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The contribution of urban green and blue spaces to the United Nation's Sustainable Development Goals: An evidence gap map

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ABSTRACT

Urban green and blue spaces (UGBS) have the potential to make a significant contribution to the United Nation's Sustainable Development Goals (SDGs). Research shows the need for UGBS to mitigate the adverse environmental impacts of urbanisation and provide equitable access to resources that reduce social and health inequalities. However, no previous review has attempted to consolidate this evidence within the context of the SDGs. The aim of this study was to review the evidence pertaining to the role of UGBS in achieving the SDGs and identify important knowledge gaps. Using systematic review methods, we developed an evidence gap map of the literature that explores the role of UGBS in the achievement of the SDGs. Five databases (Scopus, MEDLINE, PubMed, EMBASE, and GreenFILE) were searched for studies published since 2015 that investigated at least one outcome that corresponded to the SDGs. Following screening, study characteristics were extracted, and the data were imported into EPPI-Mapper to create the interactive evidence gap map. In total n = 1872 studies were identified. Following screening, n = 181 eligible studies were included in the evidence synthesis. The majority of studies focused on the impact of UGBS on health and wellbeing (SDG3; *n* = 115), pollution, and urban heat island effects (SDG11 and SDG13; *n* = 73 and *n* = 46, respectively). SDGs that were not addressed by the studies included SDG5 (gender equality), SDG9 (industry, innovation and infrastructure), SDG12 (responsible consumptions and production), SDG14 (life below water) and SDG17 (partnership for the goals). In addition, there was a relative lack of studies conducted in low- and middle-income countries. Theoretically, UGBS could contribute to 15 of the 17 SDGs. More research is needed to address the evidence gaps towards SDGs 5,9, and 12. Related research in low- and middle-income countries must also be accelerated and more research is needed that assesses the multifunctional benefits of UGBS, drawing explicit links between UGBS and the SDGs.

1. Introduction

As a growing proportion of the global population now lives in cities, and urban land cover is projected to triple between 2000 and 2030 (Seto et al., 2012), it is crucial that the urban environment is improved to support a higher quality of life. Urban green and blue spaces (UGBS; e.g., parks, greenway paths, forests, lakes) are components of urban ecosystems with the potential to improve population health and wellbeing (Gascon et al., 2016; Nieuwenhuijsen et al., 2017; van den Bosch & Ode Sang, 2017), while reducing preventable mortality burden in towns and cities (Barboza et al., 2021; Hartig et al., 2014) and providing a range of social, environmental and economic co-benefits (Haq, 2011; Heidt & Neef, 2008; Hunter et al., 2019). UGBS can also offset the detrimental impacts of rapid urbanisation such as increased noise, air pollution and urban heat island (UHI) effects (Markevych et al., 2017; Nieuwenhuijsen et al., 2017).

The United Nations (UN) launched the Sustainable Development Goals (SDGs) in 2015, transitioning from the previous Millennium Development Goals (United Nations General Assembly, 2015). The SDGs are 17 defined goals, sub-divided into 169 targets, which are further sub-

Abbreviations: EGM, evidence gap map; GAPPA, Global Action Plan on Physical Activity; LMIC, low- and middle-income country; NCD, non-communicable disease; PA, physical activity; SDG, sustainable development goal; UGBS, urban green and blue spaces; UHI, urban heat island; UN, United Nations; WHO, World Health Organisation.

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divided into 231 indicators. As part of the 2030 Agenda for Sustainable Development, the UN General Assembly acknowledged the significance of sustainable urban development and the need to limit the environmental impact of cities. In addition, the UN set out its goal to minimise the negative impacts of urban activities on human health. The World Health Organisation (WHO) recognised the capacity for UGBS to reduce the environmental health risks of living in urban settings and provide diverse, long-term public health benefits (World Health Organization, 2017).

Given the magnitude and scale of urbanisation since the early 2000s, urban ecosystems need to be improved to ensure that, above all, they are sustainable, resilient and can support a higher quality of life for their growing populations (Capon, 2017). Investing in high-quality, equitable UGBS has the potential to make a significant contribution to the SDGs, and represents an invaluable resource for delivering sustainable urban development. This is underscored by SDG 11.7, which states: "…provide universal access to safe, inclusive and accessible, green and public spaces". However, the evidence linking UGBS to the SDGs is scarce.

The potential health and wellbeing benefits conferred by UGBS are well documented. For example, green spaces offer outdoor settings that can be used for exercise (Bedimo-Rung et al., 2005; Brown et al., 2014; Coombes et al., 2010; James et al., 2015; Schipperijn et al., 2013), reducing cardiovascular morbidity and mortality (Gascon et al., 2016; Mitchell & Popham, 2008), respiratory disease (Villeneuve et al., 2012), obesity (Lachowycz & Jones, 2011) and risk for type 2 diabetes (Bodicoat et al., 2014; De la Fuente et al., 2020), thus contributing directly to SDG 3.4: "…reduce by one third premature mortality from non-communicable diseases through prevention and treatment and promote mental health and well-being". In addition, health inequalities can be reduced by providing equitable access to UGBS (Mitchell & Popham, 2008) which, in turn, can be protective against a range of risk factors for ill health that disproportionately affect disadvantaged populations, such as low levels of exercise (Murakami et al., 2011; Murray et al., 2012), cardiovascular disease (Sommer et al., 2015), stress (Algren et al., 2018; Lazzarino et al., 2013), and air pollution (Forastiere et al., 2007).

Air pollution poses a significant risk to the health of urban populations (Cohen et al., 2017; Khomenko et al., 2021). Multiple studies have demonstrated how UGBSs can mitigate against the risk of exposure to high concentrations of ambient particulate matter and other forms of air pollution (Jaafari et al., 2020; Jim & Chen, 2008; Nowak et al., 2006; Y. Sun et al., 2019; Zhao et al., 2021; Zhu & Zeng, 2018). For example, UGBS act as 'carbon sinks', capable of capturing atmospheric CO_2 and other greenhouse gases (Nero et al., 2017; Shadman et al., 2022); tree canopies can disrupt the flow and movement of particulate matter (Salmond et al., 2013); while plants and shrubbery are able to capture fine particles (Shackleton et al., 2010). These effects have important relevance for SDG 11.6: "…reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management".

The environmental hazards, and concomitant health risks brought about by urbanisation are being compounded by an increase in ambient temperatures or UHI effects in cities (Tong et al., 2021; Xu et al., 2014). UHI refers to the increase in air and surface temperature that stems from the spatial and physical characteristics of cities such as a higher proportion of impervious surfaces, low levels of vegetation and water cover, and the presence of heat-trapping street canyons (Grimm et al., 2008). Combined, these factors can increase heat stress (J. Tan et al., 2010) and exposure to extreme temperatures which contributes to heat-related morbidity and mortality (Patz et al., 2005). Higher temperatures also increase energy consumption in cities, as more people rely on air conditioning (Santamouris et al., 2015) to negate the warmth. To offset this, UGBS provides vegetation cover that promotes evapotranspiration (Qiu et al., 2017), which creates a cooling effect by intercepting solar radiation (Oke, 1989), and shading that further reduces temperatures (Bowler et al., 2010). This also helps to reduce energy consumption (supporting SDG 7.3 to "double the global rate of improvement in energy efficiency"), particularly during warmer periods (Akbari et al., 2001), and stabilise fluctuations in ambient air temperature (C. Yu & Hien, 2006). Additional environmental benefits of UGBS include: flood risk reduction (Bai et al., 2018); storm water management (Hunter et al., 2019); improved biodiversity (Ahern, 2013; Aida et al., 2016); and habitat provision for wildlife (Felappi et al., 2020; Jim, 2004). Consequently, UGBS can not only ameliorate the short-term impacts of climate change, but they also help to "strengthen resilience and adaptive capacity to climate-related hazards and natural disasters…" (SDG 13.1) and "ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems…" (SDG 15.1).

In addition to the environmental benefits, there is both social and economic value in UGBS. For example, UGBS can promote greater social cohesion within communities (Jennings & Bamkole, 2019; Wan et al., 2021), as well as social support mechanisms (Fan et al., 2011), which improve residents' sense of belonging and neighbourhood satisfaction, leading to better mental health (Callaghan et al., 2021; K. Chen et al., 2021). Furthermore, studies have reported reduced incidences of criminal and antisocial behaviour linked to improved access to UGBS (Bogar & Beyer, 2016) which directly contributes to SDG 16.1.4: "Proportion of population that feel safe walking alone around the area they live". Thus, UGBS help to engender more positive overall perceptions of the social environment among urban residents which, in addition to health-promoting effects, can foster "collective efficacy" (Sampson et al., 1997), improve quality of place (Hunter et al., 2020; Mason, 2010), and increase both residential property values (Daams et al., 2019; J. Wu et al., 2015).

Studies have also investigated the role of UGBS in promoting tourism (Hunter et al., 2020; Nesbitt et al., 2017), and creating more enriching experiences for tourists that complement other popular attractions in cities (Deng et al., 2010). Accordingly, UGBS are an important resource to advance SDG 8.9: "…devise and implement policies to promote sustainable tourism that creates jobs and promotes local culture and products". The economic value of UGBS extends to its educational benefits and therefore SDG 4.6: "…ensure that all youth and a substantial proportion of adults, both men and women, achieve literacy and numeracy". Studies have documented a positive relationship between access to UGBS and educational achievement (C.-D. Wu et al., 2014) and cognitive functioning (Dadvand et al., 2015; Schutte et al., 2017). Additionally, the presence of green spaces in urban settings has been shown to reduce the risk of developing psychiatric disorders between childhood and adulthood (Engemann et al., 2019), thereby contributing to SDG 4.2.1: "Proportion of children aged 24–59 months who are developmentally on track in health, learning and psychosocial well-being.".

It is worth noting that these facets of UGBS are relatively underexplored in the literature when compared to other benefits that encompass the environmental and health considerations of urban settings. As such, there is lack of research that makes a strong argument for UGBS as an instrument to improve the social and economic outcomes of urban populations and act as a countermeasure against widening inequalities. This gap in the literature is even more conspicuous in LMICs, where the number of studies examining the economic and social benefits of UGBS is very low. Equally, there are few studies that target the intersection of urban nature and cultural adaptation, which holds particular relevance for marginalised population subgroups such as female migrants (Ono et al., 2023).

To our knowledge, this is the first review that consolidates the evidence pertaining to the role of UGBS in achieving the SDGs in low-, middle-, and high-income countries. The objectives of this review were to: i) to create an evidence gap map (EGM) illustrating contribution of UGBS towards the SDGs identified from both primary studies and systematic reviews; ii) identify gaps in the existing body of evidence; and iii) consider how the current distribution of evidence reflects research priorities in this area and creates opportunities for future research to explore.

2. Methods

Evidence Gap Maps (EGMs) are a method of evidence synthesis, similar to evidence mapping. We followed the guidelines by Snilstveit et al. (Snilstveit et al., 2016) and White et al. (White et al., 2020) to conduct this EGM. Our approach was divided into six steps shown in Table S1 in the Appendix (Supplementary File 1). The EGM was supported by methods of evidence synthesis underpinned by a systematic methodology to improve reliability and reproducibility.

We operationalised urban green spaces to include publicly accessible designated areas in urban settings with a high percentage of vegetative ground cover that represents a site of increased natural representation and/or recreational value (Schipperijn et al., 2013). Examples of green spaces include parks, gardens, community farms, greenway paths, greened vacant lots, and urban forests (Kabisch & Haase, 2013). For the purposes of this study we excluded sports and leisure facilities (e.g., tennis courts, athletics tracks, football stadiums) due to the presence of a high volume of impervious surfaces. Green infrastructure including roadside greenery, green roofs and vertical greenery systems were included under our definition of UGS, in line with the WHO (World Health Organization, 2017). Urban blue spaces were operationalised to include all natural and manmade surface water in urban environments (Smith et al., 2021). Examples of blue spaces include coasts, rivers, lakes, canals, ponds, and fountains (Smith et al., 2021). Given the potential overlap between urban green spaces and urban blue spaces, we adopted an overarching definition of "urban green and blue spaces" that included publicly accessible areas that incorporate both green (e.g., vegetative cover) and blue (e.g., lakes) elements.

2.1. Developing the outcome framework and linking study outcomes to the SDGs

The outcome framework was based on the UN SDGs and is included in Table S2 in the Appendix (Supplementary File 1). Each SDG is comprised of three parts: the goal, its targets, and various indicators. During data extraction, we recorded each study's main objectives as well as the outcomes it assessed. Study outcomes were then linked to each SDG by manually searching the outcome framework to identify the corresponding indicator. For example, if a study stated that its objective was to investigate the role of an urban park in reducing ambient particulate matter concentrations, the SDG framework was searched to identify: first, the relevant SDG (i.e., SDG11: Make cities and human settlements inclusive, safe, resilient and sustainable); second, the relevant SDG target that references air quality (i.e., SDG11.6: By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management); and third, where applicable, the specific SDG indicator that directly alludes to the outcome in question (i.e., SDG11.6.2: Annual mean levels of fine particulate matter (e.g. PM2.5 and PM10) in cities). In instances where a study outcome did not correspond to an SDG indicator, it was linked to the most relevant SDG target.

2.2. Study inclusion criteria

The inclusion and exclusion criteria (shown in Table 1) were developed in consultation with academic researchers from public health, environmental science, complexity science, and planetary health to accurately define the scope of the study, ensure research prioritisation, and to refine the research protocol in order to minimise any potential limitations.

Definitions of each intervention type are included in Table 2.

2.3. Study search

Five databases (Scopus, Medline, PubMed, Embase, and GreenFILE) were searched in March 2022 to identify studies that examined the role of UGBS in the achievement of at least one of the SDGs. Multiple combinations of the search terms *urban green space*, *urban blue space*, and SDG-specific terms (see Tables S3 and S4 in the Appendix [Supplementary File 1]), including other associated terms, were used across all the databases. Exploded terms were used to elicit potential entries using narrower subject terms associated with the subject heading. Reference management software (Mendeley) was used to systematically remove duplicated literature.

Table 1
Inclusion and exclusion criteria.

Inclusion criteria	Exclusion criteria
Studies must investigate the role of UGBS in achieving outcomes that corresponded to at least one of the 17 SDGs.	Studies assessing populations with pre-existing clinical diagnoses.
Studies must be published from 2015 onwards (when the SDGs were introduced).	Dissertations, theses, letters, comments, and narrative/qualitative reviews.
Studies must address the contribution to the SDGs of existing UGBS or interventions that include[1]: i) the introduction of a new UGBS. ii) the modification of existing UGBS. iii) establishment of programmes catered towards increasing the utilisation of UGBS. Eligible study designs include: i) Longitudinal and cross-sectional studies. ii) Observational and experimental study designs (e.g., natural experiments). iii) Systematic reviews and meta-analyses. Studies must be published in English.	Studies that do not explicitly invoke outcomes that correspond to any of the SDGs within the context of their investigation.

Table 2
Operationalisation of UGBS intervention types.

Existing UGBS	Pre-existing urban green or blue spaces that were established at the time of the study.
Introduction of new UGBS	The intervention primarily involves the introduction of a new urban green or blue space to an area. Examples include the creation of a new park facility or new greenway path.
Modification of existing UGBS	The intervention primarily involves the modification of a pre- existing urban green or blue space to an area. Examples include the addition of a community garden or skate park to a local greenspace.
Establishment of programmes that primarily involve increased utilisation of UGBS	The intervention primarily involves the establishment of new programmes within an urban green or blue space. Examples include the introduction of a community sports programme or a new play group for children within a local green space. UGBS can be promoted in various ways: • Websites, improved and more accessible signage, and brochures; • Facilitated activities and public events including family-based events, sports days, festivals, and markets; • Small group activities such as guided walks or outdoor exercise classes; • Engagement with local celebrities and other public figures to promote UGBS and engage the local community; and • Collaboration with local organisations or societies to help with maintenance and promotion of the UGBS.

2.4. Screening and selecting studies

Title and abstract screening were performed by one researcher to identify papers that met the aforementioned eligibility criteria. Full text articles that were deemed eligible during title and abstract screening were subsequently reviewed by two researchers independently to ascertain their eligibility for inclusion in the final analysis.

2.5. Data extraction

The data were extracted by two researchers independently and included relevant SDG(s), author(s), year of publication, study design, country, country income level (based on World Bank classifications (The World Bank, 2023)), population subgroup(s), UGBS type (e.g., UGS, UBS, or combination), UGBS intervention (e.g., introduction of new UGBS, modification of existing UGBS), study aims, and main findings. We developed and refined data extraction coding tools using an online systematic review application (EPPI-Reviewer V.4) and used this to manage the literature database and extract data.

2.6. Rendering the evidence gap map

Coded data were exported via a "coding report" in JSON format from EPPI-Reviewer V.4. Next, the exported data were imported into EPPI-Mapper to create an interactive matrix where each cell contains information on studies (see sample map in Fig. 1). By clicking on any cell, a pop-up window opens displaying the list of studies (and bibliographic data) included in that cell. Studies in the EGM can be filtered according to various characteristics that include study type, country, country income level, UGBS type, and population subgroups(s). The interactive EGM also allows users to change between a bubble-map, heat-map, mosaic, and donut-map. By default, the EGM will launch as a bubble-map with collapsed headers. A study may appear in more than one cell if it includes multiple UGBS intervention types or investigates outcomes associated with multiple SDGs.

3. Results

Fig. 2 shows the flow of articles through the screening process.

The initial search of the literature yielded 1872 articles. After removing duplicates ($n = 215$), 1657 papers were screened by title and abstract. In total, 275 articles were retrieved for full-text screening. As detailed in Fig. 2, the main reasons for exclusion during full-text screening included: the outcomes were not linked to SDGS; the study was a narrative review; and the full-text was not available. The final EGM was made up of 181 studies.

3.1. Study characteristics

Study characteristics are shown in Table 3, and a more detailed overview is provided in Supplementary File 2. The majority of articles were primary studies ($n = 159$), while the remaining were either systematic or scoping reviews ($n = 22$). Overall, 73 countries were targeted by primary studies or by studies that were included in reviews, the largest proportion of which were in China (19 %) and the United States (6 %). Fig. 3 shows the geographical distribution of studies that were included in the EGM.

Most primary studies and reviews targeted high-income ($n = 178$) and upper-middle income ($n = 89$) countries. Green spaces were the most frequently investigated UGBS type (n = 159), while only a small fraction of studies examined urban blue spaces ($n = 6$). Existing UGBSs were investigated in 160 studies, while very few studies investigated interventions pertaining to the development of new UGBS (n = 21), the modification of existing UGBS ($n = 9$), and programmes to promote the usage of UGBS ($n = 4$). There was a dearth of studies in lower-middle and low-income countries (n = 9 and n = 1 respectively). The majority of studies were published between 2019 and 2021.

3.2. Evidence gap map and SDGs

The two-dimensional interactive EGM matrix is included in

		UN Sustainable Development Goals																
		SDG1	SDG2	SDG3	SDG4	SDG5	SDG6	SDG7	SDG8	SDG9	SDG10	SDG11	SDG12	SDG13	SDG14	SDG15	SDG16	SDG17
UGBS Interventions	Existing UGBS																	
	Introduction of new UGBS																	
	Modification of existing UGBS																	
	Programmes to promote the utilisation of UGBS																	

Fig. 1. Sample evidence gap map.

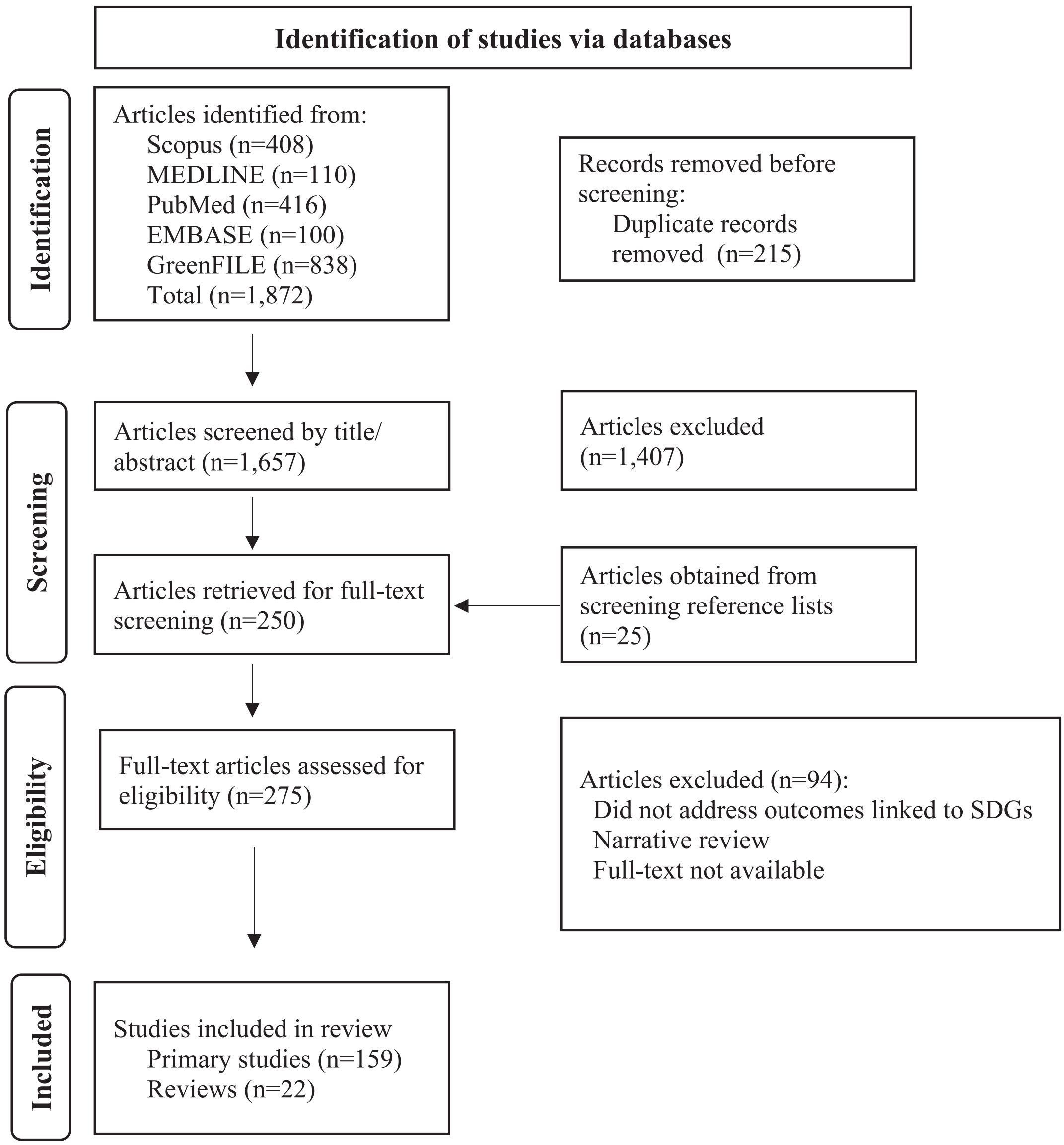

Fig. 2. Flow diagram.

Supplementary File 3. Included studies are rendered visually using a bubble plot by default. Green bubbles represent primary studies, and blue bubbles represent reviews. The size of the bubble corresponds to the number of studies. As such, a larger bubble would indicate a greater number of studies in the respective SDG category and UGBS intervention type. Each SDG column header can be expanded to show the various SDG targets within. Information regarding the SDG global indicators assigned to each study is included in Supplementary File 2 as these data could not be included in the interactive EGM matrix.

As the EGM shows, outcomes that related to SDG3 (good health and wellbeing), SDG11 (sustainable cities and communities) and SDG13 (climate action) were investigated with relative consistency across the 181 studies. SDGs that were not addressed by the studies included SDG5 (gender equality), SDG9 (industry, innovation and infrastructure), SDG12 (responsible consumptions and production), SDG14 (life below water) and SDG17 (partnership for the goals). Few studies assessed the various co-benefits of UGBS, possibly as a result of narrow research objectives or resource limitations. The majority of studies focussed on a small number of outcomes, and this is reflected by the manner in which studies are distributed across the EGM.

Table S5 in the Appendix (Supplementary File 1) provides a condensed summary of the SDGs that were addressed by studies included in the EGM. It is intended that the remaining section should be read in conjunction with the interactive EGM in order to more easily identify the papers being discussed under each subheading.

3.2.1. SDG1: end poverty in all its forms everywhere (total number of studies: 1)

One primary study included in the EGM examined the association between exposure to greenness in early childhood and future earnings. While UGBS has been linked to the developmental trajectories of children and adolescents (Kahn & Kellert, 2002), it has not been comprehensively studied as a mechanism to improve the socioeconomic outcomes of this age group. This may also be linked to the lack of studies in LMICs and a wider lack of robust research infrastructure in countries where poverty is most pervasive.

3.2.2. SDG2: end hunger, achieve food security and improved nutrition and promote sustainable agriculture (total number of studies: 7)

Two primary studies assessed the role of UGBS to reduce the risk of overweight/obesity among children, while one study focused on adults and another focused on older adults. Overweight and obesity were the

Table 3
Study characteristics.

	n	%
Study type		
Primary study	159	88
Review	22	12
Country		
China	52	19
United States	17	6
United Kingdom	11	4
Australia	10	4
Netherlands	9	3
Spain	9	3
Germany	8	3
Canada	7	3
Turkey	7	3
Other	147	53
Country income level		
High	178	64 %
Upper-middle	89	32 %
Lower-middle	9	3 %
Low	1	<1 %
UGBS type		
Green space	159	88
Blue space	6	3
Both	16	9
Intervention type		
Existing UGBS	160	83
New UGBS	21	10
Modification of existing UGBS	9	5
Programmes	4	2
Publication year		
2015	6	3
2016	18	10
2017	20	11
2018	16	9
2019	32	18
2020	30	17
2021	53	29
2022	6	3

only outcomes relating to this SDG that were investigated in included studies. No studies investigated the role of UGBS in reducing hunger or using UGBS as a countermeasure against food scarcity in urban settings.

3.2.3. SDG3: ensure healthy lives and promote well-being for all at all ages (total number of studies: 115)

The most frequently investigated outcomes that corresponded to SDG3 were physical activity (PA), self-reported general health, cardiovascular and respiratory disease, and psychological wellbeing. The 115 included studies related to SDG3 generally showed improved health and wellbeing outcomes associated with access to and use of UGBS. A small number of studies ($n = 6$) investigated the co-benefits of UGBS to mitigate exposure to ambient air pollution and provide a mechanism through which it can improve health. There were gaps in the literature with regard to maternal mortality, communicable diseases, substance abuse, and road traffic injuries and deaths.

3.2.4. SDG4: ensure inclusive and equitable quality education and promote lifelong learning opportunities for all (total number of studies: 8)

There was a small sample of studies ($n = 7$) that considered the impact of UGBS on educational and developmental outcomes among children and adolescents, and the other study in this category investigated the vocational training opportunities provided by UGBS or UGBS interventions for youth and young adult. Educational considerations around sustainable development were not addressed by any of the studies, nor was the role of UGBS as an "educational facility" (Ko & Son, 2018) to be used to promote greater awareness of sustainable development and silviculture. As a setting that holds educational value, it is surprising that few interventions were catered towards harnessing natural ecosystems to improve academic outcomes, as demonstrated by "forest schools" (O'Brien & Murray, 2007; Waite et al., 2016). While there was some evidence to support the role of UGBS in promoting improved developmental outcomes, the evidence supporting academic performance was mixed.

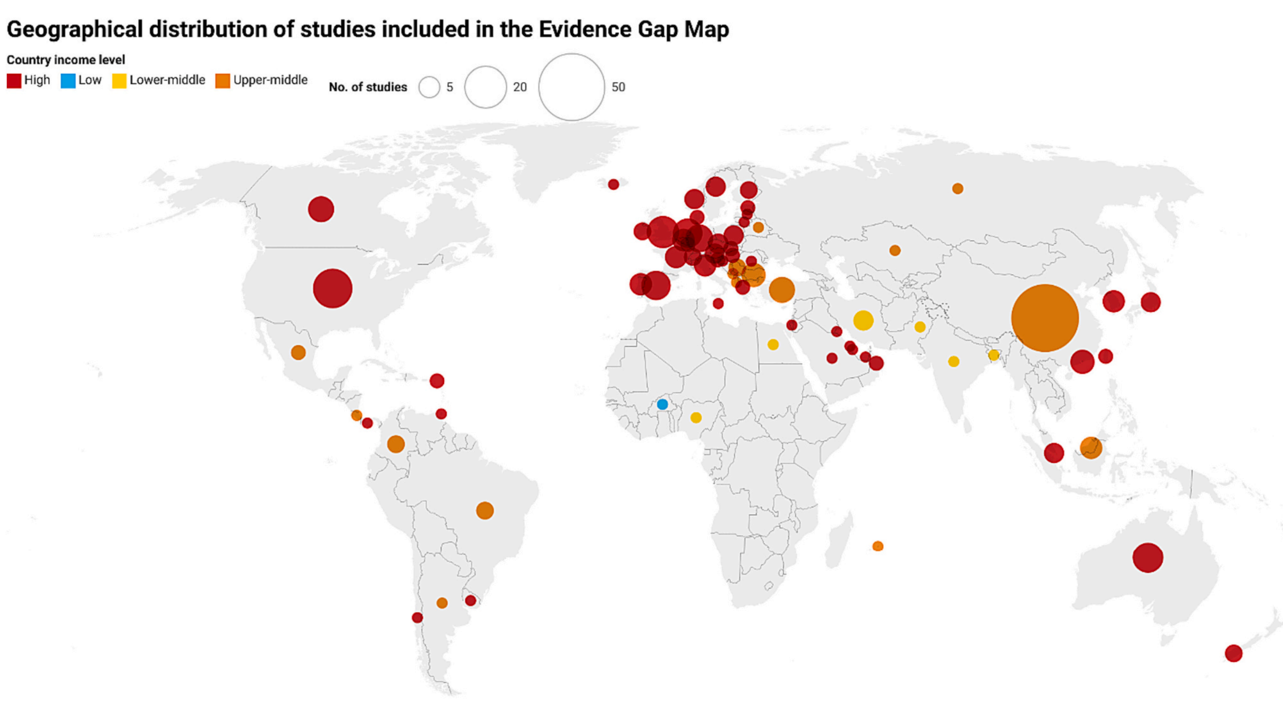

Fig. 3. Geographical distribution of studies included in the Evidence Gap Map.
Source: https://datawrapper.dwcdn.net/gae31/2/.

3.2.5. SDG5: achieve gender equality and empower all women and girls (total number of studies: 0)

No studies investigated the role of UGBS in reducing gender disparities or promoting equal opportunities for women were identified. While crime and violence were assessed in a small number of studies, it was not examined within the context of violence against women.

3.2.6. SDG6: ensure availability and sustainable management of water and sanitation for all (total number of studies: 2)

One primary study assessed the co-benefits of green-blue-grey infrastructure to reduce flood risk and found that among the many co-benefits, green-blue infrastructure can reduce water consumption. Another primary study investigated the ecological benefits of urban wetland parks such as habitat creation. Considering the low number of studies that examined urban blue spaces exclusively, it was not surprising to see that this SDG was largely overlooked in the EGM. More specifically, although it has been estimated that 60 % of residential water use is attributed to cities (Grimm et al., 2008), studies have not explored the potential for UGBS to improve water use efficiency.

3.2.7. SDG7: ensure access to affordable, reliable, sustainable and modern energy for all (total number of studies: 1)

As previously mentioned, one primary study assessed the co-benefits of green-blue-grey infrastructure to reduce flood risk and found that among the many co-benefits, green-blue infrastructure can reduce energy consumption by improving the cooling efficiency of buildings. It has been shown in studies published before 2015 (and hence not eligible for this review) that UGBS can reduce air conditioning demand which in turn reduces CO_2 emissions (B. Zhang et al., 2014). However, no studies included in the EGM directly examined the role of UGBS as a source of renewable energy or energy-saving resource. While a large number of included studies assessed the cooling potential of UGBS, none attempted to empirically measure how this improves energy efficiency through reduced dependence/expenditure on air conditioning.

3.2.8. SDG8: promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all (total number of studies: 5)

Four primary studies included in the EGM evaluated the economic value of UGBS, primarily through the use of hedonic pricing models to estimate the effect of UGBS on house prices. Beyond the hedonic pricing models, there were few studies that examined the direct economic impacts of UGBS, and how GDP is affected by the introduction of new UGBS. Only one study evaluated a broader range of socioeconomic implications including the provision of jobs and vocational training opportunities from the introduction of a new urban greenway.

Two primary studies and one review examined the impact of UGBS on tourism and how natural resources such as urban wetland parks can attract tourists. With regard to studies published since 2015, this area has been relatively under-researched. It is also noteworthy that in larger cities, which often serve as tourist destinations for many countries, few studies have investigated the potential of utilising UGBS as a resource for attracting visitors and boosting tourism.

3.2.9. SDG9: build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation (total number of studies: 0)

No studies were identified that attempted to capture the influence of UGBS on sustainable industrialization and innovation. Additionally, there were no studies that assessed the role of UGBS in establishing more sustainable and resilient infrastructure to support health and wellbeing. While UGBS does constitute a sustainable, resilient, and inclusive component of urban infrastructure, these characteristics were not directly measured as an outcome in any of the studies.

3.2.10. SDG10: reduce inequality within and among countries (total number of studies: 1)

One primary study examined how UGBS can promote better income growth and more equitable economic outcomes for a cohort of children living in socioeconomically disadvantaged areas in the United States.

3.2.11. SDG11: make cities and human settlements inclusive, safe, resilient and sustainable (total number of studies: 73)

There was significant overlap across studies that investigated outcomes relating to SDG11 and SDG13. This was due in large part to the task of assigning an SDG to studies that evaluated the role of UGBS in attenuating UHI effects in cities. Specifically, we found studies that examined the role of UGBS to reduce surface and air temperatures in cities fulfilled outcomes corresponding to SDG11.6 ("By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management"), SDG13.1 ("Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries"), and SDG13.2 ("Integrate climate change measures into national policies, strategies and planning"). As a result, there are a large number of studies ($n = 73$ for SDG11; $n = 46$ for SDG13) included under these SDGs in the EGM. The most common outcomes investigated in these studies were particulate matter concentration, UHI effects (operationalised as air or land surface temperatures), and presence of greenhouse gases. Generally, these studies illustrated a positive environmental effect of UGBS in urban contexts.

3.2.12. SDG12: ensure sustainable consumption and production patterns (total number of studies: 0)

No studies of the impact of UGBS on sustainable consumption and production patterns were identified.

3.2.13. SDG13: take urgent action to combat climate change and its impacts (total number of studies: 46)

As previously mentioned, there was significant overlap between SDG11 and SDG13. This was due to the outcomes (predominantly air pollution and urban heat island) aligning with multiple SDG targets. As noted under SDG4, there were no UGBS interventions included in studies that used the spaces to promote better awareness and education of climate change (SDG13.3). SDG13.b was not addressed due to the lack of studies in LMICs.

3.2.14. SDG14: conserve and sustainably use the oceans, seas and marine resources for sustainable development (total number of studies: 0)

No studies that included outcomes linked to SDG14 were identified.

3.2.15. SDG15: protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss (total number of studies: 14)

Studies that addressed SDG15 predominantly examined the potential for UGBS to reduce flood risk and improve stormwater management in urban environments. However, very few studies were focused exclusively on these outcomes, and instead integrated flood risk and stormwater management into a collection of other environmental outcomes (e.g., biodiversity, air quality). There was a small number of studies that examined the role of UGBS in preserving freshwater ecosystems. These studies centred primarily around forest parks, wetland parks, and one study used perceived naturalness and "parkification" of natural areas to explore how these ecosystems could be preserved.

3.2.16. SDG16: promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels (total number of studies: 11)

Similar to outcomes corresponding with SDG15, relatively few studies exclusively investigated outcomes linked to SDG16. Instead, they were mainly investigated with relative frequency in studies that employed socioecological frameworks that were broad in scope.

3.2.17. SDG17: strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development (total number of studies: 0)

No studies that included outcomes linked to SDG17 were identified.

4. Discussion

This review provides the first interactive EGM showing the contribution of UGBS towards the achievement of the UN SDGs. The results indicate that the majority of studies that have examined the relationship between UGBS and outcomes corresponding to the SDGs have been concentrated around health and wellbeing (SDG3), and anthropogenic outcomes such as UHI and air pollution (SDG11 and SDG13). Further, the results highlighted a lack of studies that addressed outcomes related to SDG5, SDG9, SDG12, SDG14 and SDG17. There was also a gap in the literature with regard to LMICs, and a paucity of studies that investigated multiple co-benefits of UGBS.

4.1. Health and wellbeing

An important causative mechanism underpinning the relationship between UGBS and better health is PA (Maas et al., 2008; Richardson et al., 2013). UGBS support residents in urban settings to engage in physical activities such as walking, jogging, and cycling, thus reducing the risks associated with sedentary behaviour. A number of studies included in the EGM linked specific features of UGBS (e.g., spatial design, vegetation/tree coverage, sports facilities) with PA (Akpinar, 2016; Akpınar, 2019; Du, Zhou, Cai, Li, & Xu, 2021; Knobel et al., 2021; Miralles-Guasch et al., 2019; Reyes-Riveros et al., 2021; C. L. Y. Tan, Chang, et al., 2021; H. Wang et al., 2019; M. Wang, Qiu, et al., 2021). The WHO Global Action Plan on Physical Activity (GAPPA) (World Health Organisation, 2018) proposed that policy actions to improve PA will directly contribute to SDG3, and indirectly contribute to 12 other SDGs. For instance, PA can contribute indirectly to SDG4.1 by improving cognitive function among school children which can subsequently lead to better, more equitable, academic outcomes.

A recent study by Salvo et al. (Salvo et al., 2021) reaffirmed the importance of policies to promote PA and the contributions this can make to multiple SDGs. However, as noted earlier, few studies in the EGM attempted to capture a complex, overlapping system of SDG-specific benefits (as done by Salvo et al.) associated with UGBS and the indirect pathways through which PA can contribute to them. Thus, if PA is the one of the principle mechanisms through which UGBS can improve health outcomes, intervention programmes designed to increase usage of UGBS should have a prominent PA component. There are several studies in the EGM that demonstrated the effectiveness of UGBS interventions to increase PA (Benton et al., 2018; Cranney et al., 2016; Gubbels et al., 2016; He et al., 2021; Hunter et al., 2021; Jarden et al., 2016; Jin et al., 2021; Slater et al., 2016; Xie et al., 2021).

Another focus of studies that examined the contribution of UGBS to better health outcomes for urban populations was the reduction of exposure to ambient air pollution (SDG3.9.1: "Mortality rate attributed to household and ambient air pollution"). Specifically, studies examined the protective role of UGBS to reduce exposure to air pollution and the consequent risk of respiratory disease (e Almeida et al., 2020; Jaafari et al., 2020; S. Sun et al., 2020), cardiovascular disease (Heo & Bell, 2019; H.-B. Hu et al., 2022), and premature birth (Asta et al., 2019). These studies show that UGBS can act as a buffer against air pollution, safeguarding urban populations from one of the most common environmental hazards associated with urbanisation and reducing the risk for a number of non-communicable diseases (NCDs). A slightly larger number of included studies examined the effect of UGBS on the risk for cardiovascular disease which corresponds directly with SDG3.4.1 ("Mortality rate attributed to cardiovascular disease, cancer, diabetes or chronic respiratory disease") (Astell-Burt & Feng, 2020; Geneshka et al., 2021; Kondo et al., 2018; Lanki et al., 2017; Ngom et al., 2016; Rahnama & Shaddel, 2019; Rigolon et al., 2021; Seo et al., 2019; Vienneau et al., 2017; L. Yang et al., 2021; Yeh et al., 2020).

SDG3 encompasses a broad range of goals that aim to promote better health and wellbeing. It also shares a common goal with SDG2.2 which aims to "end all forms of malnutrition" including malnourishment and obesity. Interestingly, only a small proportion of studies examined the role of UGBS in reducing risk for overweight and obesity (Akpinar, 2017; Bozkurt, 2021; Dempsey et al., 2018; Geneshka et al., 2021; Islam et al., 2020; Knobel et al., 2021; Rigolon et al., 2021). As such, future research in this area should explore the ways in which UGBS can provide sustainable solutions that accommodate the dietary needs of urban populations, as demonstrated in case studies in the United Kingdom (Nicholls et al., 2020; Walsh et al., 2022) and United States (Corrigan, 2011; Grewal & Grewal, 2012).

A review by Lai et al. (Lai et al., 2019) identified a small number of studies ($n = 4$) published after 2015 that described negative associations between UGBS and health, including a higher risk of asthma among children aged 4–6 years (Andrusaityte et al., 2016), and a negative association between recreational green space and commuting physical activity (Mäki-Opas et al., 2016). A later study (L. Wu & Kim, 2021) found that vegetation cover had a negative impact on self-rated health, which the authors hypothesised was due to the lack of accessibility associated with non-park green spaces and lack of visibility.

4.2. Urban heat island, pollution and climate change

In addition to the salutogenic effects of UGBS, a large number of studies included in the EGM considered the impact of UGBS on anthropogenic changes associated with urbanisation, namely, UHI effects, increased particulate matter concentrations, and greenhouse gas emissions. This emphasis on air quality in studies speaks to the important part played by UGBS in offsetting the environmental degradation caused by urbanisation. Some of the studies that included outcomes relating to SDG11.6 assessed particulate matter concentrations in isolation (Cai et al., 2020; M. Chen et al., 2019b, 2019a; Zhao et al., 2021; Zhu & Zeng, 2018), while a smaller number examined the impact of UGBS on particulate matter in conjunction with other outcomes such as carbon emissions (Van Ryswyk et al., 2019), UHI (Ghazalli et al., 2018; Van Ryswyk et al., 2019; Ye & Qiu, 2021) and ozone (S. Sun et al., 2020).

There is growing evidence of a shift in the distribution of concentrations of ambient fine particulate matter ($PM_{2.5}$) across the socioeconomic gradient, with many urban settings in LMICs experiencing increases in $PM_{2.5}$ concentrations compared to cities in high-income countries (Apte et al., 2021). Despite efforts to curb the increase in air pollution (Jonidi Jafari et al., 2021), global $PM_{2.5}$ concentrations remain high (in 2019, it was estimated that 86 % of urban inhabitants lived in areas that exceeded WHO's 2005 guideline) and contribute significantly to premature mortality and morbidity from NCDs (Southerland et al., 2022).

Features of urban morphology - impervious surfaces, street canyons, anthropogenic heat sources, densely populated residential areas - have contributed to global temperature increases (Yan et al., 2014; Z. Yang et al., 2020). Within UGBS, vegetation structures such as trees with dense canopies can reduce ambient air temperatures through evapotranspiration and by absorbing solar radiation (Millward et al., 2014), and by providing shading from sunlight (J. K. N. Tan, Belcher, et al., 2021). The salience of UHI effects in the literature illustrates its importance in the global context. In addition to heat stress (Scherer et al., 2014; Wolf et al., 2009), the increased heat loads ascribed to climate change can have a detrimental effect on UGBS, threatening vegetation and further compounding rising ambient temperatures (Allen et al., 2021). There are many factors that determine the cooling capacity of UGBS including presence/density of vegetation (Lehmann et al., 2014), tree species (Rahman et al., 2020; Shashua-Bar et al., 2010) and tree diversity (X. Wang, Dallimer, et al., 2021), soil composition (Rahman et al., 2011), and spatial characteristics such as size and shape (Ren et al., 2013). Consequently, there is significant variability in the capacity of different types of UGBS to reduce air temperature and mitigate UHI effects. A small number of studies in the EGM investigated the direct impact of UGBS on UHI effects (R. Chen & You, 2020; Cui et al., 2021; Di Leo et al., 2016; Herrera-Gomez et al., 2017; Knaus & Haase, 2020; Sugawara et al., 2016; Z. Yu et al., 2018; Žuvela-Aloise et al., 2016), while a larger sample investigated how the specific properties of UGBS attenuate UHI effects (Aram et al., 2019; Du et al., 2017; Du, Zhou, Cai, Cai, & Xu, 2021; Ekwe et al., 2021; Grilo et al., 2020; Y. Hu et al., 2021; Jaganmohan et al., 2016; Ke et al., 2021; Klemm et al., 2015; P. Li & Wang, 2021; Y. Li et al., 2021; Napoli et al., 2016; Nastran et al., 2019; Park et al., 2017; S. Sun et al., 2017; S. Wu et al., 2021; Z. Yu et al., 2020; Yuan et al., 2021; X. Zhang et al., 2017).

By increasing water infiltration and storing excess rainwater, UGBS can beneficially alter the hydrological processes in heavily urbanised areas (Scott et al., 2016). SDG15.3 was largely addressed by studies that considered the efficacy of UGBS to reduce flood risk (Alves et al., 2020; Bai et al., 2018; Kim et al., 2017). Two studies included cost-benefit analyses to assess the financial viability of different green infrastructure measures to minimise stormwater risks (Alves et al., 2019; Liu et al., 2016). There is scope, however, for more studies to be conducted in LMICs which would help to identify the role of UGBS as a potential mechanism to promote better climate-related planning and management in these settings.

Being responsible for a large proportion of global greenhouse gas emissions (Frumkin & Haines, 2019), cities have contributed significantly to climate change (United Nations, n.d.). Therefore, investment in urban design to mitigate against further damage to the climate must be underpinned by evidence-based policy frameworks that support practical and cost-effective solutions that support sustainable urbanisation. However, climate change is a reality that urban populations face. The frequency and intensity of extreme weather events are increasing at an alarming rate (Mishra et al., 2015), placing significant pressure on the critical infrastructures that support cities (Lomba-Fernández et al., 2019). Thus, measures to reduce the impact of urban centres on the climate must be balanced with the need to make cities themselves more climate-resilient. UGBS is one such mechanism that can add to the capacity of cities to respond to the challenges of climate change (Mabon et al., 2019).

4.3. Gaps and implications for future research

In order to address the environmental, social and economic challenges of urbanisation, complementary solutions that leverage existing natural resources are needed. Policies should target the preservation of natural ecosystems that can improve the lives of urban populations through the provision of safe and equitable access to green and blue spaces, while avoiding the disbenefits associated with gentrification and the adverse impacts this can have on urban communities. The achievement of this goal necessitates a shift in the trajectory of research towards a transdisciplinary orientation that looks at the synergies and trade-offs of UGBS through a multifunctional lens (Hunter et al., 2019), and across settings with diverse social and economic characteristics.

4.3.1. Environmental challenges

A major obstacle to improving the sustainability of cities is the worsening burden of greenhouse gas emissions (SDG13.2.2), one of the main drivers of which is the use of road vehicles (Karagulian et al., 2015). However, there is limited research pointing to the mechanisms through which UGBS can reduce car dependency and facilitate the uptake of active transportation modes, thereby reducing the harmful emissions generated by traffic. For example, urban greenways serve as active travel corridors, supporting pedestrian travel, improving the connectivity of cities, and subsequently reducing reliance on vehicles (Horte & Eisenman, 2020). Results from a greenway intervention study in Vancouver showed promising reductions in greenhouse gas emissions as residents opted to reduce vehicle use in favour of non-motorised travel modes (Ngo et al., 2018). It remains to be seen how these measures translate across to rapidly industrialising economies with relatively limited resources and more difficult ecological characteristics to contend with.

Evidence suggests LMICs are disproportionately affected by extreme weather events that are a result of climate change (United Nations Office for Disaster Risk Reduction, 2018). Therefore, more research is needed to evaluate the contribution of UGBS to the adaptive capacity and climate resilience of cities in LMICs (Moser & Satterthwaite, 2008) and specifically how UGBS can "build the resilience of the poor and those in vulnerable situations and reduce their exposure and vulnerability to climate-related extreme events" (SDG1.5). A cost-benefit analysis of the co-benefits of UGBS found that in addition to flood risk management, green-blue infrastructure grants other benefits such as reduced energy costs and reduced water consumption (Alves et al., 2019). However, the maintenance of UGBS can place significant strain on cities where water resources are already scarce. This is a problem most keenly felt in arid regions (Nouri et al., 2019), but nevertheless calls attention to the kind of resources (both economic and natural) that are required to support the construction and ongoing maintenance of these spaces. This has the potential to negatively impact SDG6 ("Ensure availability and sustainable management of water and sanitation for all") if new UGBS come at the cost of drinking water services. Blue spaces could theoretically provide better access to drinking water and sanitation; however, this is not a link that was explored in the included studies. Our search of the literature identified only six studies that examined urban blue spaces (Crouse et al., 2018; Garrett et al., 2019; Tuofu et al., 2021; S. Wu et al., 2021; Ye & Qiu, 2021; Zhu & Zeng, 2018). Of these, three addressed the environmental impact of blue spaces on urban heat island (S. Wu et al., 2021), particulate matter concentration (Zhu & Zeng, 2018), habitat provision and stormwater management (Ye & Qiu, 2021). However, more evidence is needed that supports the role of blue spaces in achieving the SDGs.

A recent study in subtropical Asian cities highlighted the complexities of navigating diverse governance structures in these regions and how climate change adaptation strategies (such as the introduction of UGBS) must be sensitive to the context within which they are implemented (Mabon & Shih, 2021). This feeds into SDG17 ("Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development") which was not directly addressed by any of the studies included in the EGM, but nonetheless signals the need for multilateral participation by countries to address climate change.

4.3.2. Social and economic challenges

Few primary studies in the EGM investigated the social and economic implications of UGBS. Considering that the largest increase in urban population in the next decades is projected to be in LMICs (United Nations, 2018), this is an important consideration. There is scope for further research in this area, particularly to provide a more robust case for the economic value of equal access to vocational training and employment opportunities created through UGBS, thus serving SDG4.3 ("…ensure equal access for all women and men to affordable and quality technical, vocational and tertiary education…") which was not addressed in any included studies. LMICs may stand to benefit the most from this type of research given higher levels of unemployment (King & Shackleton, 2020). While property values were included as a metric to gauge the economic value of UGBS in two studies (A Samad et al., 2020; Tuofu et al., 2021), only two attempted to estimate a wider array of socioeconomic benefits together with house prices (Hunter et al., 2020; Roebeling et al., 2017). Social capital was similarly underexplored, with one study illustrating the social support functions served by community gardens (Kingsley et al., 2020).

The creation of new UGBS risks exacerbating environmental inequalities in cities (Checker, 2011; Eckerd, 2011), precipitating an increase in property values that inadvertently leads to the displacement of lower income households (Atkinson, 2000). Thus, 'green gentrification' can reinforce disparities in access to natural amenities, and worsen existing social and health inequalities (Anguelovski et al., 2022). To date, there are few studies that have attempted to address these adverse impacts. There is evidence that suggests health benefits associated with UGBS are unevenly distributed across sociodemographic groups, with those who have higher levels of education and income deriving the greatest benefit from green space in gentrifying neighbourhoods (Cole et al., 2019).

A study by Giannico et al. (Giannico et al., 2021), found that the effect of urban greenness on perceived quality of life was moderated by per capita income, suggesting that UGBS had a greater impact on quality of life in lower-income cities. This was supported in a review that reported the protective effects of UGBS were stronger for low socioeconomic status groups (Rigolon et al., 2021). Given that the burden of rapid urbanisation is projected to affect LMICs more acutely over the next few decades, a better understanding of the socioeconomic benefits is required. Only then, and with a stronger evidence base supporting the multifunctional benefits of UGBS, can sufficient resources be dedicated to the development of nature-based solutions in these settings.

4.3.3. UGBS interventions and the UN SDGs

Relative to the number of studies that investigated existing UGBS, there were very few studies that assessed UGBS interventions that had been implemented since 2015. Moreover, there was also a lack of studies that explicitly invoked the SDGs in their analysis or attempted to situate their findings within that framework. Nature-based solutions, via UGBS, are a platform upon which other technological and social solutions can be built to alleviate the burden of climate change (Lin et al., 2021). For instance, UGBS can support active transport infrastructure (Hogendorf et al., 2020) which can be augmented by social initiatives to promote their use (Hunter et al., 2015). However, without a clear consensus on how UGBS serves the SDGs, these potential synergies may never be fully realised.

Fig. 4 summarises the key findings from the literature with regards to the identified gaps and potential ways in which future research can address them.

4.4. Strengths and limitations

This study provides a unique perspective on the contribution of UGBS to the SDGs. The EGM is a novel interactive visualisation tool that maps the linkages between study outcomes and the SDGs. In addition to its accessibility, the EGM offers users the ability to filter studies according to various characteristics and identify where gaps are evident in the literature. There are, however, some limitations that must be acknowledged. Firstly, our EGM does not show the direction or significance of association between the SDG outcomes used in primary studies and UGBS. Secondly, we did not conduct a quality appraisal of the studies included in the EGM. Thirdly, due to the expansive scope of the SDGs, and our limiting of eligible studies to those published in English from 2015, it is possible that we did not capture all studies that correspond to outcomes relating to the SDGs in our search. In order to mitigate against this, we used a broad range of search terms that related to each SDG, and systematically applied the inclusion criteria during screening.

5. Conclusions

In sum, the studies included in the review have illustrated the multifaceted role of UGBS in achieving the SDGs. We observed a relative abundance of research examining the beneficial impacts of UGBS on health and wellbeing (SDG3), pollution and urban heat island effects (SDG11 and SDG13). There was, however, a relative lack of studies that assessed the social and economic benefits of UGBS and the contributions

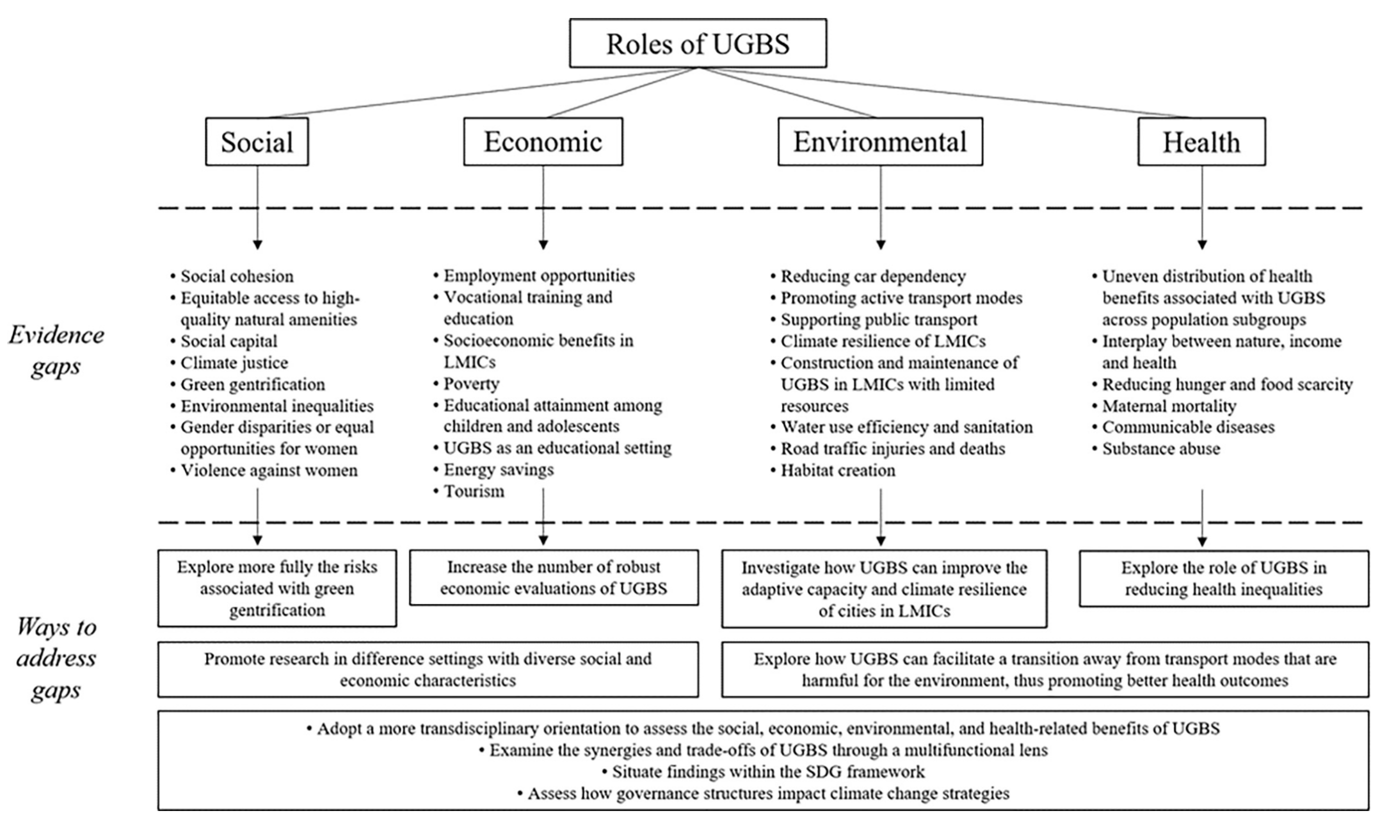

Fig. 4. Summary of key gaps and potential directions for future research.

these can make to the SDGs.

The outcomes reported in a large number of the studies were seldom investigated in conjunction with other co-benefits. We also found that few studies concurrently investigated the synergistic environmental, health, social and economic co-benefits associated with UGBS. Given the extent to which the SDGs are inherently interlinked with one another (X. Wu et al., 2022), future research in this area will benefit from a transdisciplinary approach that attempts to capture and explore the many co-benefits of UGBS across the different SDG dimensions.

We contend that future research on the benefits of UGBS should be more transdisciplinary in scope and better aligned with the outcomes presented in the SDGs. By examining the nexus of challenges associated with urbanisation through a multifunctional lens, more effective policies and interventions can be catered towards improving the wellbeing of urban populations. These research goals are consonant with our view that by harnessing knowledge from multiple disciplinary traditions, the evidence base around UGBS can profit from a range of novel methodologies and insights. A multifunctional framework that maps the contribution of UGBS to the SDGs will provide a platform for additional research in this area and reaffirm the importance of UGBS to mitigate the health, social, economic, and environmental degradation caused by rapid urbanisation which threatens the ecological stability and population health of cities.

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Contributors

CT and RH proposed and initiated the current piece of research. CT led on writing the manuscript with input from all co-authors. Database searches were carried out by CT with input from RH. Title and abstract screening were carried out by CT to retrieve articles for full-text screening. Full text screening was carried by CT and SA. Data extraction was carried out by CT and SA. The protocol for mapping the literature using the Evidence Gap Map methodology was developed by KB. MC informed the systematic elements of the literature searches. All co-authors provided input into interpretation of the results. All authors reviewed and approved the final manuscript.

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CRediT authorship contribution statement

Christopher Tate: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing. **Ruoyu Wang:** Writing – review & editing. **Selin Akaraci:** Formal analysis, Writing – review & editing. **Catherine Burns:** Methodology, Writing – review & editing. **Leandro Garcia:** Writing – review & editing. **Mike Clarke:** Methodology, Writing – review & editing. **Ruth Hunter:** Conceptualization, Funding acquisition, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no competing interests.

Data availability

No data was used for the research described in the article.

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