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How green and blue spaces promote health among vulnerable urban populations facing climate hazards. A scoping review

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ABSTRACT

Green and blue spaces contribute to physical, mental, and social well-being, particularly in urban areas and populations with limited access to nature and increasing climate-related stressors. Vulnerable groups, such as older adults, children, and low-income populations, are more susceptible to health and climate risks, while also facing physical and social barriers to accessing these health-promoting spaces. This scoping review synthesizes the current state of knowledge regarding the impact of green and blue spaces on the health and well-being of vulnerable urban populations in the context of extreme climate events, including heat waves and flooding. Following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses checklist for scoping reviews (PRISMA – ScR), we searched the Web of Science database with ASReview assisting in screening, resulting in 28 papers published between 2012 and 2024, included for analysis. Findings confirm a well-established link between green spaces and heat, and highlight the need for further research on specific well-being outcomes for vulnerable groups, including underlying pathways and the unique benefits of blue spaces. We developed an Inclusive Climate and Health Resilience Framework for Urban Spaces that integrates and illustrates the interconnections of these complex components of space, society, and well-being. Future studies should prioritize integrated, interdisciplinary approaches and involve co-designing solutions with affected communities, actively incorporating their diverse perspectives and needs. Health resilience, inclusive urban planning and the development of healthy, climate-resilient cities could be further strengthened through green and blue spaces by applying the Inclusive Climate and Health Resilience Framework for Urban Spaces.

1. Introduction

Green and blue spaces, such as parks, forests, rivers, lakes and other waterways hold benefits for human health. Growing evidence particularly indicates the positive effects on our physical, mental and social health and well-being (Ekkel and de Vries, 2017; Föllmer et al., 2020; McDougall et al., 2024; Völker and Kistemann, 2011). They are linked to health and well-being through different pathways (Markevych et al., 2017). Natural elements in these spaces can reduce stress, fatigue, and mental exhaustion through attention restoration and stress reduction (Barakat and Yousufzai, 2020; Gascón et al., 2015; Kaplan, 1995; Kaplan and Kaplan, 1989; Ulrich et al., 1991). Furthermore, they promote physical activity, social interaction, and nature connectedness to build health capacity (Andreucci et al., 2019; Hunter et al., 2023). Vegetation and water elements in build environments, such as street trees or fountains can reduce population exposure to climate events, as these elements absorb heat and water, with vegetation providing cooling effect through evapotranspiration and shade while filtering air pollutants and noise, enhancing environmental quality (Anderson and Gough, 2021; Kumar et al., 2024).

Studies show that proximity to green and blue spaces is associated with increased levels of physical activity, which in turn contributes to both better physical and mental health outcomes (Coombes et al., 2010; Vich et al., 2019). In fact, the presence of water bodies, such as rivers

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and lakes, alongside green areas create a combined effect that amplifies these benefits. Physical activity near blue spaces is associated with even more positive emotions, better mood outcomes, and reductions of stress levels (White et al., 2019). More generally, environments with blue spaces are ideal locations for people to spend time with friends and family and for promoting positive social relationships (White et al., 2020). On the other hand, green and blue spaces can also have adverse health and well-being effects, e.g., with increased pollination, or exposure to vector-borne diseases risk transmitted by mosquitoes or ticks (Braubach et al., 2017; Heylen et al., 2019).

In urban environments, stressors of city can exacerbate health issues. One of the pressing concerns is the increasing impacts of climate-related hazards, as extreme weather events are becoming more frequent and intense. These effects are exacerbated in urban areas due to factors like impermeable surfaces and high population densities, which amplify the intensity and impact of climate stressors. This highlights the importance of urban green and blue spaces for health resilience. During heatwaves, publicly accessible natural or built blue spaces provide cooling and relaxation, and urban green spaces such as parks or forests provide shading, thereby serving as vital health-promoting spaces. During flooding, green spaces, whether natural or human-made, offer flood retention and relief as they transition from green into blue spaces, such as bioswales or rainwater playgrounds (Hunter et al., 2023; Völker and Kistemann, 2011).

Studies have shown that individuals living in greener environments with or without water bodies report better self-rated health, suggesting that the restorative, capacity building and mitigating qualities of these spaces are vital for promoting resilience of urban populations (Wang, 2024). These and similar contextual factors, related to social, economic or institutional structures, shape vulnerability. However, these factors remain underreported in public health research (Rodgers et al., 2025). Therefore, it is important to consider the complexity of a population's vulnerability.

Individual or group position, based, for example, on demographic and socio-economic characteristics, contributes to vulnerability. In this context, age as a demographic factor, increases sensitivity to environmental and health effects. Income or minority status can affect people's capacity to respond to these effects. Diverse vulnerable groups are at high risk of adverse health and climate effects (Cassarino et al., 2021). For this reason, they can particularly benefit from green and blue spaces (Nawrath et al., 2021; Rigolon et al., 2021). Yet, they often miss out on these health benefits due to several barriers.

Another important factor is geographic location. Vulnerable communities are more likely to live in densely built-up urban areas with fewer green spaces (Anguelovski et al., 2022). Even when such spaces are nearby, physical barriers like highways or busy roads can restrict access and contribute to noise pollution (Aiello et al., 2025). Accessibility is a major factor in park usage among low-income communities, with closer proximity often resulting in higher engagement (Cohen-Cline et al., 2015). In addition to limited availability and access constraints, the quality of green spaces in disadvantaged areas is often poorer, with fewer and lower-quality amenities (Dobbinson et al., 2020) and inadequate maintenance. Overgrown vegetation, litter, and damaged facilities can reduce satisfaction and discourage use (Xian et al., 2024). Social factors such as safety concerns, particularly for women, children, and older adults (Chenyang et al., 2022; Derose et al., 2019) and experiences of discrimination or exclusion faced by minority groups (Stjernborg et al., 2014) can further discourage use. As a result, vulnerable populations are less likely to fully experience the physical, mental and social health benefits that green and blue spaces can provide, while facing greater exposure to increasing extreme climate events that can further exacerbate their vulnerable situation.

Factors shaping vulnerability further expand into environmental justice dimensions - distributional, procedural and recognitional. Existing frameworks structure these dimensions in a form of an iceberg, showing visible and invisible challenges (Loos et al., 2022; Zuniga-Teran et al., 2021). The previously mentioned geographic factor is related to distribution, where challenges of accessibility and availability are often visible. In turn, procedural justice concerns who is involved in decision-making and how decisions are made. Procedural processes are not always transparent or accessible to everyone. One layer deeper is recognitional justice, to recognize and understand the diversity of involved people's perspectives, experiences and identities, especially vulnerable populations.

Overall, the relationship between green and blue spaces, health and well-being among vulnerable urban populations, and climate events is complex and not yet fully understood. While research has examined individual aspects of these topics, there is a lack of comprehensive studies that integrate the multiple interconnections between these factors. This review aims to address this gap by synthesizing existing research to provide a comprehensive understanding of how green and blue spaces influence the positive health effects and well-being of vulnerable urban populations, particularly in the context of extreme climate events. In this study, vulnerable groups refer to populations who we hypothesize to have limited capacity to cope with the effects of the extreme climate events due to health-related, social, economic or other factors. These groups include, for example, older adults, persons with disabilities, children, ethnic minorities or low-income populations. Based on the review's findings, an *Inclusive Climate and Health Resilience Framework for Urban Spaces* was developed to illustrate the complex links between these topics.

2. Methods

To identify and understand the links between green and blue spaces, health and well-being, vulnerable population groups, and climate events in cities, a research topic which i) is complex in terms of types of impact and systems involved, ii) understudied and iii) combines different knowledge gaps, we chose a scoping review approach. We chose a scoping review over a systematic review as our main aim was to scope the available body of literature, identify knowledge gaps, link different dimensions and concepts and clarify these links, and develop a framework based on this (Munn et al., 2018). We followed the five-stage scoping review framework defined by Arksey and O'Malley (2005) and advanced by Levac et al. (2010), identifying the research question and relevant results, selecting studies, extracting information from included studies, and reporting results. Questions that we aimed to address with this review are:

1. What are the characteristics of the selected studies, in terms of research discipline, geographical context, and content specifications?
2. What approaches and methods have been used to study the links between the positive effects of urban green and blue spaces, health and well-being and vulnerable population groups in the context of extreme climate events?
3. What does the literature reveal about the existing links between green and blue spaces, health and well-being among vulnerable population groups and extreme climate events in urban areas?

2.1. Search strategy

In an iterative process, a search strategy was developed to identify the peer-reviewed literature relevant to these research questions, and based on it, a review was executed between April and November 2024. Due to the complexity of our scoping search and review, and the multitude and diversity of topics and concepts covered and linked, our search strategy and search string became comprehensive, and very detailed. After being refined with Web of Science, the database which we identified to best cater for our search needs, the search strategy was tested for Scopus and MEDLINE (via PubMed). Due to a search limit of

50 terms (Scopus) and irrelevant results (MEDLINE), both databases were excluded, and only Web of Science was searched for peer-reviewed literature. While this limitation may have resulted in missing potentially relevant studies from those sources, the comprehensive search and analysis conducted within the Web of Science database provides a robust foundation for understanding the key themes and findings within the existing literature on this topic. Furthermore, only publications in English were considered, which may have led to the exclusion of relevant studies published in other languages. This entails the risk of excluding relevant locally published studies. However, including non-English sources would have required at least one native or fluent speaker to appropriately extract and analyse the content.

We conducted this literature search in adherence with the preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklist for scoping reviews (PRISMA – ScR) (Fig. 1) (Moher et al., 2016). We divided our search terms into five blocks, namely: green and blue spaces (Block 1); health and well-being (Block 2); vulnerable population groups (Block 3); extreme climate events (Block 4) and urban (Block 5). Blocks were combined using the boolean operator AND, while search terms within the blocks were connected with the boolean operator OR. The detailed search strategy applied for Web of Science database is provided in Supplementary file 1.

We executed our scoping review with the help of ASReview (Van de Schoot et al., 2021), an open-source AI-based programme that uses state-of-the-art active learning techniques in screening large amounts of text. ASReview aims is to save reviewing time by rearranging the order of publications in which they need to be screened. This is done by a machine learning algorithm which is trained based on starting literature (training data) and each decision of relevant or irrelevant publication made by the reviewer during the screening process. Five relevant and five irrelevant publications were selected as starting literature with the help of the filter option from most to least relevant in Web of Science. In this case, we screened all publications using ASReview, thus, not using the advantage of time-saving of the tool in favour of a fully comprehensive and complete early-stage understanding of the literature.

2.2. Selection of studies

In the ASReview environment, titles and abstracts of each publication were screened by one reviewer and checked against the inclusion and exclusion criteria for a full-text review (Table 1). Only studies that met the criteria and were relevant to the research questions were included. The screening process included studies related to green and/or blue spaces and studies focused on enhanced human health and well-being, particularly for vulnerable groups. This was done in a two-step process, as shown in Fig. 1, first, by identifying studies that focus on human health and well-being, and second, by assessing whether it includes vulnerable groups. To account for extreme climate events, studies related to heat, floods, or other climate hazards were considered. With regards to location, only studies conducted in urban and peri-urban areas were considered eligible. There were no publication date restrictions.

Table 1
Inclusion and exclusion criteria for the scoping review of literature on how green and blue spaces promote health among vulnerable urban populations facing climate hazards.

Criteria	Inclusion	Exclusion
Type of space	Related to green and/or blue spaces*	Related to other types of spaces
Vulnerable groups**	1. Related to population groups 2. Related to vulnerable population groups	1. Not related to population group 2. Not related to vulnerable population group
Health and well-being	Related to effects on well-being, in form of physical, mental or social health	Not related to well-being or related to negative effects on health and/or well-being
Extreme climate events	Related to heat and/or floods and/or other climate-related extreme events	Not related to heat and/or floods and/or other events
Location	Study was conducted in urban or peri-urban area	Study was conducted in rural, or non-defined area
Language	Published in English	Not in English
Type of publication	Reporting empirical research and new data or analysis	No new data or analysis (e.g., literature review, opinion piece)

* We follow Jones et al. (2022), who distinguish between green and blue spaces, considering i) gardens, ii) parks, iii) amenity areas, iv) other public space, v) linear features/routes, vi) constructed green; and blue space on infrastructure, vii) hybrid green and blue space for water, viii) water bodies, ix) other non-sealed urban areas.
** Vulnerable groups refer to populations who we hypothesize to have limited capacity to cope with the effects of the extreme climate events due to health-related, social, economic or other factors. These groups include, for example, older adults, persons with disabilities, children, ethnic minorities or low-income populations.

2.3. Data extraction and analysis

The information extracted from each included study comprised: (i) study characteristics (e.g., year of publication, country of data collection, setting details, study population), (ii) methodological approach (e.

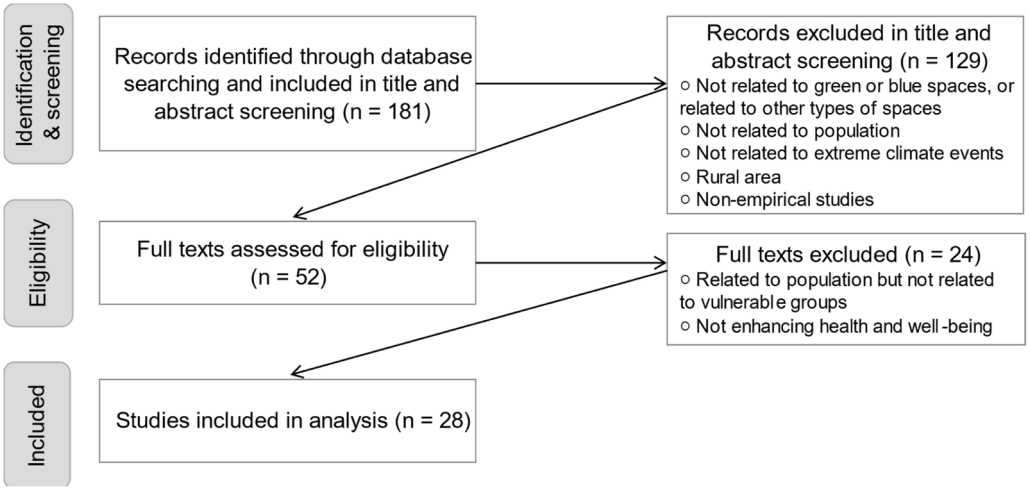

Fig. 1. PRISMA flowchart for the scoping literature review on how green and blue spaces promote health among vulnerable urban populations facing climate hazards, based on n = 28 publications (2012-2024).

g. objective, methods, index used, limitations), and (iii) a summary of those findings relevant to answer our research questions. Methodological approaches were classified into (a) geospatial, if they collected, used or analysed geodata or satellite imagery; (b) tech / sensor, if they used other technological approaches or sensor data; (c) health, if they measured health indicators or collected human samples; (d) social / behaviour, if they collected social and behavioural data and information; (e) co-creation, if they involved citizens or stakeholders in the design of the method. After extraction, data were tabulated to identify trends across studies and contextualize and synthesize results (Table 2 and Table 3). Based on the results of this review, the complex links between green and blue spaces, health and well-being among vulnerable population groups, and extreme climate events in cities were operationalized and displayed in our *Inclusive Climate and Health Resilience Framework for Urban Spaces* framework (Fig. 2).

3. Results

3.1. Search results, study characteristics and content specifications

The screening process used for this scoping review is detailed in Fig. 1 and resulted in 28 studies included in the final analysis (Table 2). Based on the published studies, the trend points to a growth in literature linking green and blue spaces, health and well-being among vulnerable population groups, and effects of extreme climate events in cities over the past twelve years (2012-2024). This research was conducted across a wide range of disciplines, including Environmental Psychology, Public Health, Social and Behavioural Sciences, Urban Planning, Community Engagement, Environmental Sciences, Landscape Architecture, Health Geography and Public Policy. While the studies cover a wide geographical range, they mainly focused on the United States (n=9, 32%), China (n=8, 29%), countries in Europe (n=6, 21%), with additional insights from other countries (n=5, 18%). An overview of this study distribution is illustrated in Fig. 2.

The following sections provide an overview of green and blue spaces, various health and well-being outcomes, diverse vulnerable population groups, and extreme climate effects in cities and their links that are covered in the reviewed studies (Table 3 and Fig. 2). While all the reviewed studies include empirical assessments on green or blue spaces, their links to well-being of vulnerable groups or climate hazards are either empirically assessed or conceptually grounded. Table 3 indicates which studies offer in-depth analysis and which focus on conceptual connections between the studied topics.

Mark with ‘x’ indicates that the topic is analysed in-depth. Mark with ‘o’ indicates that the study considers the topic on a conceptual level. Regarding category of vulnerable groups, ‘o’ indicates that the study analyses general public while including vulnerable groups, and boxes around marks indicate that components of vulnerability are treated in isolation, not as a composite. Nine studies highlighted in grey analyse all the topics in-depth.

We found that eight studies (29%) considered green space in a city or study area context as the land that is covered with vegetation (Carrier et al., 2016; Chen et al., 2021; Fusaro et al., 2023; Gruebner et al., 2012; Kucera and Janerette, 2023; Neier et al., 2023; Sabrin et al., 2020; Xiong et al., 2023). Similarly, some studies focused on trees in cities (de Guzman et al., 2022; Lanza et al., 2023; McDonald et al., 2021; Nyelele and Kroll, 2020; Pena et al., 2024). On a unit-level, seven studies looked at parks (Arifwidodo and Chandrasiri, 2020; Du et al., 2021; Duan et al., 2018; Kabisch and Kraemer, 2020; Ma et al., 2021; Yung et al., 2019; Zhang et al., 2021), five studied green schoolyards or playgrounds (Huang et al., 2021; Lanza et al., 2023; Olsen et al., 2019; Raney et al., 2023; Tarpani et al., 2023), and few looked at in- or outdoor greening measures (Borzino et al., 2020; Halbmayer et al., 2021; Murtagh and Frost, 2023). From all these studies that considered any type of green space, nine (32%) also addressed blue spaces, spanning various spatial scales. Some looked at it at a broader scale and considered any waterbodies in the study area (Lanza et al., 2023; Sabrin et al., 2020), one specified wetland as the land cover type (Xiong et al., 2023). The majority of these studies focused on parks or playgrounds with water features, ranging from large-scale lakes (Duan et al., 2018; Ma et al., 2021) and water bodies (Huang et al., 2021; Du et al., 2021) to smaller-scale elements such as fountains and ponds (Kabisch and Kraemer, 2020; Yung et al., 2019). Only one study focused on blue spaces in the context of flood risk, considering water coverage and proximity to rivers in slums (Gruebner et al., 2012) (Table 3).

Studies addressed health and well-being in different ways and often multiple outcome categories were analysed. Physical health (n=25, 89%) received the most attention, followed by mental health (n=17, 61%), and social health (n=10, 36%). Of all 28 studies, 13 studies (46%) addressed health and well-being in-depth. Aspects of physical activities (Kabisch and Kraemer, 2020; Murtagh and Frost, 2023), thermal comfort (Halbmayer et al., 2021; Tarpani et al., 2023), heat-related health risks (Huang et al., 2021; Lanza et al., 2023), emotional balance (Du et al, 2021; Lanza et al., 2021), cognition (Duan, 2018), life satisfaction (Arifwidodo and Chandrasiri, 2020; Gruebner et al., 2012) and social interactions (Raney et al., 2023; Yung et al., 2019) were examined.

While all included studies focused on vulnerable population groups, the specific study populations varied. Low-income populations (n=18, 64%), vulnerable age groups of older adults (n=14, 50%), and children (n=11, 38%) were covered the most. Fewer studies focused on ethnicity or race (n=10, 31%), populations in vulnerable urban environments, such as highly dense or polluted urban areas or poor housing conditions (e.g., slums) (n=9, 31%), gender (n=7, 25%), or occupation (n=5, 22%). Low education level received the least attention in the reviewed studies (n=4, 13%). Almost all studies addressed more than one component of vulnerability. Twenty studies (61%) created a composite from factors of vulnerable populations, such as residents of colour in a low-income community (Lanza et al., 2023). Others analysed these components in isolation (n=8, 29%), for example, Carrier et al. (2016) found disparities by income and by children age group. Furthermore, four studies primarily focused on the general public but also included vulnerable groups (Table 3).

Regarding extreme climate events in cities, heat was the most addressed event (n=26, 93%), floods (n=9, 32%), and other stressors such as air pollution (n=9, 32%) received less attention. Moreover, some studies addressed two or more of extreme events simultaneously (Duan et al., 2018; Murtagh and Frost, 2023; Nyelele and Kroll, 2020; Sabrin et al., 2020; Tarpani et al., 2023). Among the 28 studies, 20 (71%) provided an in-depth analysis of climate events, while the remaining studies conceptually discussed and linked to other themes, such as health or vulnerable populations, without detailed investigation (Table 3).

Each circle on the map represents a country where relevant studies have been conducted, with the size of the circle reflecting the number of publications, larger circles indicate more studies. The colour of each circle identifies the focus of the studies: green for articles on green spaces only, and a mix of blue and green for those addressing both blue and green spaces.

3.2. Methodological approaches

This review section summarizes the methods applied in 28 articles, categorising methods into geospatial, technological, health, social and co-creation, as outlined and explained in Table 2. A large number of studies (n=19, 68%) used geospatial approaches with satellite data and spatial analyses to assess urban vegetation, green space accessibility, urban heat islands, and environmental equity. Technological approaches (n=10, 36%), such as sensor-based environmental measurements, were less common but provided insights into thermal conditions, humidity, and other environmental parameters. Health-related methods (n=8, 29%) focused on self-reported health in terms of symptoms related to high heat, thermal comfort, levels of physical activity,

Table 2
Articles identified in the scoping search meeting criteria on green and/or blue spaces, vulnerable population groups, health and well-being, extreme climate events and urban or peri-urban areas (n=28, 2012-2024).

Author (year)	Title	Objective	Method	Geo-spatial	Tech/ Sensor	Health	Social/ Behaviour	Co-creation
Arifwidodo & Chandrasiri (2020)	Urban heat stress and human health in Bangkok, Thailand	Understand urban factors contributing to heat stress and its health impacts using self-reported assessments.	Quantitative assessment of urban heat stress.		x	x		
Borzino et al. (2020)	Willingness to pay for urban heat island mitigation: a case study of Singapore	Assess Singaporeans' willingness to pay for urban heat mitigation	Spatial and qualitative analysis of urban heat island effect and willingness to pay for interventions.	x			x	
Carrier et al. (2016)	Application of a global environmental equity index in Montreal: diagnostic and further implications	Construct an environmental equity index and analyse its impact on vulnerable groups in urban areas	Spatial analysis of urban heat island effect.	x	x		x	
Chen et al. (2021)	Can smaller parks limit green gentrification? Insights from Hangzhou, China	Assess the potential gentrification effects of a new public green space in the urban central area	Quantitative and remote sensing assessment of green gentrification.	x			x	
de Guzman et al. (2022)	A socio-ecological approach to align tree stewardship programs with public health benefits in marginalized neighbourhoods in Los Angeles, USA	Evaluate the Tree Ambassador program in Los Angeles to address urban forest equity and well-being.	Mixed methods socio-ecological approach to align tree stewardship programme with public health benefits in marginalized neighbourhoods.				x	
Du et al. (2021)	Influence of features of green spaces on health and well-being: case study of Shanghai, China	Investigate which urban green space features influence health and well-being.	Quantitative analysis of the impact of green spaces on health and well-being.				x	
Duan et al. (2018)	Perception of urban environmental risks and the effects of urban green infrastructures (UGIs) on human well-being in four public green spaces of Guangzhou, China	Investigate urban green infrastructure users' perceptions of its effects on the environment and their relationship with sociodemographic variables.	Quantitative assessment of urban green space user perceptions of positive and negative effects of green space, and their relationship with sociodemographic variables.			x	x	
Fusaro et al. (2023)	Supply and demand mismatch analysis to improve regulating ecosystem services in mediterranean urban areas: insights from four Italian municipalities	Assess air quality ecosystem service mismatches across Italian cities seasonally.	Spatial analysis of regulating ecosystem services.	x		x	x	
Gruebner et al. (2012)	Mental health in the slums of Dhaka - a geoepidemiological study	Identify factors that contribute to the mental well-being in the slums of Dhaka.	Geo-epidemiological approach to understand mental health in slums.	x		x	x	
Halbmayer et al. (2021)	Green: cool & care—research and development of greening measures in nursing homes in Austria. Technical and social interconnections	Develop, implement and evaluate greening measures in nursing homes that improve the living conditions and well-being of elderly residents.	Quantitative assessment of effects of greening measures in nursing homes, combining technical and social considerations and methods through co-design approach.		x		x	x
Huang et al. (2021)	Outdoor thermal benchmarks and thermal safety for children: a study in China's cold region	Evaluate children's thermal perception and propose bioclimatic park design strategies.	Quantitative assessment of outdoor thermal benchmarks and thermal safety for children.	x	x		x	
Kabisch & Kraemer (2020)	Physical activity patterns in two differently characterised urban parks under conditions of summer heat	Investigate urban park designs' effects on usage and accessibility across age groups during heat and drought.	Quantitative assessment of physical activity patterns in urban parks under conditions of summer heat.		x		x	
Kucera & Janerette (2023)	Urban greenness and its cooling effects are influenced by changes in drought, physiography, and socio-demographics in Los Angeles, CA	Evaluate how aridity, water demand, and income influence heat distribution and equity in neighbourhoods.	Quantitative assessment of urban greenness and cooling effects related to changes in drought, physiography, and socio-demographics.	x			x	
Lanza et al. (2023)	Heat vulnerability of Latino and black residents in a low-income community and their recommended adaptation strategies: a qualitative study	Assess heat-related health impacts, vulnerability, and adaptation strategies among economically vulnerable Latino and Black residents in a high urban heat island area.	Qualitative assessment of heat vulnerability of Latino and Black residents in a low-income community and co-design by recommending adaptation strategies.			x	x	x
Lanza et al. (2021)	Effects of trees, gardens, and nature trails on heat index and child health: design and	Evaluate how school park green features affect children's heat exposure, activity, and well-being.	Spatial analysis on the effects of trees, gardens, and nature trails on heat index and child health.	x	x		x	

(continued on next page)

Table 2 (*continued*)

Author (year)	Title	Objective	Method	Geo-spatial	Tech/ Sensor	Health	Social/ Behaviour	Co-creation
	methods of the green schoolyards							
Ma et al. (2021)	How to design comfortable open spaces for the elderly? Implications of their thermal perceptions in an urban park	Investigate elderly visitors' thermal comfort and health needs in parks to improve design.	Spatial and mixed method analysis on design of open spaces for older adults.	x	x	x	x	
McDonald et al. (2021)	The tree cover and temperature disparity in us urbanized areas: quantifying the association with income across 5,723 communities	Examine tree cover inequality by comparing tree cover and land surface temperature between low-income and high-income blocks and estimate the investment needed to address this gap	Spatial analysis of tree cover and temperature disparity in urbanized areas.	x			x	
Murtagh & Frost (2023)	Motivations for urban front gardening: a quantitative analysis	Explore and categorize the motivations of urban and suburban dwellers for front gardening.	Quantitative assessment of motivations for urban front gardening.				x	
Neier (2023)	The green divide: a spatial analysis of segregation-based environmental inequality in Vienna	Assess urban vegetation inequality among ethnic minorities using segregation-based indices.	Spatial analysis of segregation-based environmental inequality.	x				
Nyelele & Kroll (2020)	The equity of urban forest ecosystem services and benefits in the Bronx, NY	Explores the distribution of ecosystem services and benefits provided by tree cover.	Spatial and quantitative assessment on relationship between ecosystem service, values (monetary benefits), socio-demographic and socio-economic variables.	x			x	
Olsen et al. (2019)	Shade provision in public playgrounds for thermal safety and sun protection: a case study across 100 play spaces in the United States	Assess the safety and health risks of playgrounds based on temperature and UV exposure	Spatial and quantitative assessment of shade provision in public playgrounds (public parks, schools) for thermal safety and sun protection.	x	x		x	
Pena et al. (2024)	The street tree distribution across a streetscape reflects the social inequality of Latin American cities	Examine the relationship between socioeconomic and the distribution and diversity of street trees	Spatial analysis of street tree distribution across a streetscape, and association with social inequality.	x				
Raney et al. (2023)	Impact of urban schoolyard play zone diversity and nature-based design features on unstructured recess play behaviours	Examine the impact of schoolyard design features and green space on children's recess play behaviours	Qualitative assessment of impact of urban schoolyard play zone diversity and nature-based design features on unstructured recess play behaviours in low-income neighbourhoods.	x		x	x	
Sabrin et al. (2020)	Developing vulnerability index to quantify urban heat islands effects coupled with air pollution: a case study of Camden, NJ	Assess combined urban heat islands and air pollution effects on human health in the economically distressed city.	Spatial assessment and development of vulnerability index to quantify urban heat island's effects coupled with air pollution.	x			x	
Tarpani et al. (2023)	On kids' environmental well-being and their access to nature in urban heat islands: hyperlocal microclimate analysis via surveys, modelling, and wearable sensing in urban playgrounds	Develop and test a wearable device for assessing children's environmental exposure outdoors	Mixed method assessment of kids' environmental well-being and their access to nature in urban heat islands.	x	x		x	
Xiong et al. (2023)	Environmental inequalities in ecosystem services benefits of green infrastructure: a case study from China	Evaluate green infrastructure contributions to well-being, equity, and urban heat mitigation in metro areas	Spatial analysis of environmental inequalities in ecosystem services benefits of green infrastructure.	x				
Yung et al. (2019)	Thermal perceptions of the elderly, use patterns and satisfaction with open space	Examine older adults' thermal perceptions and their satisfaction with open space designs.	Quantitative assessment of thermal perceptions of older adults, use patterns and satisfaction with open space.		x	x	x	
Zhang et al. (2021)	Accessibility of urban park benefits with different spatial coverage: Spatial and social inequity	Investigate urban park benefits' accessibility and examine the benefit relation to socioeconomic status and demographic factors.	Spatial analysis of accessibility of urban park benefits with different spatial coverage considering spatial and social inequity	x				

Methodological approaches were classified into (a) geo-spatial, if they collected, used or analysed geodata; (b) tech / sensor, if they used technological approaches or sensor data; (c) health, if they measured health indicators or collected human samples; (d) social / behaviour, if they collected social and behavioural data and information; (e) co-creation, if they involved citizens or stakeholders in the design of the method.

Table 3
Content covered by literature included in review, related to green and/or blue spaces, health and well-being, vulnerable population groups, extreme climate events in urban and peri-urban areas (n=28, 2012-2024).

	Spaces		Health			Vulnerable groups								Climate			
Author (year)	Green	Blue	Physical	Mental	Social	Gender	Older adults	Children	Income	Ethnicity	Occupation	Education	Environment*	Heat	Floods	Others	Urban
Arifwidodo and Chandrasiri (2020)	x		x	x					x				X	x			x
Borzino et al. (2020)	x		o						o					x			x
Carrier et al. (2016)	x		o	o	o		x	x	x	x			X	o		o	x
Chen et al. (2021)	x		o	o			x				x	x		o	o		x
de Guzman et al. (2022)	x		x	x					x	x				x			x
Du et al. (2021a)	x	x	x	x	x	o	o		o		o	o		o			x
Duan et al. (2018)	x	x	x	x	x	o	o							x	x	x	x
Fusaro et al. (2023)	x		o				x	x					X			x	x
Gruebner et al. (2012)	x	x		x		x			x	x		x	X		x		x
Halbmayer et al. (2021)	x		x	o			x							o			x
Huang et al. (2021)	x	x	x			x		x						x			x
Kabisch and Kraemer (2020)	x	x	x		x		x	x						x			x
Kucera and Janerette (2023)	x		o						x	x				x			x
Lanza et al. (2023)	x	x	x	x	x				x	x				x			x
Lanza et al. (2021)	x		x	x				x	x	x				x			x
Ma et al. (2021)	x	x	x	o			x							x			x
McDonald et al. (2021)	x		o						x				X	x			x
Murtagh & Frost (2023)	x		x	x	x	o	o		o	o	o		o	x	x		x
Neier (2023)	x		o	o					x	x				o	o	o	x
Nyelele and Kroll (2020)	x		o	o	o				x	x			x	x	x	x	x
Olsen et al. (2019)	x		o	o				x						x			x
Pena et al. (2024)	x		o	o			x	x	x					o	o	o	x
Raney et al. (2023)	x		x		x	x		x	x					o			x
Sabrin et al. (2020)	x	x					x	x	x				x	x		x	x
Tarpani et al. (2023)	x		x					x						x		x	x
Xiong et al. (2023)	x	x	o				x		x		x		x	x	x		x
Yung et al. (2019)	x	x	x		x	x	x		x		x			x			x
Zhang et al. (2021)	x			o	o		x	x			x			o	o	o	x

*Environment refers to vulnerability in poor housing conditions or urban setting such as highly dense or polluted area.

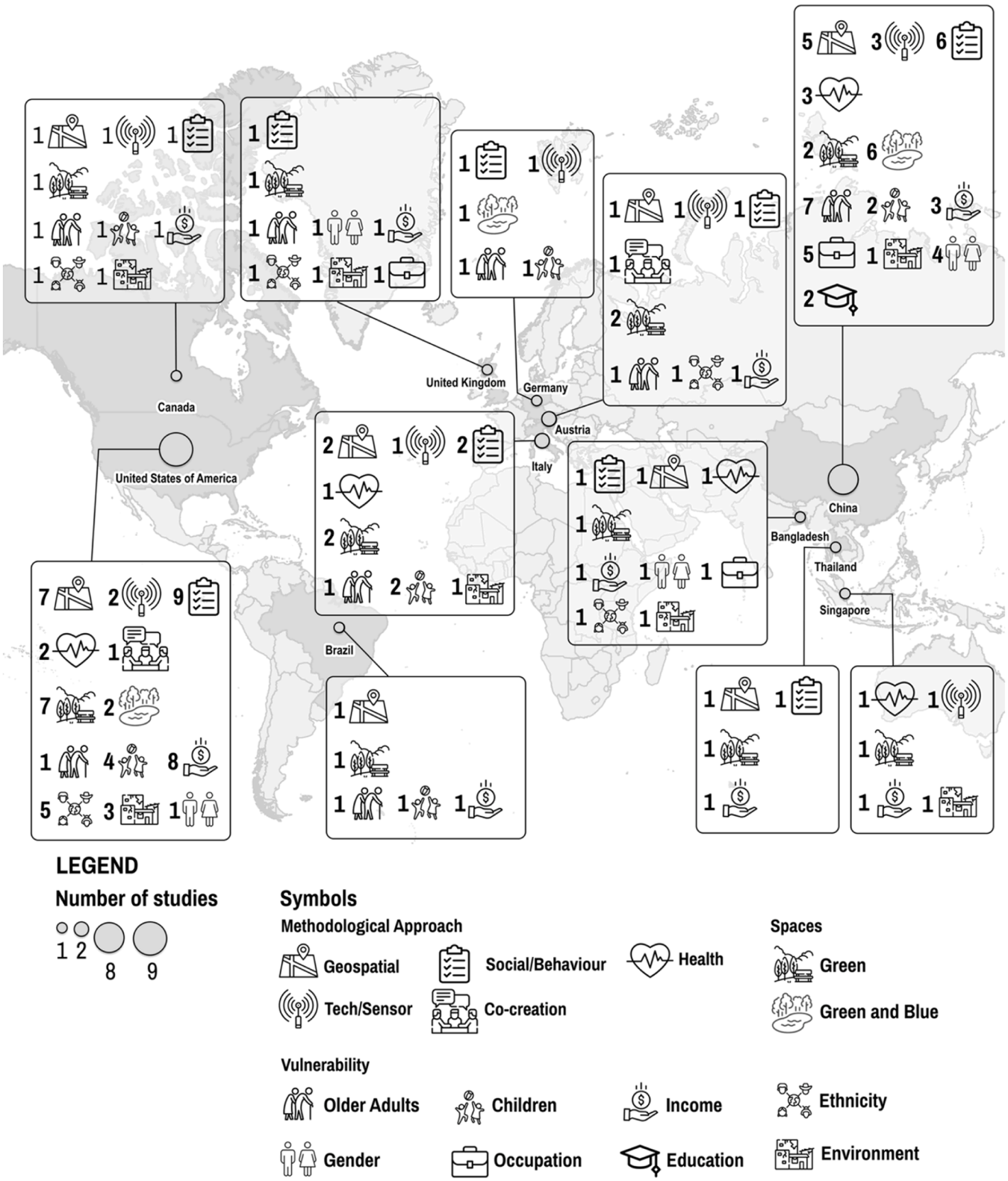

Fig. 2. Spatial distribution of peer-reviewed publications addressing green and/or blue spaces in relation to vulnerable populations, health and well-being, and extreme climate events in urban or peri-urban areas (n=28, 2012 - 2024).

emotional balance, cognitive capacity, and life satisfaction, particularly in relation to urban green and blue spaces. The review reveals a major use of social science-based methods (n= 23, 82%) with surveys being the most common tool, along with other methods of in-depth interviews, go-along interviews, and observational studies. Co-creation approaches were rare (n=2, 7%) and these studies showed participatory engagement taking place in nursing homes and low-income communities of colour (Halbmayer et al., 2021; Lanza et al., 2023).

Between these five categories, we also found integration of approaches, which involved combining quantitative and qualitative

methods. One study (4%) had the highest integration by using mixed methods and combining four different approaches (geospatial, technical, health, social) to investigate how parks affect thermal comfort, health, and activity of older adults (Ma et al., 2021). Furthermore, ten studies (36%) combined three approaches to study environmental justice (Carrier et al., 2016; Fusaro et al., 2023), greening measures (Halbmayer et al., 2021; Lanza et al., 2021; Raney et al., 2023), and health (Gruebner et al., 2012; Huang et al., 2021; Olsen et al. 2019; Tarpani et al., 2023; Yung et al., 2019). Two approaches were combined in ten studies (36%), which mainly focused on urban heat (Arifwidodo and Chandrasiri, 2020; Borzino et al., 2020; Kucera and Janerette, 2023), heat vulnerability (Lanza et al., 2023; Sabrin et al., 2020), environmental equity (Chen et al., 2021; McDonald et al., 2021; Nyelele and Kroll, 2020), greening measures (Duan et al., 2018), and green space user patterns (Kabisch and Kraemer, 2020). The remaining seven studies (24%) used one approach, either geospatial or social science-based, which were also the most employed approaches across all studies.

While our scoping review aimed at identifying what approaches and methods have been used to study the links between *positive* effects of urban green and blue spaces, health and well-being, and vulnerable population groups in the context of extreme climate events, the included studies (n=28) did not exclusively consider positive effects. Two included studies also addressed *negative* health effects such as infectious diseases and adverse mental health (using tree approaches, see Gruebner et al., 2012) and well-being effects of flooding (using two approaches, see Duan et al., 2018).

3.3. Links between the topics covered

3.3.1. Health and well-being promotion

The reviewed literature reveals that green and blue spaces promote physical, mental and social health and well-being among vulnerable population groups. This link reflects nature's non-material contribution to health and unfolds through two interconnected pathways: the physical, mental and social experiences these spaces afford, and their role in regulating extreme climate events.

Green and blue urban fabrics provide spaces for experiences that promote health across physical, mental and social dimensions. Physical health is enhanced through physical activities such as walking, exercising, playing and gardening. These behaviours are encouraged by intrinsic motivations (Murtagh and Frost, 2023) and by the design of green spaces and their functional features. These include parks (small or large) with walkways, lawns, fitness facilities (Du et al., 2021; Duan et al., 2018; Ma et al., 2021), or green playgrounds (Kabisch and Kraemer, 2020) and schoolyards (Raney et al., 2023). Both physical and sedentary activities in natural surroundings provide benefits for mental health. Biodiverse greenery and water bodies offer calming effects that restore emotional balance, reduce stress, support cognitive function and overall life satisfaction (Du et al., 2021; Gruebner et al., 2012; Halbmayer et al., 2021; Lanza et al., 2023). Du et al. (2021) found that water bodies with floating platforms, along with accessible lawns, were essential design features of urban green spaces that positively influenced overall health and various aspects of well-being, such as relaxation, enhanced communication, calming effects, as well as promoting fitness, vitality, and proactivity. In addition, these spaces offer opportunities to improve social health among vulnerable groups. They facilitate structured and unstructured social interactions that enable social connectedness and cohesion (Du et al., 2021; Lanza et al., 2023). Together, these diverse benefits gained in green and blue spaces promote public health.

Simultaneously, nature promotes health through climate regulating processes. Benefits of areas with more green and blue spaces include reduced air temperature, higher-capacity stormwater management, and better air quality compared to those with fewer such spaces. Consequently, these lower human exposure to heat, flooding, and air pollution. Vegetation and water bodies absorb heat, creating a cooling effect, which provides the primary health benefit of (hydro)thermal comfort to humans (Huang et al., 2021; Halbmayer et al., 2021). At the city scale, Sabrin et al. (2020) highlighted water fraction and proportional vegetation among four key environmental factors influencing heat and air quality vulnerability in an economically disadvantaged city with a primarily minority population. Furthermore, vegetation helps reduce flood risks by capturing, absorbing, and reducing water runoff. Meanwhile, air pollution is mitigated as vegetation absorbs pollutants such as carbon dioxide and nitrogen oxides (Carrier et al., 2016). Park users also strongly believe in the benefits of urban green infrastructure for well-being and mitigation of environmental health risks, particularly in improving air quality and reducing heat, more so than flooding (Duan et al., 2018).

3.3.2. Adverse health effects of extreme climate events

Some of the 28 included studies indicated adverse health effects from climate events, such as heat waves, floods and in some studies in combination with air pollution. Children and older adults are especially sensitive to heat due to the limitations of their thermoregulatory systems (Lanza et al., 2023; Ma et al., 2021; Tarpani et al., 2023). As temperatures rise, the number of children and older adults visiting green spaces decreases and those present seek shade to protect their health (Kabisch & Kraemer, 2021; Lanza et al., 2021; Olsen et al., 2019; Yung et al., 2019). Under heat exposure, individuals may experience mild short-term effects (sunburns, fatigue, headaches, nausea, dizziness, trouble breathing) to moderate health consequences (heat stress during sleep, daily travel, work and exercise), or even severe cardiovascular and respiratory problems. These health-related problems further influence mental health, including lower life satisfaction, reduced energy levels, and emotional problems (Arifwidodo and Chandrasiri, 2020; Lanza et al., 2023).

Under disadvantageous environmental and socio-economic conditions, the natural environment, including vegetation and blue spaces, can have negative impacts and pose threats to human health, such as increased flood risks and infectious diseases (Gruebner et al., 2012). For instance, in the urban slums of Dhaka, vegetation patches that are predominantly found in flood-prone areas and coincide with poor sanitation and waste management, heighten the risk of diseases such as diarrhoea. Increased exposure, such as living closer to rivers, is also associated with greater adverse effects on mental health, particularly in terms of overall happiness (Gruebner et al., 2012). Flooding events also negatively impact well-being, particularly safety and social interactions, with variations based on age, education, and length of residence (Duan et al., 2018).

3.3.3. Environmental justice

The equitable distribution of accessible green and blue spaces, along with the inclusion of vulnerable groups' needs, is a core aspect of environmental justice. Vulnerable socio-economic groups, including low-income communities and ethnic minorities, often reside in areas with limited availability of green spaces due to built-up density and historical inequities in urban planning (Carrier et al., 2016; de Guzman et al., 2022; Fusaro et al., 2023; Kucera and Janerette, 2023; McDonald et al., 2021; Neier, 2023; Nyelele and Kroll, 2020; Pena et al., 2024; Sabrin et al., 2020; Xiong et al., 2023; Zhang et al., 2021). This unequal distribution exacerbates health inequalities, as these groups are more vulnerable when exposed to climate events and lack access to the physical and mental health benefits that green spaces provide. In addition, low socio-economic status areas experience increasing loss of green spaces (Kucera and Janerette, 2023), which, in some cases, contributes to the green gentrification phenomenon (Chen et al., 2021). Moreover, even when green spaces are available, not all are equally accessible. For example, areas can have restricted opening times and entrance fees. In this case, low-income individuals and older adults often prefer small open-access green spaces that are free of charge (Chen et al., 2021).

Different population groups, particularly those from vulnerable socio-economic backgrounds, value green and blue spaces for various

reasons related to health and well-being. However, preferences for specific types of green spaces vary across groups, and not all spaces equally contribute to health outcomes. For example, young children predominantly use playgrounds and natural lawn areas, while school-aged children and teenagers prefer sports facilities and spaces for recreation and socializing (Kabisch & Kraemer, 2021). These spaces offer different health benefits, such as physical activity opportunities or social interaction, which may be more limited in certain areas.

Importantly, the equitable distribution of these spaces is critical because not all vulnerable groups have equal access to green and blue spaces that can improve health. For instance, elderly individuals often prefer quiet spaces like benches for rest and social interaction, but these spaces may not always be available in low-income areas (Kabisch & Kraemer, 2021). Moreover, within vulnerable groups, preferences vary based on specific needs. Older adults, for instance, may prioritize benches for rest, while children may benefit more from cooling water features like drinking fountains or splash pads (Lanza et al., 2023). Similarly, while water features are widely valued for their cooling effects, the availability of such features is often limited in areas with higher socio-economic vulnerability (Ma et al., 2021; Huang et al., 2021). The lack of diverse and accessible green and blue spaces in these areas contributes to inequities in thermal comfort, physical health, and social well-being.

The interconnected relationships between green and blue spaces, the health of vulnerable groups and climate events are summarized and visualized in the framework presented in Fig. 3.

4. Discussion

Green and blue spaces offer many benefits for human physical, mental and social **health** by encouraging physical activities, providing restorative effects, and promoting social connectedness. These spaces also mitigate the effects of **climate events** by reducing exposure of populations to such hazards and their adverse health effects, as such contributing to overall health resilience. **Vulnerable populations** groups, such as children and older adults, are more sensitive to climate hazards, while economically disadvantaged individuals and residents with a migration background have less capacity to cope due to, for example, limited financial resources, reduced access to health and social services, language and cultural barriers. Using green and blue spaces to strengthen their health resilience is important for **inclusive urban planning** of health-promoting and climate-sensitive cities.

4.1. Green and blue spaces in cities with climate hazards

In recent decades, numerous studies have investigated various characteristics of **green spaces**, including their type, size, specific features, and functions, as well as provided benefits for well-being. While a consensus on how to define green spaces has not been reached yet (Beute et al., 2023), major categories of green spaces, such as gardens, parks,

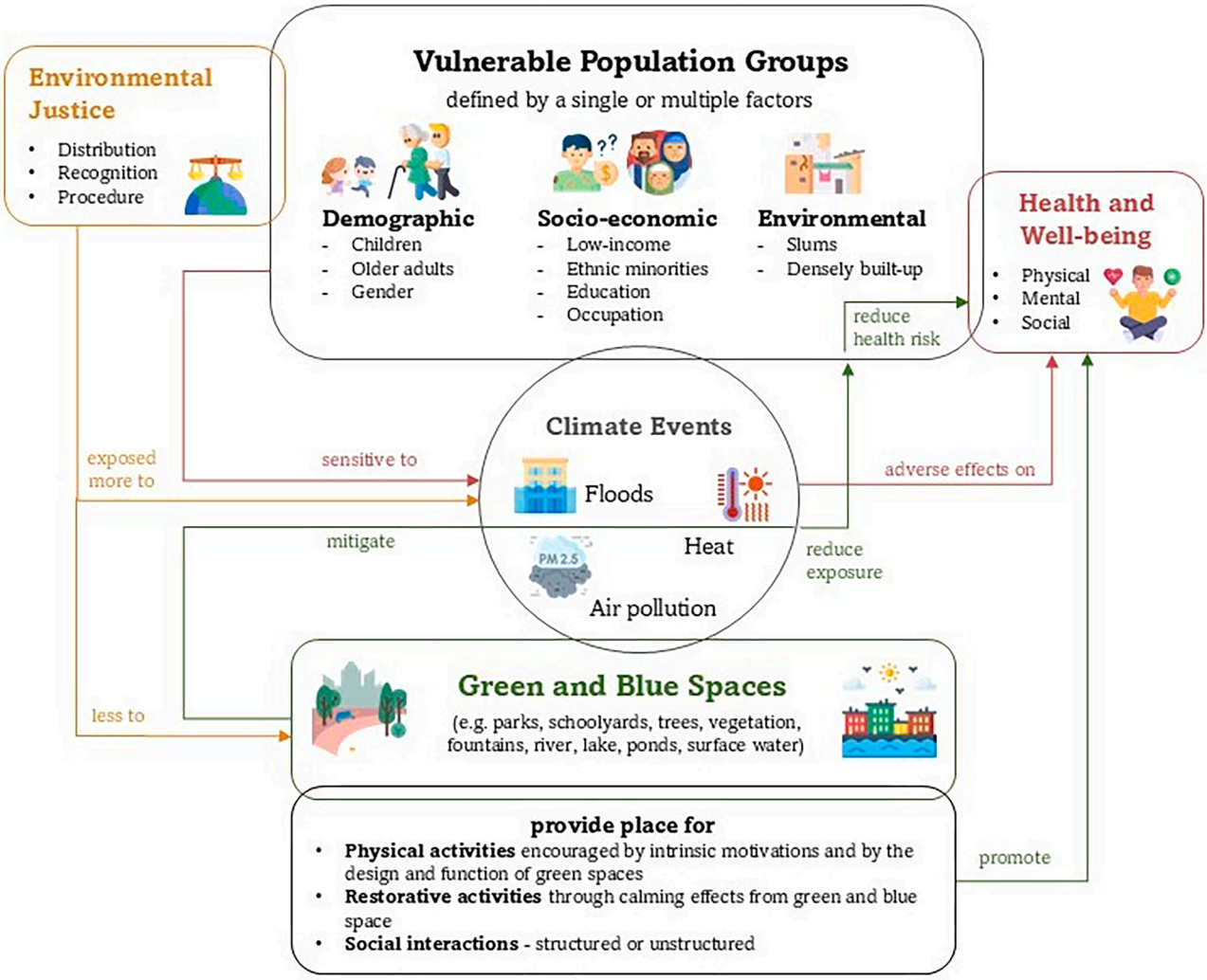

Fig. 3. Inclusive Climate and Health Resilience Framework for Urban Spaces. Resulting from scoping review (n=28, 2012-2024).

amenity areas like playgrounds and schoolyards, and general urban vegetation, are well covered in the literature. As different types or categories of green spaces (e.g., parks versus forest settings) hold different well-being benefits, there is still room for further exploration on additional types of green spaces, for example, community gardens or climate-adaptive green corridors designed for cycling or walking.

Additionally, some scholars have explored the distinction between incidental and purposeful exposure (Bratman at al., 2019). The studies examined in our review address both purposeful visits to green spaces as well as incidental exposure to greenery, such as general urban vegetation or private gardens that individuals encounter unintentionally. Our findings suggest that vulnerable groups are less exposed to incidental greenery, which reduces their potential well-being benefits from unintentional exposure. While they still benefit from purposeful visits to green areas, accessibility challenges may make it more difficult for them to reach these spaces, resulting in a two-folded disadvantage for vulnerable populations.

To better support the health and well-being of vulnerable groups, it is essential to improve not only the availability and accessibility but also the quality of local urban green and blue spaces (Mossabir et al., 2021). Urban green and blue spaces can promote health and well-being in various ways, as spaces of experience, activity, social interaction, and symbolic meaning (Völker and Kistemann, 2011). It is important to better understand how specific design features can enable these therapeutic experiences in vulnerable populations, especially those with mobility limitations or limited resources. For instance, research addressing health and well-being of older adults points to the importance of well-maintained paths and places to rest to address comfort and safety needs, in particular for older adults, or individuals with mobility issues (Van Houwelingen-Snippe et al., 2023). Urban green and blue spaces enable people with limited physical capacity to stay active through gentle, meaningful activities, while their sensory and symbolic qualities make them also suited for passive restoration. These spaces also foster a sense of inclusion by offering welcoming settings for family and multigenerational social interaction (Mossabir et al., 2021). For older adults with limited financial resources, urban green and blue spaces offer affordable opportunities to remain physically active, engage socially across generations through both planned and spontaneous interactions, and experience a sense of renewal, restoration, and spiritual connection (Finlay et al., 2015).

Research related to urban blue and green spaces as therapeutic landscapes is still in its early stages, particularly studying experiences in vulnerable populations. Hence, careful consideration of how green and blue places can promote inclusion and respond to the needs of the most vulnerable through physical and spatial landscape features, as well as sensory experiences and symbolic meanings, is key to safeguarding inclusion and public health. Recent studies have shifted focus from enhancing well-being through passive perception of the healing effects of therapeutic landscapes to emphasizing active experiences and perceptions within these spaces (Han and Liang, 2023). Ultimately, green and blue spaces should not be seen as passive environmental features but as active interventions in public health and environmental justice.

Our review indicates that no studies have focused exclusively on **blue spaces**; instead, studies considered blue spaces alongside or as part of green spaces. Given this, we identified limited focus on the specific links between blue spaces, climate events, and the well-being of vulnerable population groups. Blue spaces are predominantly associated with their heat mitigation potential (Table 3), such as thermal comfort in urban parks featuring water elements (Huang et al., 2021; Kabisch and Kraemer, 2020; Lanza et al., 2023; Ma et al., 2021; Yung et al., 2019). Only three studies (Huang et al., 2021; Lanza et al., 2023; Ma et al., 2021) have explicitly explored the potential of water features to enhance microclimates through design recommendations, highlighting a gap in research on optimizing blue space design for improved thermal comfort. Additionally, limited research has examined how the effects of blue spaces differ from those of green spaces and how these environments can complement each other to enhance well-being and mitigate extreme climate events.

Overall, an increasing number of studies stresses the unique benefits of blue spaces (e.g., Smith et al., 2022; White et al., 2020). For instance, Wheeler et al. (2012) suggest that effects of proximity to blue space on health and well-being may be particularly pronounced for deprived communities, suggesting their potential to mitigate health inequalities. Furthermore, blue spaces may be more effective than green spaces for promoting positive social relationships, as perceived social support has been found higher for those with access to blue, rather than green, spaces (Triguero-Mas et al., 2015). For older adults with limited financial resources, combined green and blue spaces offer various therapeutic benefits, while each type of space also has its own unique impact. Blue spaces are especially beneficial for mental health and spiritual restoration, while green spaces play a crucial role in fostering community interactions and supporting social well-being (Finlay et al., 2015). Follow-up research could further disentangle blue and green space benefits and identify the unique potential of blue spaces to vulnerable populations in particular. There is lack of research addressing how the effects of blue spaces differ from those of green spaces.

An increasing number of studies has also been published on **urban heat and flood risk.** However, existing publications addressed mostly the phenomenon itself, e.g., the characteristics and management of urban floods (e.g., Cea and Costabile 2022), the horizontal and vertical range and intensity of the urban heat island (e.g., by Kim and Brown 2021) or the role of urban green space for mitigating thermal stress (e.g., Javadi and Nasrollahi 2021) and to improve well-being (e.g., Reyes--Riveros et al. 2021). However, most of these studies did not combine environmental sciences, social sciences and health sciences, but rather provide insights within their disciplinary boundaries. For example, recently, the concept of sponge cities (e.g., Zevenbergen et al. 2018) has gained popularity, since it provides tools to manage water-related risks by combining technical, blue and green infrastructures and helps to mitigate urban heat. However, the concept has a strong technical focus, which fails to consider vulnerable groups and their needs.

4.2. Underexplored health and well-being benefits among vulnerable groups

Health and well-being are often contextualized as important benefits of green and blue spaces. While many studies conceptually link green and blue spaces to health (as indicated by the circles in Table 3), others analyse health-related outcomes. We found limited investigations into the specific pathways through which these spaces promote health among vulnerable groups. Few studies incorporate concrete indices related to physical health, such as temperature measurements and concrete health outcomes, or attempt to capture mental and social well-being through indicators like attention span or mood levels. Additionally, understanding of the benefits of urban green and blue spaces may be shortcut by a lack of insights in the psychological mechanisms involved. Next to attention restoration (Kaplan and Kaplan, 1989) and stress reduction (Ulrich et al., 1991), more recently connectedness to nature (Mayer et al., 2009) and the experience of awe ('feeling in the presence of something greater than the self'; Keltner & Haidt, 2003) have been proposed as important psychological working mechanisms promoting pro-social and pro-environmental behaviours and connectedness with nature, others, and the world at large (Van Rompay et al., 2023; Yaden et al., 2018).

Additionally, there is a need to **identify the specific effects of these urban spaces on vulnerable population groups** and deprived areas. Cassarino et al. (2021) identified evidence gaps for individuals with disabilities, migrants, or racial minority groups. While vulnerable groups are often mentioned, their specific challenges and perspectives are commonly overlooked. These include mobility issues and intersected vulnerabilities such as those experienced by residents of slums, multiple deprived areas or unhoused communities (Anthonj et al., 2024a;

Anthonj et al., 2024b; Anthonj et al., 2020). We identified only one study that focused specifically on slum areas (Gruebner et al., 2012), while two studies addressed low-income communities (Lanza et al. 2023; Raney et al. 2023) (Table 2). Most of the reviewed studies considered low-income populations or specific vulnerable groups such as children, older adults, ethnic minorities but they rarely looked into the challenges experienced by those affected by **overlapping vulnerability (intersectionality)**. For example, persons from vulnerable groups such as older adults or people with disabilities, living in slums or poor neighbourhoods, face multiple layers of deprivation (e.g., limited access to green infrastructure and high exposure to flooding).

Existing literature, including our identified studies, establishes that climate events disproportionately affect vulnerable populations, further exacerbating health inequities. A similar pattern is observed in other fields, for example, water insecurity among unhoused populations. As Anthonj et al. (2024a) highlight, people experiencing homelessness in urban areas already face major barriers in accessing safe water and hygiene services, challenges that become even more severe during extreme weather events. At the same time, environmental justice remains context specific. For example, cities, such as Barcelona, demonstrate rather equitable distribution of green and blue spaces (Calderón-Argelich, 2023). Our findings show that, in many cases, interventions reinforce resilience in already well-resourced areas while neglecting vulnerable populations with higher health risks. As a result, an issue of inequality emerges, where those already highly exposed to climate hazards receive less support from green and blue spaces, as a result becoming even more vulnerable.

4.3. Framework complexity in relation to existing work

We recognize that each of the components - green and blue spaces, health and well-being, and vulnerable groups - is complex on its own. Existing frameworks capture topic complexities, for example, the EnvironMental Health framework highlights intersections of environment and mental health through human-nature nexus, natural environmental factors and planetary health related to neurological, mental and interactive elements (Ratjen et al., 2025). However, the potential of green and blue space is not central to the EnvironMental Health framework. Furthermore, in the field of urban planning and quality of life, a conceptual model by Mouratidis (2021) identifies pathways linking the built environment to subjective well-being through seven potential pathways, including travel, leisure, work, social relationships, residential well-being, emotional responses, and health. The aim of this model is to offer specific entry points for urban planning and interventions, therefore, looking at items and pathways individually is highly relevant. Additionally, it points to the need for consideration of different groups, and particularly vulnerable groups, but lacks specificity about what groups exist, and what the literature reveals about their needs.

Our work extends previous frameworks in different ways, and to different extends. In our *Framework on Inclusive Climate and Health Resilience for Urban Spaces,* the central elements are vulnerable populations, climate and urban context, offering an in-depth overview of their complex interlinkages. Green and blue spaces involve numerous ecological and social processes, and their relationship with health and well-being is multifaceted. Additionally, population vulnerabilities are diverse and overlapping, further complicating these links and respective analyses. Moreover, heat and flooding implications in cities affect people and the environment. In our scoping review, we present the first attempt to link these complex components of space, society and climate by highlighting their interconnected relationships, making it a cross-cutting topic.

4.4. Methodological approaches for capturing complexity, and inclusive co-design of climate-resilient urban spaces

Our research highlights the importance of integrated, interdisciplinary approaches in studying the complex links between climate, health, and urban environments. Siloed thinking limits our ability to understand these interconnections and identify effective solutions. Most studies in our review used multiple methods and drew on various disciplines, reflecting the need for diverse perspectives to tackle complex, multifaced issues. However, combining different methods in a single study presents both opportunities and challenges, especially when it comes to integrating and interpreting data from different fields. Additionally, working across disciplines can be time-consuming and difficult, yet it is important to fully understand the societal challenges – and identify solutions.

While current methods improve understanding of how green and blue spaces affect health and well-being, they often fall short in capturing the intersectional and overlapping vulnerabilities of different populations. The frequent reliance on surveys and geospatial data may exclude the qualitative insights needed to contextualize these vulnerabilities. Without these insights, interventions risk perpetuating inequities and environmental injustices. Challenges related to distribution of benefits and burdens are well documented in our identified set of literature; thus, this work brings attention to the underexplored dimensions of recognitional and procedural justice.

The importance of recognition was a consistent theme across studies. Different residents have different needs, not only in how they use public space, but also in how they are affected by climate extremes such as heat, and thus in need of cooling functions from green and blue spaces (Schrammeijer et al., 2022). Only a few studies identified in our research provided recommendations for decision-making procedures, from which two studies (Halbmayer et al., 2021; Lanza et al., 2023) incorporated participatory design elements (Table 2). Note that these studies were identified by the Web of Science search and additional relevant literature outside this database can be mentioned. In particular, literature on co-design and methodological approaches in climate resilience, green and blue spaces also addresses this theme (see e.g., Curran et al., 2023; Liu et al., 2023; Mengyun and Guangsi, 2023; Schrammeijer et al., 2022). Overall, participatory or co-design approaches, where citizens are not merely studied but actively involved throughout the research and decision-making process, remain rare.

While our included literature cannot provide an answer to the reasons of why meaningful inclusion of vulnerable groups remains rare, methodological, institutional, as well as epistemological barriers might be some of them. Low participation among vulnerable populations signals distrust, perceived lack of voice or limited recognition of their needs in planning processes (Pellerey and Giezen, 2024). Participatory approaches are often challenging in terms of administration and logistics, time-consuming and costly, particularly when engaging population groups that might be hesitant or reluctant to engage with research activities in the first place (Anthonj et al., 2025). Institutional and governance barriers might be even greater, as political will of engaging with, representing the needs, and taking action to improve urban environments, and environmental justice, for vulnerable groups, might be lacking, with resources allocated to other priorities and groups instead. Institutional and governance reforms are needed to embed co-design and participation process, avoiding lower rungs of participation as coined by Arnstein (1969), such as “manipulation” or “tokenism” and aiming at higher levels of citizen participation and power, where residents are actively involved in decision-making, can decide on the interventions, and have delegated power on the final decisions. Examples on how to implement that can be learned from the experiences on participatory budget initiated in the Global South (e.g., Cabannes, 2015)

Most studies involved citizens as data sources rather than as co-creators, limiting the inclusion of lived experiences and local knowledge. However, procedural innovations, such as co-design workshops, living labs, and the establishment of community stewardship councils, offer practical mechanisms for shifting power dynamics and transforming residents into engaged co-creators of their own neighbourhoods (Epp et al., 2025; Holland, 2017). These participatory approaches can be

further enhanced through the integration of emerging technologies. For instance, AI can be embedded into co-design initiatives and scenario-building exercises to promote deeper and more inclusive participation. By analysing public input, identifying community priorities, and visualizing potential green and blue space scenarios, AI enhances citizen engagement, making urban planning and public health strategies more inclusive and adaptive. Additionally, AI-driven tools, such as machine learning, can process complex environmental data to uncover patterns that traditional statistical methods might overlook. Real-time monitoring further improves the precision and efficiency of assessing health impacts from climate events, enabling more responsive and data-driven interventions (Berigüete et al., 2024; Sacco et al., 2023).

4.5. Limitations of this review

Our complex search strategy, which integrates terminology related to green and blue spaces, health and well-being among vulnerable populations, and extreme climate events in urban settings, relied on an extensive list of search terms supported only by Web of Science, along with the use of AI-supported tools for screening. These factors may have limited the inclusion of all relevant literature. In the articles included in our review, we found that health and well-being was not clearly defined, features of vulnerability were considered in isolation, blue space was underreported, there was more evidence on heat than on floods, and no studies focused on translating knowledge into action. It is unclear whether these gaps reflect the actual state of the literature or indicate potential limitations in our search strategy or screening tool.

We did not include grey literature or non-English documents, although we acknowledge that non-peer-reviewed sources, such as reports and policy documents, could have provided valuable insights. However, analysing grey literature was outside the scope of this study. The evidence captured in the publications we included was drawn from various geographical regions, organizational scales, and disciplines, and applied different methodological approaches and definitions. The depth and quality of information varied between studies, making cross-comparison of evidence challenging. It is important to note that research is discipline- and method-specific and evidence is often context-specific, shaped by factors like geography, ecology, and social structures, which vary globally, regionally, nationally, and locally. Therefore, the Fig.s and maps in our review should be interpreted as providing a general overview rather than precise, comparative data.

The regional coverage of included studies may not necessarily reflect the full geographical range. While we assume that our results are also valid for other parts of the world, we cannot rule out that we missed region-specific insights. Thus, the transferability of the results in particular to the non-English speaking Global South such as Latin America, Francophone Africa, or parts of Asia requires caution.

Considering the complexity and various dimensions and concepts covered and linked through our review, we identified a scoping review to be the most useful and feasible tool for synthesis and framework development. To increase rigor and transparency, we conducted our scoping search in adherence with the preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklist for scoping reviews (PRISMA – ScR). This complexity and combination of different dimensions and concepts also resulted in comprehensive, and very detailed, search strings which we could only combine and run with Web of Science, while other databases such Scopus could not run our search strategy and were therefore not used. Likewise, MEDLINE was not used due to the small and irrelevant number of results. We acknowledge that we might have missed relevant studies for inclusion and might have touched upon important points only at the surface. We recommend a systematic review, or even a set of systematic reviews that ensure deeper, and more targeted, insights into available literature building on this current scoping review (Munn et al., 2018).

Despite these limitations, this scoping review makes a valuable contribution by addressing knowledge gaps in understanding the links between green and blue spaces, health and well-being among vulnerable groups and extreme climate events in urban areas. It provides a comprehensive synthesis of existing academic literature on the connections between climate change, vulnerable populations, and the health-promoting potential of nature. Furthermore, by highlighting the disproportionate impacts of climate change on vulnerable groups and the role of green and blue spaces in mitigating these effects, this review aims to guide future research, policy, and practice toward more equitable and resilient urban environments.

5. Conclusions, recommendations and future research directions

This scoping review highlights ways of green and blue spaces promoting physical, mental, and social well-being, especially for vulnerable urban populations facing extreme climate events. Yet, it also reveals inequities in access to these health-promoting environments, with vulnerable communities facing greater barriers restricting access and having less green space around in their immediate living environments. Recently, policy recommendations have been developed aimed at counteracting these social inequalities. For instance, the 3–30–300 guideline (Konijnendijk, 2023) seeks to provide equitable access by recommending that there should be at least 3 trees in view from every home, at least 30% tree canopy in every neighbourhood, and that the nearest public green space should be located within a range of 300 meter from every home.

In addition to ‘where’ trees and green spaces are implemented in cities, in urban planning practice, it is equally important to consider for whom and how they are designed, taking into account specific vulnerabilities related to, for instance, ageing and mobility restrictions. To support this goal, we propose the *Inclusive Climate and Health Resilience Framework for Urban Spaces,* which provides an integrated perspective on the dynamic relationships between urban green and blue spaces, vulnerable groups, health outcomes, and climate hazards.

Looking ahead, several directions can help strengthen research and practice in this field. First, there is a need to expand the research on the health impacts of different types of green and blue spaces, especially less-studied types like linear green spaces or blue spaces (e.g., rivers, canals), and how their added benefits vary across urban contexts. Second, advancing integrated studies is important to better understand the complex interactions between environmental elements, social vulnerability, and health. Achieving this requires inter- and transdisciplinary collaboration, bringing together insights from environmental science, urban planning, public health, and social equity research.

On a practical level, participatory co-design approaches must be more widely implemented and studied to ensure that urban nature provides a space for restorative experiences and meets the needs of those most affected by climate events. Emerging digital and spatial tools, such as AI and participatory mapping, can enhance these inclusive, evidence-based planning efforts.

Ultimately, health resilience, inclusive urban planning and the development of healthy, climate-resilient cities crucially depend on the design, implementation and management of spaces, green and blue spaces. We therefore recommend the application of the *Inclusive Climate and Health Resilience Framework for Urban Spaces* for health-promoting, climate-sensitive, inclusive urban planning.

Ethics in publishing statement

I testify on behalf of all co-authors that our article submitted followed ethical principles in publishing.

Title: How green and blue spaces promote health among vulnerable urban populations facing climate hazards. A systematic scoping review

All authors agree that:

This research presents an accurate account of the work performed, all data presented are accurate and methodologies detailed enough to

permit others to replicate the work.

This manuscript represents entirely original works and or if work and/or words of others have been used, that this has been appropriately cited or quoted and permission has been obtained where necessary.

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All authors have been personally and actively involved in substantive work leading to the manuscript and will hold themselves jointly and individually responsible for its content.

CRediT authorship contribution statement

Paula Janeka: Writing – original draft, Visualization, Methodology, Investigation, Formal analysis. **Julia Foellmer:** Writing – original draft, Visualization, Formal analysis. **Javier A. Martinez:** Writing – review & editing, Funding acquisition, Conceptualization. **Elizabeth A. Schrammeijer:** Writing – review & editing, Funding acquisition, Conceptualization. **Elke Hertig:** Writing – original draft. **Thomas J.L. van Rompay:** Writing – review & editing. **Damiano Cerrone:** Writing – review & editing. **Azzadiva R. Sawungrana:** Visualization. **Carmen Anthonj:** Writing – original draft, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

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