	Urban green (vegetation) and urban blue (proximity to water bodies)	Heat-related all-cause natural excess mortality.
Kusaka (2022) [18]	Tsukuba, Ibaraki, Japan; evaluated thermal comfort under wisteria trellises and tents vs. direct sunlight for students around 20 years old.	2017	Shade provided by wisteria trellises and tents	Subjective thermal comfort and physiological responses to heat such as skin temperature, heart rate, and sweat rate.
Sinha (2021) [19]	Baltimore, Maryland, USA; used mortality, census, weather data, and climate projections.	2007–2017	Urban green space coverage	Reductions in mortality attributable to extreme heat events
McDonald (2019) [20]	United States (97 cities); Tree cover and land use in 97 US cities were analyzed	2011	Urban green space coverage	Reductions in temperature, heat-related mortality, morbidity, and electricity consumption for air-conditioning
Sadeghi (2021) [21]	Sydney, Australia; Population = 5.7 million. Used weather stations across Sydney GMR for full spatial coverage (12,367 km²), calculating average hourly UTCI for 2017.	2017	Urban greening infrastructure	Reduction in daily average UTCI and heat-attributable deaths.

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 out review question, reflecting relevance to the investigation of urban green spaces and their influence on heat-related mortality and morbidity.

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

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 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 hospitalization of children under [10]. They used two-stage model, including a distributed non-linear model coupled with multivariate meta-analysis. Hospitalization in the central districts which are hotter and crowded increased significantly at temperatures > 34 °C. Heat significantly increased the risk of hospitalization among children under 5 [12]. In another study conducted in Lisbon, authors emphasized on the relevance of urban green on heat mitigation. Heat and mortality had a significant association in 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].

Table 3. Comparison of results and interpretation

Title	**Methods**	**Results and interpretation**

Song J (2022) [10]	Time-series analyses used generalized linear mixed models.	No significant effect modifications of green and blue spaces on heat-related mortality risk were observed in Hong Kong.
Chen D (2014) [11]	A meso-scale model estimated the climate impact of ten urban vegetation schemes for 2009, 2030, and 2050.	Simulation results showed that the average seasonal summer temperatures can be reduced in the range of around 0.5 and 2 C if Melbourne CBD were replaced by vegetated suburbs and planted parklands, respectively.
Nguyen (2022) [12]	Estimated 2010-2014 district-specific weather using dynamic downscaling and a fine-resolution climate model.	This study confirmed the protective effect of green space on heat risk on respiratory hospitalization among children under 5.
Kalkstein (2022) [13]	Used the Weather Research and Forecasting model to study the mortality reduction effects of tree cover and albedo.	The study found that roughly one in four lives currently lost during heat waves could be saved. We also found that climate change–induced warming could be delayed approximately 40–70 years under business-as-usual and moderate mitigation scenarios, respectively.
Son (2016) [14]	Assessed Seoul's urban vegetation with Normalized Difference Vegetation Index (NDVI) and a Poisson model to study how it modifies the temperature-mortality link.	Findings suggest a higher mortality effect of high temperature in areas with lower vegetation in Seoul, Korea
Chaston (2022) [15]	Linked mortality records with census, weather, and climate projections to 2100 to model UTCI and NDVI interactions during summer.	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 (2015) [16]	Examined heatwave mortality impacts in each city using Poisson generalized additive models.	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 to those using the warm season or the whole year data.

Burkart (2015) [17]	Fitted Poisson models to analyze the interaction of UTCI with NDVI quartiles and water proximity while adjusting for confounders.	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 area.
Kusaka (2022) [18]	Studied heat stress mitigation of wisteria trellis, tent, and sunlight using meteorological measurements and physiological tests.	The thermal environment under a wisteria trellis showed significantly lower heat stress compared to 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 (2021) [19]	Used i-Tree Cool Air to model and value the mortality changes from urban tree cover alterations in Baltimore.	Existing tree cover reduced annual mortality by 543 deaths compared to a 0% tree cover scenario. Increasing tree cover by 10% reduced baseline annual mortality by 83 to 247 deaths. The benefits were greater for individuals over 65 years and for regions with greater tree cover.
McDonald (2019) [20]	Compiled land-cover data for 97 US cities to analyze urban tree cover's effects on temperatures, health, and electricity use.	The research found urban tree cover helps avoid 245–346 deaths annually and provides heat-reduction services estimated to be worth $5.3–12.1 billion annually for the entire US urban population.
Sadeghi (2021) [21]	Applied the HHI method with 2017 Sydney meteorological data to explore three greening scenarios and their effects on mortality.	Greening interventions reduced the daily average UTCI by -0.2 to -1.7 °C, decreasing heat-attributable deaths by up to 11.7 per day. This emphasizes the health benefits of urban greening in mitigating heatwave effects.

Positive effect on heat related mortality /morbidity:

Interestingly, three studies included in this review are conducted in Australia. Chen et al. used two scale modelling approach to quantify the effect of then 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 CBD were replaced by vegetated suburbs and planted parklands, respectively [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 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 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 to 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 to tents, even demonstrating psychological relaxation effects [18]. In the United States, 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 emphasized 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, 65000 people were taken to the hospital with heat related o lack of access to air conditioning symptoms [23]. Heat related deaths are also reported in countries like 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 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 e.g., 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 wellbeing of urban residents and improves quality of life.

It is also important to accurately measure accessibility to green spaces, for this we propose a multi-dimensional 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 Geographic Information Systems (GIS) 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. Secondly, 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 urbanization patterns and climate change effects. However, it also introduces variability in data due to evolving environmental policies, green space management practices, and socio-economic factors. We discuss the methodological approaches to mitigate these challenges, such as standardizing 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 to 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's 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, socio-economic status, and others.

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DATA AVAILABILITY: All relevant documents including protocol, data extraction form; data extracted from included studies can be requested directly from the corresponding author (AN).

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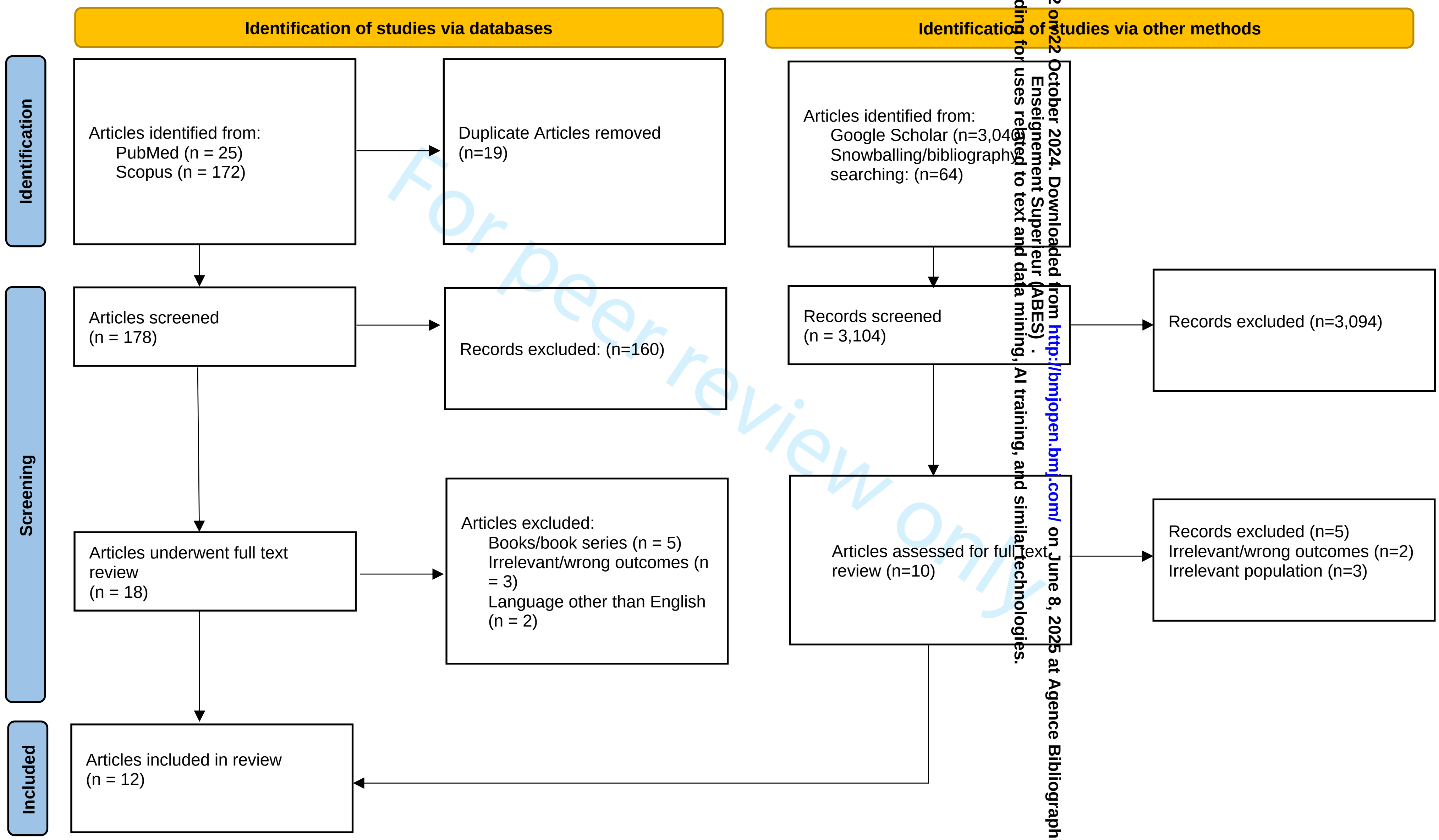
Figure 1 legend – Study search and selection - flow diagram

This figure illustrates the study selection process for a systematic review on the impact of urban green spaces on heat-related morbidity and mortality. A total of 3,301 publications were identified from the selected databases. After removing duplicates, titles and abstracts were screened resulting in 28 potentially relevant articles. After full-text screening, 12 articles met the inclusion criteria for final selection in this review.

Figure 1: Study search and selection- flow diagram



Supplemental Table S1

Database	Key terms related to 'Urban Green Spaces') AND	Key terms 'Heat-related Morbidity and Mortality'	Combined Keywords
Pubmed	("Urban Green Space"[Title/Abstract] OR "Urban Greenery"[Title/Abstract] OR "Urban Vegetation"[Title/Abstract] OR "Urban Trees"[Title/Abstract] OR "Urban Parks"[Title/Abstract] OR "Urban Green Zones"[Title/Abstract] OR "Green Roofs"[Title/Abstract] OR "Green Infrastructure"[Title/Abstract])	("Heat-related Mortality"[Title/Abstract] OR "Heat-related Morbidity"[Title/Abstract] OR "Heat Stress"[Title/Abstract] OR "Heat Illness"[Title/Abstract] OR "Heat Stroke"[Title/Abstract] OR "Heat Exhaustion"[Title/Abstrac t] OR "Heat-related Health Outcomes"[Title/Abstract])	("Urban Green Space"[Title/Abstract] OR "Urban Greenery"[Title/Abstract] OR "Urban Vegetation"[Title/Abstract] OR "Urban Trees"[Title/Abstract] OR "Urban Parks"[Title/Abstract] OR "Urban Green Zones"[Title/Abstract] OR "Green Roofs"[Title/Abstract] OR "Green Infrastructure"[Title/Abstract])) AND (("Heat-related Mortality"[Title/Abstract] OR "Heat-related Morbidity"[Title/Abstract] OR "Heat Stress"[Title/Abstract] OR "Heat Illness"[Title/Abstract] OR "Heat Stroke"[Title/Abstract] OR "Heat Exhaustion"[Title/Abstract] OR "Heat-related Health Outcomes"[Title/Abstract])
Scopus	"Urban Green Space" OR "Urban Greenery" OR "Urban Vegetation" OR "Urban Trees" OR "Urban Parks" OR "Urban Green Zones" OR "Green Roofs" OR "Green Infrastructure"	"Heat-related Mortality" OR "Heat-related Morbidity" OR "Heat Stress" OR "Heat Illness" OR "Heat Stroke" OR "Heat Exhaustion" OR "Heat-related Health Outcomes"	"Urban Green Space" OR "Urban Greenery" OR "Urban Vegetation" OR "Urban Trees" OR "Urban Parks" OR "Urban Green Zones" OR "Green Roofs" OR "Green Infrastructure" AND "Heat-related Mortality" OR "Heat-related Morbidity" OR "Heat Stress" OR "Heat Illness" OR "Heat Stroke" OR "Heat Exhaustion" OR "Heat-related Health Outcomes"
Google Scholar	("Urban Green Space" OR "Urban Greenery" OR "Urban Vegetation" OR "Urban Trees" OR "Urban Parks" OR "Urban Green Zones" OR	("Heat-related Mortality" OR "Heat-related Morbidity")	("Urban Green Space" OR "Urban Greenery" OR "Urban Vegetation" OR "Urban Trees" OR "Urban Parks" OR "Urban Green Zones" OR

	"Green Roofs" OR "Green Infrastructure")		"Green Roofs" OR "Green Infrastructure") AND ("Heat-related Mortality" OR "Heat-related Morbidity")

PRISMA 2020 Checklist

Section and Topic	Item #	Checklist item	Location where item is reported
TITLE			
Title	1	Identify the report as a systematic review.	1
ABSTRACT			
Abstract	2	See the PRISMA 2020 for Abstracts checklist.	1
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	2
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	2
METHODS			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	2-3
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	3
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	3, S1
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	3-4
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	3-4
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	3-4
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	3-4
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	3
Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.	4
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	4
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	4
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	4
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	4
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).	N/A
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	N/A
Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	N/A
Certainty	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	N/A

PRISMA 2020 Checklist

Section and Topic	Item #	Checklist item	Location where item is reported
assessment			
RESULTS			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	4
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	Figure 1
Study characteristics	17	Cite each included study and present its characteristics.	4, Table 1,2
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	Table 3, 9-10
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	N/A
Results of syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	4-10
	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	N/A
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	N/A
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	N/A
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	N/A
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	N/A
DISCUSSION			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	16-17
	23b	Discuss any limitations of the evidence included in the review.	16-17
	23c	Discuss any limitations of the review processes used.	17
	23d	Discuss implications of the results for practice, policy, and future research.	17
OTHER INFORMATION			
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	2
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	2
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	N/A
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	18
Competing interests	26	Declare any competing interests of review authors.	18
Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	18

From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi:

PRISMA 2020 Checklist

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The 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 scrutinize 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 (PRISMA) 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 randomized controlled trials, observational, and modeling studies, were included.

Data Extraction and Synthesis: A total of 3,301 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 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, socio-economic status, among others.

Strengths:

1. 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.
2. The study employed well-defined inclusion and exclusion criteria to select relevant research, enhancing the precision and quality of the included studies.
3. Prior to selection, each paper underwent a systematic quality assessment using the CHARMS (CHecklist for critical Appraisal and data extraction for systematic Reviews of prediction Modelling Studies) checklist, ensuring a rigorous approach to data inclusion.

Limitations:

1. 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 utilizing experimental methods.
2. 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.

KEYWORDS: air pollution, global warming, green spaces, heat risk, morbidity and mortality, urban vegetation.

INTRODUCTION

As consequences of urbanization 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 urbanization.[1] Counteracting these global challenges - encompassing climate change, health inequity, and sustainable urbanization - green areas or urban vegetation are deemed critical. In this vein, the United Nations Sustainable Development Goal (SDG) 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 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 (PRISMA) 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 randomized 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 through 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 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 finalized, data extraction for descriptive parameters was independently performed by the two researchers (AN and KA) who undertook screening procedures. A standardized charting form was developed for data extraction and categorization. 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 domain. 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 the many and context-specific ways that urban green spaces may affect heat-related illness and death.

Patient and public involvement

No patient involved.

RESULTS

Study Characteristics

A total of 3,301 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 summarizes 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], United States[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.

Table 1: Description of studies

Author (year)	Location	Characteristics	Study Duration	Exposure Variable	Outcome Variable
Song J (2022) [10]	Hong Kong, China	Daily mortality and meteorological data were analyzed, using the Normalized Difference Vegetation Index 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 D (2014) [11]	Melbourne, Australia	Mortality data were analyzed. 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 (2022) [12]	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 hospitalization among children under 5 years of age.
Kalkstein (2022) [13]	Los Angeles, California, USA	Used historical weather data and mortality data. Mortality data was assessed to estimate excess deaths during extreme heat events.	1985–2010	Tree canopy and albedo modifications	Heat-related mortality reduction
Son (2016) [14]	Seoul, Korea	Mortality data and NDVI data from MODIS satellite images were used to assess urban vegetation.	2000-2009	Urban vegetation measured by Normalized	Heat-related mortality.

				Difference Vegetation Index	
Chaston (2022) [15]	Sydney, Australia	Mortality records, census population data, weather observations and climate change projections.	1997 - 2018 and projected data up to 2100.	Urban Heat Island (UHI) effect and tree cover	Heatwave-attributable excess deaths
Wang (2015) [16]	Brisbane, Melbourne, and Sydney, Australia	Daily climate variables and mortality data were assessed. It focused on non-accidental and circulatory mortality.	1988-2011	Heatwaves, defined consistently across the cities.	Non-accidental (heart attacks and strokes) and circulatory mortality.
Burkart (2015) [17]	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 (2022) [18]	Tsukuba, Ibaraki, Japan	Thermal comfort of healthy individuals was assessed under wisteria trellises and tents, compared to direct sunlight.	Specific dates in August and September 2017	Shade provided by wisteria trellises and tents	Subjective thermal comfort and physiological responses.
Sinha (2021) [19]	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 (2019) [20]	United States (97 cities)	Analyzed 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 (2021) [21]	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.

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 out review question, reflecting relevance to the investigation of urban green spaces and their influence on heat-related mortality and morbidity.

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

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 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 hospitalization of children under.[10] They used two-stage model, including a distributed non-linear model coupled with multivariate meta-analysis. Hospitalization in the central districts which are hotter and crowded increased significantly at temperatures > 34 °C. Heat significantly increased the risk of hospitalization among children under 5.[12] In another study conducted in Lisbon, authors emphasized on the relevance of urban green on heat mitigation. Heat and mortality had a significant association in 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]

Table 3. Comparison of results and interpretation

Author (year)	Results and interpretation
Song J (2022) [10]	No significant effect modifications of green and blue spaces on heat-related mortality risk.

Chen D (2014) [11]	Simulation revealed the average seasonal summer temperatures can be reduced in the range of around 0.5 and 2 C if region is replaced by vegetated suburbs and planted parklands, respectively.
Nguyen (2022) [12]	This study confirmed the protective effect of green space on heat risk on respiratory hospitalization among children under 5
Kalkstein (2022) [13]	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 (2016) [14]	Findings suggest a higher mortality effect of high temperature in areas with lower vegetation in Seoul, Korea
Chaston (2022) [15]	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 (2015) [16]	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 to those using the warm season or the whole year data.
Burkart (2015) [17]	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 area.
Kusaka (2022) [18]	The thermal environment under a wisteria trellis showed significantly lower heat stress compared to 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 (2021) [19]	Existing tree cover reduced annual mortality by 543 deaths compared to a 0% tree cover scenario. Increasing tree cover by 10% reduced baseline annual mortality by 83 to 247 deaths. The benefits were greater for individuals over 65 years and for regions with greater tree cover.
McDonald (2019) [20]	The research found urban tree cover helps avoid 245–346 deaths annually and provides heat-reduction services estimated to be worth $5.3–12.1 billion annually for the entire US urban population.
Sadeghi (2021) [21]	Greening interventions reduced the daily average UTCI by -0.2 to -1.7 °C, decreasing heat-attributable deaths by up to 11.7 per day. This emphasizes the health benefits of urban greening in mitigating heatwave effects.

Positive effect on heat related mortality /morbidity:

Interestingly, three studies included in this review are conducted in Australia. Chen et al. used two scale modelling approach to quantify the effect of then 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 CBD were replaced by vegetated suburbs and planted parklands, respectively.[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 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 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 to 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 to tents, even demonstrating psychological relaxation effects.[18] In the United States, 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 emphasized 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 the 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, 65000 people were taken to the hospital with heat related o lack of access to air conditioning symptoms.[23] Heat related deaths are also reported in countries like 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 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 e.g., 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 wellbeing of urban residents and improves quality of life.

It is also important to accurately measure accessibility to green spaces, for this we propose a multi-dimensional 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 Geographic Information Systems (GIS) 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. Secondly, 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 urbanization patterns and climate change effects. However, it also introduces variability in data due to evolving environmental policies, green space management practices, and socio-economic factors. We discuss the methodological approaches to mitigate these challenges, such as standardizing 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 to 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's 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, socio-economic status, and others.

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CONTRIBUTION STATEMENT: Dr Ahsana Nazish conceptualized, planned the study, undertook the screening process, data extraction, draft writing, and proofread the manuscript. Dr Kiran Abbas undertook the data extraction, analysis, interpretation and draft writing. Dr Emmama Sattar did draft writing and proof reading. Dr Ahsana Nazish is the is responsible for the overall content of the manuscript as guarantor.

DATA SHARING STATEMENT:

Data are available upon reasonable request.

RESEARCH ETHICS APPROVAL: Not applicable

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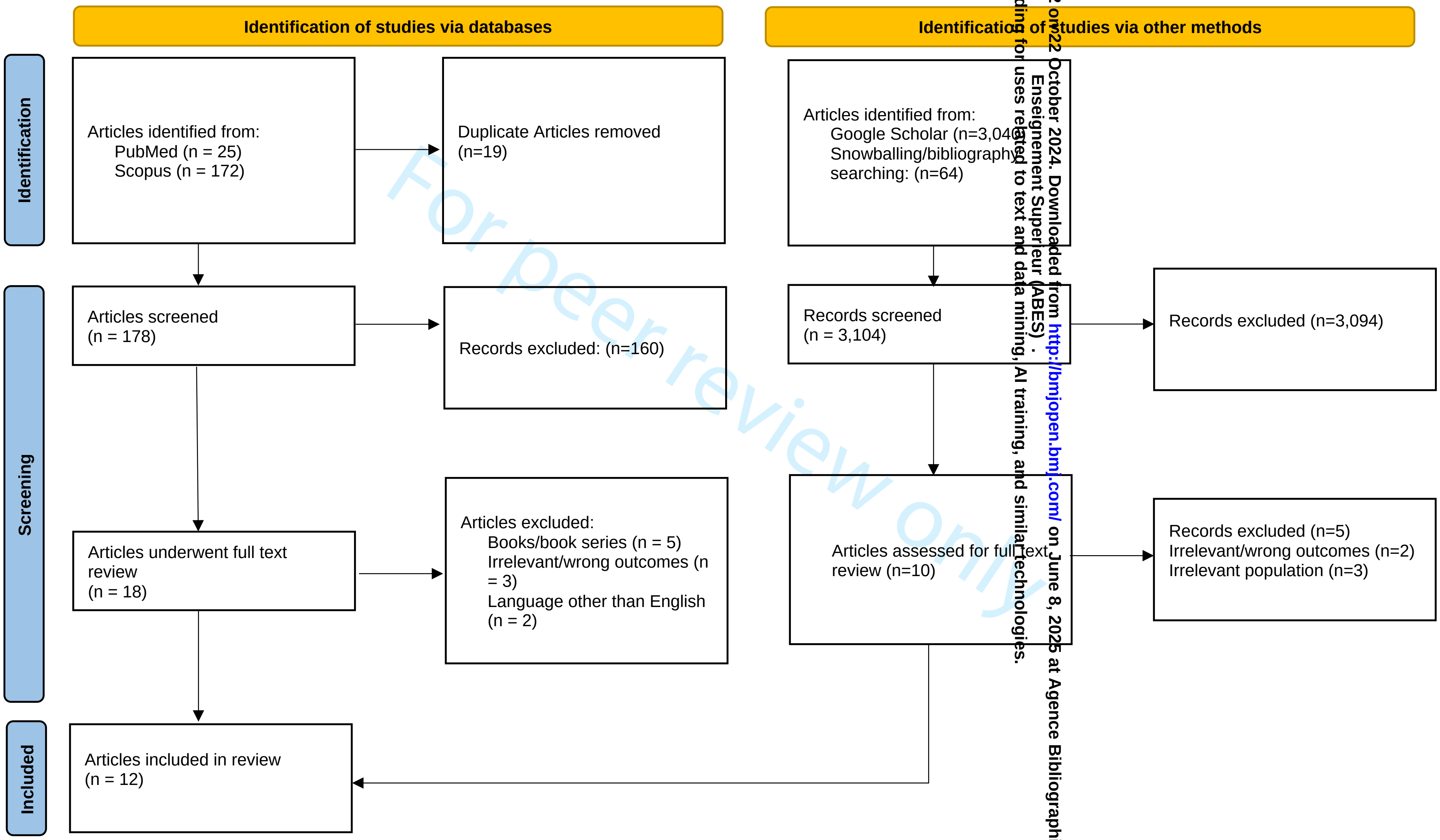
Figure Legend:

Figure 1 - Flow chart

Figure 1: Study search and selection- flow diagram



Supplemental Table S1

Database	Key terms related to 'Urban Green Spaces') AND	Key terms 'Heat-related Morbidity and Mortality'	Combined Keywords
Pubmed	("Urban Green Space"[Title/Abstract] OR "Urban Greenery"[Title/Abstract] OR "Urban Vegetation"[Title/Abstract] OR "Urban Trees"[Title/Abstract] OR "Urban Parks"[Title/Abstract] OR "Urban Green Zones"[Title/Abstract] OR "Green Roofs"[Title/Abstract] OR "Green Infrastructure"[Title/Abstract])	("Heat-related Mortality"[Title/Abstract] OR "Heat-related Morbidity"[Title/Abstract] OR "Heat Stress"[Title/Abstract] OR "Heat Illness"[Title/Abstract] OR "Heat Stroke"[Title/Abstract] OR "Heat Exhaustion"[Title/Abstract] OR "Heat-related Health Outcomes"[Title/Abstract])	("Urban Green Space"[Title/Abstract] OR "Urban Greenery"[Title/Abstract] OR "Urban Vegetation"[Title/Abstract] OR "Urban Trees"[Title/Abstract] OR "Urban Parks"[Title/Abstract] OR "Urban Green Zones"[Title/Abstract] OR "Green Roofs"[Title/Abstract] OR "Green Infrastructure"[Title/Abstract])) AND (("Heat-related Mortality"[Title/Abstract] OR "Heat-related Morbidity"[Title/Abstract] OR "Heat Stress"[Title/Abstract] OR "Heat Illness"[Title/Abstract] OR "Heat Stroke"[Title/Abstract] OR "Heat Exhaustion"[Title/Abstract] OR "Heat-related Health Outcomes"[Title/Abstract])
Scopus	"Urban Green Space" OR "Urban Greenery" OR "Urban Vegetation" OR "Urban Trees" OR "Urban Parks" OR "Urban Green Zones" OR "Green Roofs" OR "Green Infrastructure"	"Heat-related Mortality" OR "Heat-related Morbidity" OR "Heat Stress" OR "Heat Illness" OR "Heat Stroke" OR "Heat Exhaustion" OR "Heat-related Health Outcomes"	"Urban Green Space" OR "Urban Greenery" OR "Urban Vegetation" OR "Urban Trees" OR "Urban Parks" OR "Urban Green Zones" OR "Green Roofs" OR "Green Infrastructure" AND "Heat-related Mortality" OR "Heat-related Morbidity" OR "Heat Stress" OR "Heat Illness" OR "Heat Stroke" OR "Heat Exhaustion" OR "Heat-related Health Outcomes"
Google Scholar	("Urban Green Space" OR "Urban Greenery" OR "Urban Vegetation" OR "Urban Trees" OR "Urban Parks" OR "Urban Green Zones" OR	("Heat-related Mortality" OR "Heat-related Morbidity")	("Urban Green Space" OR "Urban Greenery" OR "Urban Vegetation" OR "Urban Trees" OR "Urban Parks" OR "Urban Green Zones" OR

	"Green Roofs" OR "Green Infrastructure")		"Green Roofs" OR "Green Infrastructure") AND ("Heat-related Mortality" OR "Heat-related Morbidity")

PRISMA 2020 Checklist

Section and Topic	Item #	Checklist item	Location where item is reported
TITLE			
Title	1	Identify the report as a systematic review.	1
ABSTRACT			
Abstract	2	See the PRISMA 2020 for Abstracts checklist.	1
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	2
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	2
METHODS			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	2-3
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	3
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	3, S1
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	3-4
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	3-4
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	3-4
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	3-4
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	3
Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.	4
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	4
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	4
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	4
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	4
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).	N/A
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	N/A
Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	N/A
Certainty	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	N/A

PRISMA 2020 Checklist

Section and Topic	Item #	Checklist item	Location where item is reported
assessment			
RESULTS			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	4
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	Figure 1
Study characteristics	17	Cite each included study and present its characteristics.	4, Table 1,2
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	Table 3, 9-10
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	N/A
Results of syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	4-10
	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	N/A
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	N/A
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	N/A
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	N/A
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	N/A
DISCUSSION			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	16-17
	23b	Discuss any limitations of the evidence included in the review.	16-17
	23c	Discuss any limitations of the review processes used.	17
	23d	Discuss implications of the results for practice, policy, and future research.	17
OTHER INFORMATION			
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	2
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	2
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	N/A
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	18
Competing interests	26	Declare any competing interests of review authors.	18
Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	18

From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi:

PRISMA 2020 Checklist

10.1136/bmj.n71

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