Urban blue spaces and human health

Cities

Urban blue spaces and human health: a systematic review and meta-analysis of quantitative studies

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Abstract:	Blue spaces, defined as all forms of natural and manmade surface water, are an integral part of cities. This is the first quantitative synthesis of the health impacts of urban blue spaces. Research exploring the health benefits of blue spaces in urban contexts is emergent and, thus, a systematic review and meta-analysis of the evidence is deemed timely. We searched seven databases from inception to August 2019. From 4493 screened citations, 25 eligible studies were identified. Fourteen of these were included in a quantitative synthesis. We found a beneficial association between urban blue space and obesity (β=-0.34,95%CI[-0.19,-0.09],p <0.001), all-cause mortality (HR=0.99,95%CI[0.97,1.00],p =0.038), general health (Cohen's d=-0.09,95%CI[-0.10,-0.08],p <0.001) and self-reported mental health and wellbeing (Cohen's d=-0.25,95%CI[-0.44,-0.07],p <0.001). Effect sizes were small but statistically significant and the overall quality of evidence was good. Evidence for all other health outcomes was incommensurable, and so we provide a narrative description of study results for those outcomes. Although evidence is growing within the field of urban blue space and health, the body of evidence remains small and heterogeneous. More research is required to further understand and harness the benefits of urban blue spaces for public health and guide urban blue space management and development.
Suggested Reviewers:	Helen Charreire helene.charreire@u-pec.fr Health Geographer with interests in urban environments
	Jenny Veitch jenny.veitch@deakin.edu.au Research interests include neighbourhood built environment and its impact on physical activity and social connectedness
	Camille Perchoux camille.perchoux@liser.lu Research Associate in Urban Development & Mobility, interests in urban public health.
Response to Reviewers:	

Dear Editor,

Thank you for the opportunity to submit a revised draft of our manuscript titled *Urban blue spaces and human health: a systematic review and meta-analysis of quantitative studies* to Cities. We would be grateful if you could thank the reviewers on our behalf for their helpful and insightful comments. We appreciate the effort that has been dedicated to providing in-depth constructive feedback. We have endeavoured to address all reviewers' comments and have highlighted these in the manuscript as requested.

These are the main changes we have made to the manuscript:

- ➔ Further clarification provided on the methods to aid readers not familiar with systematic reviews and meta-analysis and to clarify the categorisation of studies for meta-analysis.
- ➔ Discussion has been reformatted to provide better interpretation of results in the context of urban planning.
- ➔ More emphasis has been placed on the need to explore blue spaces, rather than including them in green space.
- ➔ Tables and Figures have been enlarged/moved to enhance clarity.

Attached is a point by point response to both reviewers' feedback.

Sincerely,

Niamh Smith

Reviewer #1

- **Opening Comment:** *Many thanks for your paper which is an interesting read, methodologically strong, and very timely given the importance of the urban environment and local neighbourhoods at the moment, in relation to local lockdowns. In general the paper is well written and put together although there are some stylistic matters to take care of. My comments are few but important to strengthen the paper and be more attractive to readers:*

  Response: Thank you for your positive comments regarding the paper.

- **Comment 1:** *The highlights are not terribly exciting, can you rework them and in particular draw out the implications. Why is this study important? What can we learn from it?*

  Response: We agree. We think our research is exciting and so have edited the highlights in an attempt to convey this. However, we do not want to over-interpret the results. The highlights are now as follow:
    - Blue space has positive health impacts at a population level
    - Positive effects on obesity, all-cause mortality, general health and mental health
    - Quantifying these impacts is useful for urban planning
    - Our results support increasing blue space exposure to improve public health

- **Comment 2:** *In the paper your stated aim is to quantify the relationship between blue spaces and health, but there must be a bigger picture reason for wanting to do this. What is the benefit of quantifying the relationship? What kinds of actions can flow from it? You draw these out in your discussion but you don't set them up sufficiently in your aim.*

  Response: Two sentences have been added following the original aim statement. These highlight exposure-response function – what blue space exposure is needed to see any health impacts. We also highlight the wider implications of the work (to influence policy/interventions which support increased urban blue space exposure):

  "Conducting a meta-analysis allows us to obtain an exposure-response function between urban blue spaces and health outcomes. This is a step towards understanding the level of exposure required before we see a beneficial health response. Findings from this review and meta-analysis can be used to support interventions and policies to increase urban blue space as part of wider efforts to improve public health." (P6, 135-140)

- **Comment 3:** There is excellent material here but the positioning of Figure 1 and legibility of figure 2 would need to be improved. Figure 2 will probably be a full page diagram. Table 1 is very interesting but I wonder would it be better as an appendix at the end of the paper rather than being placed in the middle. There are a lot of citations in section 3 running over page 10 and 11. Stylistically this does not look right. I would be inclined to synthesise the message of this section into 2 or 3 sentences as it simply repeats what we are given in the very detailed table.

  Response: We understand that poor figure alignments can make the flow of reading challenging and have reformatted and increased the quality of these. Figure 1 (P11) is larger, with increased font size. Figure 2 (p15-16) has also been made bigger to increase eligibility. Table 1 (P56-64) has been added to the supplementary information as Table S4. In the Results (P12), the 'Characteristics of included studies' subheadings have been removed, and instead we have summarised the table – omitting the citations as, indeed, these made reading more difficult. It is necessary to keep this level of detail as it is customary for systematic reviews to summarise the characteristics of included studies within the text:

"Study characteristics and main findings are presented in Table S4. Three studies had a longitudinal design (Dzhambov, 2018; Halonen et al., 2014; Zijlema et al., 2019) and the remaining 22 were cross-sectional studies. Thirteen studies were conducted in Europe, four in North America, four in Oceania, three in Asia, and one in South America.

Twenty-four studies used individual participants ranging from 109 people (Dzhambov, 2018) to 1,475,617 people (Wood et al., 2016). One study used area as the unit of measurement for participants (Wheeler et al., 2012). The majority of studies were conducted with adult participants, two focused on older adults, while six focussed on children and young people (Amoly et al., 2015; Benita et al., 2019; Huynh et al., 2013; Rossi et al., 2018; Tillmann et al., 2018; Wood et al., 2016). One paper included participants aged 11 to 94 years (Boers et al., 2018), and one study did not specify the age of participants (Wheeler et al., 2012)." (P12, 246-258)

- **Comment 4:** *There may not be a need for all of the supplementary material. While it is interesting it may be completely overwhelming in a journal format. Possibly it would be worth considering if some of it could be removed but made available electronically for those interested. Perhaps consider what is essential and what can be left out.*

  Response: On balance, we think all of the information detailed in the supplementary material is important for the reader; it shows transparency in how we conducted the systematic review process and ensure its reproducibility. However, we are happy to make the additional files available in an open source repository, instead of being directly attached to the journal article.

- **Comment 5:** *For those who may be less familiar with the methodologies you adopt, I think it would be helpful to provide a very brief explanation of what a meta-analysis is and how it is done.*

  Response: We have added summary sentences and citations into the Methods section to provide more guidance on the purpose of systematic reviews and meta-analysis:

  "Systematic reviews use a rigorous and standardised approach to synthesise the available scientific evidence about a specific research question (Deeks, 2011). They follow a protocol that ensures they follow a transparent and reproducible process. Systematic reviews are widely used in medicine and public health to inform evidence-based practice and interventions (Khan et al., 2011). A meta-analysis is a statistical method used to pool the results of multiple studies into a quantitative estimate reflecting the relationship between an exposure and an outcome (Greco et al., 2013)." (P7, 147-154)

- **Final comment:** All in all though, a very good paper which sets out a clear research agenda. Well done!

Response: Thank you for your considered and constructive comments.

Reviewer #2

- **Opening Comment:** *This manuscript is a useful, and potentially important, contribution that synthesises the emerging evidence on blue spaces and human health. Aside from a few exceptions, which I detail below, the manuscript is well written and applies appropriate methods and interpretations.*

- **Response:** Thank you for your positive opening comments.

- **Comment 1:** *I am not convinced that the studies that were included in the meta-analyses had sufficiently similar exposures. For example, mental health (but there are similar issues with the other health outcomes): Garrett - self-reported walking time to any blue space Mavoa - Euclidean distance from residential address to coast Volker - self reported minutes to water White - Euclidean distance from population weighted centroid to coast. First, studies have shown that there are discrepancies between self-reported/perceived and objectively measured accessibility to urban features. Second, even if accurately assessed, time to water may be more likely to align with network distances and be dependent on road/footpath infrastructure. Third, as the authors acknowledge elsewhere in the manuscript, the coast is not the same as any blue space.*

- **Response:** We acknowledge and appreciate that exposure is difficult to measure. This comment has encouraged us to be more transparent in reporting the grouping of studies. We have included:

  "We made every effort to reduce heterogeneity by categorising types of exposure, and only studies that measured distance to blue space were pooled. This categorisation should be acknowledged when interpreting the pooled results." (P9, 207-210)

  These issues are common when analysing the health impact of environmental factors. Within a recent paper on green space and mortality in the Lancet, authors still gained 95% heterogeneity even when their exposure was consistent. We have also made reference to this in the limitations:

  "Studies were categorised by blue space exposure, and only those with comparable measurements of distance to blue space were included in the meta-analysis. Environmental exposure is difficult to measure and so although these studies measured distance differently, we deemed them adequately comparable". (p33, 709-713)

- **Comment 2:** *The overall conclusion is that "Effect sizes were small but statistically significant". Please can you comment on whether these effect sizes were meaningful? I understand that addressing this question may only be possible when the effect sizes were not transformed.*

- **Response:** We are grateful for this comment and have added discussion around the difficulty in assessing the meaningful significance of environmental exposure:

"Unlike clinical significance, meaningful significance for environmental exposure is more difficult to define. However, due to increased urbanisation and the prevalence of blue spaces in urban environments, small effect sizes at an individual level collectively create major public health benefits." (P25, 500-504)

And in the conclusion we have added:

"When scaled to the population level, these effect sizes may have a wide-reaching public health impact" (P34, 727-728).

- **Comment 3:** *"Exposure to urban blue spaces may offer a solution to improve population health" How modifiable are urban blue spaces? "indicate whether blue space may be a potential upstream lever for health promotion" How? The authors touch on this in a few paragraphs towards the end of the discussion but I think the manuscript needs greater clarity and discussion on how blue space exposure (and thereby health) could be modified/tweaked by different mechanisms, including those related to urban planning. E.g. how would it be possible to ensure that a greater percent of the population could live closer to the coast? Addressing this comment could perhaps be achieved when editing the Discussion (see comment 12 below). A greater engagement with planning is especially important given Cities is an urban planning journal.*

  Response: Thank you for this comment, it was very helpful in redrafting the discussion section. We have re-formatted the discussion entirely to improve clarity and flow. We have added a new section (4.2), specifically to clarify ways in which blue space could be modified to improve health and have tailored the writing to be more relevant to the Cities' readers. The discussion is now formatted:

  - Summary paragraph of results (P24-25)
    - Added "Findings from this review highlight the potential public health value of policies which protect and manage urban blue spaces, and that decision-makers should begin to consider incorporating these benefits into urban planning and water management."(P25, 508-511)

  - 4.1 Comparisons to other literature (P25-27)

  - 4.2 Incorporating health into urban blue space policy, planning and practice (P28-30)
    - This section now provides much more relevant information on how blue spaces could be incorporated into urban planning. Paragraphs are structured as follows:
      - The EU's 'Health in all policies' (P28, 571-580)
      - Blue space in new developments/nature based solutions (P28, 582-595)
      - Existing Blue spaces/Improving access (P29-30, 597-619)
      - Quality of Blue space (P30, 621-635)

  - 4.3 Future research (P30-33)

- 4.4 Strengths and Limitations of this review (P33)

We have also opened the conclusion with:

"Urban planning must be informed by the evidence for the effectiveness of urban changes on human health and wellbeing." (P34, 713-714)

- **Comment 4:** *General. The manuscript suggests that a problem with the current evidence is that it uses heterogeneous measures of blue space exposure (e.g. p. 38 " A more nuanced, homogenous measurement battery of urban blue space would be helpful"). The call for a more homogenous measurement battery seems somewhat contradictory, since when at the same time, the review considered that the blue space exposure measures were sufficiently homogenous to undertake a meta-analyses. Indeed, assessing presence, percentage, and distance seems somewhat standard, with differences being the buffer sizes used to assess presence and percentage. However, appropriate buffer sizes are likely to vary for different contexts, populations, water bodies, and health outcomes.*

  Response: Thank you for this. Indeed, our writing may have appeared contradictory. We have now highlighted in the Methods that papers were grouped, and only those with comparable exposure were included in meta-analysis (as above).

  Regarding heterogeneity, we have added:

  "The heterogeneity is in part expected in this type of research as the majority if studies were largely incommensurable and were therefore not included in the analysis; i.e., there was variation in the measurement of the blue space exposure, measurement of each health outcome, the confounder variables considered, and the analytic procedures undertaken. This heterogeneity should be taken into account when interpreting the pooled effect sizes (Bailar, 1997)." (P24, 482-487)

  We have removed the comment about a standard battery, and discuss the issues around standardisation in the Discussion:

  "There is no universally accepted standardisation of appropriate buffer sizes for either green or blue spaces (World Health Organization, 2016). Although standardised measurements allow for easier comparison across studies, they can often overlook cultural and climatic differences. Therefore, different measurement tools may be appropriate in different contexts." (P31, 648-654)

- **Comment 5:** *Introduction. P.3 "Unfortunately, these reviews do 67 not typically differentiate between green space and blue space. Instead, blue space 68 is often subsumed within "green space", "green and blue space" or the "natural 69 environment" (Bell et al., 2018; Kabisch et al., 2016; Norwood et al., 2019)". It would be useful if the authors could explicitly state and elaborate on why it is a problem that blue space is subsumed within green space.*

  Response: We have removed 'unfortunately'. We wanted to provide more direct information regarding blue spaces, as they may provide different health benefits to green.

Also, blue spaces are managed by different people than parks/green space. We have added justification for the need to consider blue spaces into the introduction:

"When we think about natural spaces in cities, we tend to visualise green spaces, such as parks; rarely do we consider the urban blue spaces that can be found within or nearby green spaces. We also rarely think about blue spaces independent of green space, such as urban rivers and canals, as natural spaces. Completely separating the health effects of green and blue spaces is difficult as blue and green spaces often co-exist. We are seeing a gentle shift towards discussions around 'green and blue spaces'. However, it has been argued that blue spaces may provide different human experiences than those offered by green space and may impact health outcomes in different ways (Haeffner et al., 2017). Also, within cities, blue space infrastructure is often developed and managed by waterway and ecosystem services, while green spaces, like parks, tend to be under the management of urban planners, housing and leisure departments. Therefore, we must consider the health impacts of blue spaces as distinct from those of green space to garner increased awareness across all sectors responsible for managing city environments." (P4, 72-85)

- **Comment 6:** *Introduction. L 74-76 "Research to date has focused primarily on the potential health hazard of urban blue spaces such as drownings, sites for water pollution, as well as breeding grounds for infectious diseases" Please provide citations for these statements.*

  Response: Citations added for each of the health hazards:

  "Research to date has focused primarily on the potential health hazard of urban blue spaces such as drownings (Tyler et al., 2017), contaminated drinking water (Villanueva et al., 2014), and breeding grounds for vectors of infectious diseases (Yang et al., 2020)." (P4, 87-90)

- **Comment 7:** *P. 34-35 "Our findings for the associations between urban blue space and all-cause mortality are comparable with this " and " Our findings indicate that the association between blue space exposure and general health has a similar effect size as green space (Cohen's d = - 0.09, 95% CI [-0.10, -0.08])". To what extent might the findings of greenness (which include blue space) overlap with the findings from your review? Similarly, I am not convinced by the statement that "Such findings all highlight the need to consider blue space independently of green space when examining the health promoting capabilities of outdoor environments, as we have shown that blue space, in isolation, can benefit health". I don't think you can draw this conclusion from the current review of studies that don't appear to have examined bluespace in isolation from green space.*

  Response: Regarding the potential overlap, we have added:

  "Therefore, blue spaces appear as valuable to public health as green spaces. There is, however, the possibility that the effects might be a result of greenness surrounding particular blue spaces. Conversely, it is also possible that some of the effect reported for green space may come from the presence of blue spaces, as often blue is subsumed within green space. Green space literature has tended to focus on parks, and so canals and rivers, which are present in most cities, are excluded from such research."(P26, 535-541)

Within the introduction we have clarified why we are measuring blue space separately from green (as above). We have also altered the language in our Discussion to:

"These findings and associated discussion highlight the need to consider blue space independently of green space when examining the health-promoting capabilities of outdoor environments, as we have shown that blue space can have health benefits that may be distinct and complementary to those provided by green space."(P26, 541-545)

- **Comment 8:** *P. 36 "Studies which objectively measure blue space exposure have done so using buffers, distance and percentage of blue space" Buffers are often used in combination with 'percentage blue space'. Do you mean "presence" instead of "buffers"?*

  Response: Yes, you're right. This was a typo and has been changed to read:

  "Studies which objectively measured blue space exposure have used presence, distance and percentage of blue space" (P31, 642-643).

- **Comment 9:** *P. 36 "The WHO guidelines define access to green space as living within a 300m buffer of green space of at least 0.5 ha (World Health Organization, 2016). Further research is required to produced similar guidelines for blue space exposure." Was the WHO guideline based on evidence?*

  Response: Very interesting comment, thank you. It's important that we are critical of WHO guidelines. It has been, indeed, a common concern with other WHO green space guidelines which actually are not evidenced anywhere!: https://www.researchgate.net/post/I-see-many-studies-citing-WHO-for-their-international-minimum-standard-for-green-space-9m2-per-capita-But-where-is-the-actual-study

  This section has been reworked:

  "There is no universally accepted standardisation of appropriate buffer sizes for either green or blue spaces (World Health Organization, 2016). Although standardised measurements allow for easier comparison across studies, they can often overlook cultural and climatic differences. Therefore, different measurement tools may be appropriate in different contexts." (P31, 649-654).

- **Comment 10:** *P. 36 " Few studies assessed the quality of the urban blue space being investigated." I read this to mean that some of the included studies did assess quality. How many studies? Which ones? How did they assess quality? Some of this might belong in the results.*

  Response: This is important and backs-up our points about the need to consider quality in of blue space, so thanks for highlighting. Only one study assessed quality of blue space. This has been added into the results and we have followed this up in the discussion:

"Only one study included an assessment of the quality of the blue space in their analyses, asking participants about perceived safety, perceptions of wildlife, litter pollution and nearby facilities (Garrett et al., 2019)." (P14, 299-301)

"Only one study assessed the quality of the urban blue space being investigated (Garrett et al., 2019)." (P30, 623-624)

- **Comment 11:** *P. 37. "Therefore, blue space has been measured through self-reported assessment of travel time and frequency of use" Please add citations*

  Response: This was repetitive and was removed when restructuring the discussion.

- **Comment 12:** *Discussion. Some excellent points here, however this section is a little disjointed, hard to follow, and has some repetition in different paragraphs. Please edit this section to improve clarity of flow/structure, and reduce repetition. Having more shorter paragraphs may aid readability in this section.*

  Response: On re-reading the discussion, we agree and the comments from reviewers have been very helpful in reshaping this section. We have detailed how this has been restructured in our response to Comment 3 above. We have also taken on board the comment about paragraph size and have structured the writing into more digestible paragraphs.

We look forward to hearing from you regarding our re-submission. We are happy to respond to any further questions and comments you may have.

Sincerely,

First Author

Highlights

- Blue space has positive health impacts at a population level
- Positive effects on obesity, all-cause mortality, general health and mental health
- Quantifying these impacts is useful for urban planning
- Our results support increasing blue space exposure to improve public health

Urban blue spaces and human health: a systematic review and meta-analysis of quantitative studies

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Urban blue spaces and human health: a systematic review and meta-analysis of quantitative studies

Abstract

Blue spaces, defined as all forms of natural and manmade surface water, are an integral part of cities. This is the first quantitative synthesis of the health impacts of urban blue spaces. Research exploring the health benefits of blue spaces in urban contexts is emergent and, thus, a systematic review and meta-analysis of the evidence is deemed timely. We searched seven databases from inception to August 2019. From 4493 screened citations, 25 eligible studies were identified. Fourteen of these were included in a quantitative synthesis. We found a beneficial association between urban blue space and obesity (β= -0.34, 95% CI [-0.19, -0.09], p< 0.001), all-cause mortality (HR= 0.99, 95% CI [0.97, 1.00], p= 0.038), general health (Cohen's d = -0.09, 95% CI [-0.10, -0.08], p< 0.001) and self-reported mental health and wellbeing (Cohen's d = -0.25, 95% CI [-0.44, -0.07], p< 0.001). Effect sizes were small but statistically significant and the overall quality of evidence was good. Evidence for all other health outcomes was incommensurable, and so we provide a narrative description of study results for those outcomes. Although evidence is growing within the field of urban blue space and health, the body of evidence remains small and heterogeneous. More research is required to further understand

and harness the benefits of urban blue spaces for public health and guide urban blue space management and development.

Keywords

Blue Space; Urban Environment; Mortality; Obesity; General Health; Mental Health

1. Introduction

Blue space, defined as all forms of natural and manmade surface water, could be an asset in achieving sustainable urban environments that promote human health. However, to date, no quantitative synthesis exists to evidence the potential beneficial health effects of urban blue spaces. Increased urbanisation and densification is a potential threat to public health; approximately 55% of the world's population is now living in urban areas, with that statistic set to rise to two-thirds of the global population by 2050 (UN, Department of Economic and Social Affairs, 2018). Characteristics of cities that can negatively affect health include increased car ownership, resulting in congestion and increased noise and air pollution; the strain on sewage systems; pressure on already stretched urban infrastructure (e.g., housing, transportation, and health care) as well as a rise in socioeconomic disparities and issues like poverty and crime (Hou et al., 2019). These factors can contribute to an increased prevalence of chronic non-communicable diseases (Goryakin et al., 2017) and poor mental health (Flies et al., 2019; Lorenc et al., 2012). For example, urbanisation may be associated with a higher incidence of psychosis and depression (Fett et al., 2019; Sampson et al., 2020). Non-communicable diseases are the leading cause of deaths globally, with coronary heart disease and stroke contributing to a combined 15.2 million deaths a year (World Health Organization, 2018). The global prevalence of obesity has almost tripled over the last 40 years, with urban areas seeing a particular increase (World Health Organization, 2020a). Paradoxically, cities can be some of the healthiest places to live, providing people with robust social networks, employment opportunities, and access to facilities and services that can promote health (World Health Organization, 2010). Such inconsistencies indicate that the influences of specific types of urban environments and urban living on health need to be further understood. By doing so, city planning activities will be able to better support positive physical, mental and social health, and potentially mitigate the dangers cities may present to health.

Exposure to natural environments in urban settings has been shown to improve health and wellbeing (van den Bosch and Ode Sang, 2017). However, evidence of the impacts of the world's natural environment on health has centred predominantly around the concept of "green" space (e.g., greenways, parks, foliage). Several reviews have focused on these relationships (Bowler et al., 2010; Gascon et al., 2015; James et al., 2015; Rojas-Rueda et al., 2019). These reviews do not typically differentiate between green space and blue space. Instead, blue space is often subsumed within "green space" or the "natural environment" (Bell et al., 2018; Kabisch et al., 2016; Norwood et al., 2019). We define urban blue space as all natural and manmade surface water in urban environments. Examples include coasts, rivers, lakes, canals, ponds, and fountains situated within cities.

When we think about natural spaces in cities, we tend to visualise green spaces, such as parks; rarely do we consider the urban blue spaces that can be found within or nearby green spaces. We also rarely think about blue spaces independent of green space, such as urban rivers and canals, as natural spaces. Completely separating the health effects of green and blue spaces is difficult as blue and green spaces often co-exist. We are seeing a gentle shift towards discussions around 'green and blue spaces'. However, it has been argued that blue spaces may provide different human experiences than those offered by green space and may impact health outcomes in different ways (Haeffner et al., 2017). Also, within cities, blue space infrastructure is often developed and managed by waterway and ecosystem services, while green spaces, like parks, tend to be under the management of urban planners, housing and leisure departments. Therefore, we must consider the health impacts of blue spaces as distinct from those of green space to garner increased awareness across all sectors responsible for managing city environments.

Research to date has focused primarily on the potential health hazard of urban blue spaces such as drownings (Tyler et al., 2017), contaminated drinking water (Villanueva et al., 2014), and breeding grounds for vectors of infectious diseases (Yang et al., 2020). Nonetheless, recent years have seen a growing interest in understanding the potential salutogenic effects of blue spaces (Antonovsky, 1996; Grellier et al., 2017). For example, it has been suggested that blue spaces might relieve stress and enhance wellbeing (Völker and Kistemann, 2013; White et al., 2013), may encourage people to participate in physical activity and have an active lifestyle (Pasanen et al., 2019), and may promote positive social interactions (Ashbullby et al., 2013). Urban blue space may also mitigate adverse environmental impacts, such as heat islands, by creating more comfortable urban temperatures (Völker et al., 2013). Anecdotal evidence suggests that wading fountains in cities may provide a physical source of respite from high temperatures. There is also evidence to suggest that people living in coastal regions live longer and healthier lives (White et al., 2013). Blue spaces are an integral part of most cities, with half of the global population living within 3km of a body of freshwater (Kummu et al., 2011). It is therefore crucial that we understand the relationships between blue space and human health.

Three reviews to date have assessed the evidence on the relationships between blue space and health (Britton et al., 2018; Gascon et al., 2017; Völker and Kistemann, 2011). Völker and Kistemann (2011) provide a scoping review of the health impacts of freshwater spaces, with evidence to suggest that blue space can positively affect health and wellbeing directly, as well as through mechanisms including recreation, landscape design and personal perceptions of space. Gascon et al.'s (2017) systematic review of 35 quantitative studies found evidence for positive associations between outdoor blue space exposure and physical activity and mental health and wellbeing. Britton et al. (2018) focused on 'blue care', which refers to using blue space as an intervention for promoting health and wellbeing. They reviewed evidence from 33 qualitative, mixed-method and quantitative studies and found that blue care can directly benefit health, particularly mental health and psychosocial wellbeing (Britton et al., 2018).

While these narrative reviews support the notion that blue spaces can have a positive impact on health, to date there is no quantitative synthesis of the current evidence. Meta-analyses can assess the strength of current evidence on the health impacts of blue space (Moher et al., 2009). Quantitative evidence can both substantially advance the field and can indicate whether blue space may be a potential upstream lever for health promotion. In addition, the reviews above do not focus specifically on urban settings, with the relationship between exposure to blue space and health likely to be different in rural areas where population density is lower (Halonen et al., 2014) and access to green and blue spaces tends to be greater (Scottish Government, 2019). Health and wellbeing are increasingly considered key determinants when planning cities (World Health Organization, 2020). Quantitative synthesis of evidence can inform recommendations to support the integration of health into future urban planning and inform policy in water management and public health. Therefore, this paper aims to systematically review the evidence for the relationship between blue space and health and quantify this relationship specifically in urban environments. Conducting a meta-analysis allows us to obtain an exposure-response function between urban blue spaces and health outcomes. This is a step towards understanding the level of exposure required before we see a beneficial health response. Findings from this review and meta-analysis can be used to support interventions and policies to increase urban blue space as part of wider efforts to improve public health.

2. Methods

Our study followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher et al., 2009) (Supplementary material Table S1). A protocol was pre-registered with PROSPERO, ID: XXXXXXXXXXX on 15

November 2018, and is available at XXXXX. Systematic reviews use a rigorous and standardised approach to synthesise the available scientific evidence about a specific research question (Deeks, 2011). They follow a protocol that ensures they follow a transparent and reproducible process. Systematic reviews are widely used in medicine and public health to inform evidence-based practice and interventions (Khan et al., 2011). A meta-analysis is a statistical method used to pool the results of multiple studies into a quantitative estimate reflecting the relationship between an exposure and an outcome (Greco et al., 2013).

2.1 Search Strategy

We developed a comprehensive search strategy with assistance from a subject-specific librarian (Supplementary material Table S2). We used a combination of free text and MeSH terms for urban environments (e.g., city, metropolitan area, non-rural), blue space exposure (e.g., canal, lake, river, coast, water), and terms related to physical and mental health outcomes (e.g., mortality, obesity, life expectancy, heart disease, blood pressure, Body Mass Index, non-communicable disease, wellbeing, stress, depression, anxiety, quality of life). We included all human populations to explore the health impacts of urban blue space across the life course.

We searched seven electronic bibliographic databases (PubMed, CINAHL [EBSCO], PsycINFO [EBSCO], Scopus, Science Direct, Web of Science and MEDLINE [OVID]). Searches were restricted to peer-reviewed studies written in English, published between database inception and 1 August 2019. In addition, the search was completed by scanning the reference lists of eligible articles in search for potential additional sources.

2.2 Inclusion Criteria

We included articles reporting original, quantitative research measuring the effects of urban blue space exposure on physical and mental health outcomes. We adopted the epidemiological definition of exposure, i.e. a factor that may be associated with a health outcome. Cross-sectional, longitudinal, and prospective studies, as well as randomised controlled trials, cross-over trials, natural experiments and quasi-experimental studies were included. We only included studies conducted in urban environments of any size, defined as areas with high population density or where built infrastructure covers a large proportion of land surface (Pickett et al., 2011).

Studies that did not report findings on blue space separately from other outdoor environments (such as parks, natural outdoor environments or other green spaces) were excluded. We also excluded studies that reported on artificial exposure to green and blue spaces, such as virtual reality or exposure to images of blue spaces, or if exposure to blue spaces was used only as a confounder or mediator in analyses. Articles reporting only on mechanisms or pathways between blue space and health (e.g., physical activity, sleep or stress) were excluded. Similarly, we excluded studies that did not report findings on blue space specifically for urban areas, for example, studies which adjusted for urbanicity rather than stratified analysis between urban and rural areas.

2.3 Study selection, data extraction and analysis

Three reviewers (A1, A2, A3) independently screened titles and abstracts of papers for eligibility. We then independently evaluated full texts of the retained articles to ascertain eligibility and to scan reference lists. The following data were extracted and recorded by A1 on a predefined and piloted data extraction form: authors, publication date, study context, study design, population, sample size, blue space exposure, blue space measurement, health outcome(s), health outcome measurement, data analysis information, statistical adjustments made, a results summary and whether results were reported statistically significant by original study authors. A second author (A2) checked the extracted data. Disparities in reviewer opinions were resolved through discussion and consensus was achieved, with the involvement of an additional reviewer where necessary.

We pooled studies for fixed-effects meta-analyses that were comparable in terms of a specific health outcome and a similar measure of exposure (either distance to blue space, presence of blue space or frequency of visits to blue spaces). We made every effort to reduce heterogeneity by categorising types of exposure, and only studies that measured distance to blue space were pooled. This categorisation should be acknowledged when interpreting the pooled results. When different estimates of effect size were reported, they were first transformed to Cohen's *d* (Lipsey and Wilson, 2001). All meta-analyses were performed using the Comprehensive Meta-Analysis (Version 3.3, Biostat Englewood NJ) (Lipsey and Wilson, 2001). We assessed statistical heterogeneity by visually inspecting funnel plots and used the I^2 statistic as an indication of the proportion of heterogeneity. We interpreted heterogeneity as low, moderate, or high, with upper limits of 25%, 50% and 75% for I^2, respectively (Higgins et al., 2003). Where studies were incommensurable and therefore could not be included in a meta-analysis, we provided a narrative description of study results rather than a meta-analysis (Deeks, 2011).

2.4 Quality appraisal and synthesis of evidence

To align with other blue space literature, we assessed the quality of included studies using the quality assessment tool designed by Gascon et al. (2017) specifically to assess research on blue spaces and health (Supplementary material Table S3). We appraised each article based on the study design, appropriateness of confounding variables, presentation of results, issues of bias and multiplicity, health measurement, blue space exposure measurement, if the use of blue space was acknowledged, the effect size of results and whether participants had lived in the same place for at least a year. Papers were assessed and given a score (%). We used the same categories of study quality as Gascon et al. (2017) to ensure consistency across the literature: excellent (≥81%), good (61-80%), fair (41-60%), poor (21-40%) and very poor (≤20%).

3. Results

3.1 Study selection

Our search of databases and reference lists identified 4499 records. The flow of information is shown in Figure 1. We identified 4926 records from seven databases: 1024 in PubMed, 1512 in CINAHL, 1395 in Scopus, 621 in MEDLINE, 285 in Science Direct, 73 in Web of Science, and 16 in PsycINFO. Six additional articles were added from searching reference lists. In total, we screened 51 articles in full. Ten studies were excluded as they did not specifically report on urban environments,

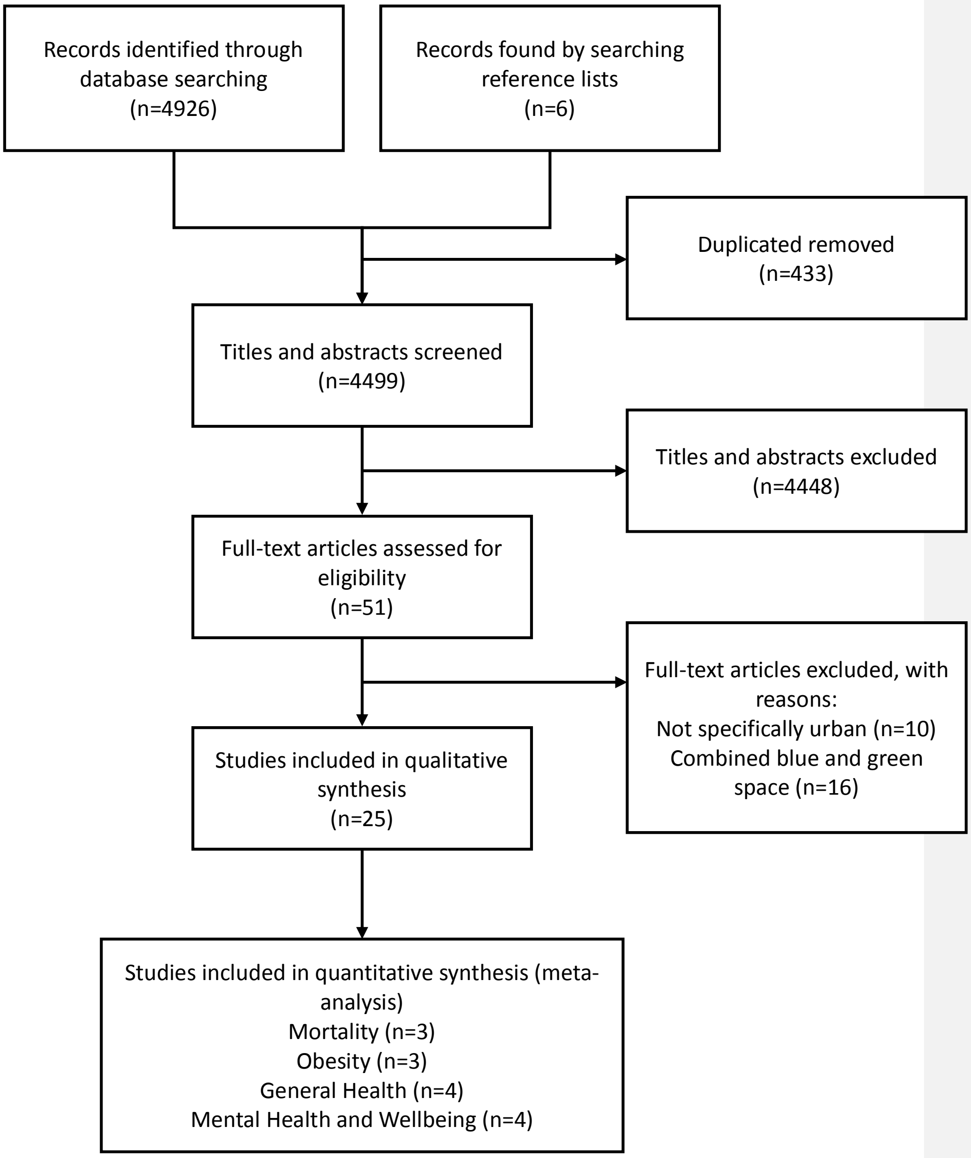

Figure 1 - Flow of studies through the review

and 16 were excluded because they did not measure blue space independently of green space. We included 25 studies in our review, 14 of which were included in our quantitative synthesis (Mortality, n=3; Obesity, n=3; General Health, n=4; Mental Health and Wellbeing, n=4).

3.2 Characteristics of included studies

Study characteristics and main findings are presented in Table S4. Three studies had a longitudinal design (Dzhambov, 2018; Halonen et al., 2014; Zijlema et al., 2019) and the remaining 22 were cross-sectional studies. Thirteen studies were conducted in Europe, four in North America, four in Oceania, three in Asia, and one in South America.

Twenty-four studies used individual participants ranging from 109 people (Dzhambov, 2018) to 1,475,617 people (Wood et al., 2016). One study used area as the unit of measurement for participants (Wheeler et al., 2012). The majority of studies were conducted with adult participants, two focused on older adults, while six focussed on children and young people (Amoly et al., 2015; Benita et al., 2019; Huynh et al., 2013; Rossi et al., 2018; Tillmann et al., 2018; Wood et al., 2016). One paper included participants aged 11 to 94 years (Boers et al., 2018), and one study did not specify the age of participants (Wheeler et al., 2012).

3.2.4 Blue space exposure

The review considered exposure to all types of urban blue space. Seven studies measured coastal blue spaces (Abelt and McLafferty, 2017; Amoly et al., 2015; Rossi et al., 2018; Wheeler et al., 2012; White et al., 2017; Witten et al., 2008; Wood et al., 2016), while the remaining 18 included all blue space environments and did not differentiate between types of blue space. Blue space measurement varied and included objective measurements as well as the self-reported frequency of use of blue spaces and travel times to blue spaces (Figure 2). Five studies used land cover maps and geographic information systems (GIS) tools to calculate the percentage of blue space coverage within a defined area (Boers et al., 2018; Huynh et al., 2013; Mavoa et al., 2019; Nieuwenhuijsen et al., 2018; Tillmann et al., 2018). Five studies used land cover maps to determine whether there was a presence (yes/no) of blue space within specific buffers (Abelt and McLafferty, 2017; Crouse et al., 2018; Dzhambov, 2018; Gascon et al., 2018; Triguero-Mas et al., 2015). The distance between neighbourhood population-weighted centroids and local blue spaces using land cover maps and GIS was used as an exposure measurement for seven studies; six used linear distance (Halonen et al., 2014; Mavoa et al., 2019; Wheeler et al., 2012; White et al., 2017; Wood et al., 2016; Zijlema et al., 2019), and one used the travel time to beach access points, following the road network (Witten et al., 2008).

As well as measuring the distance to blue space, White et al. (2017) also used a questionnaire which asked how frequently participants' visited coastal environments. Six other studies used self-reported methods to measure blue space exposure. Four of these asked participants how frequently they visited blue spaces (Amoly et al., 2015; Garrett et al., 2019; Rossi et al., 2018; Völker et al., 2018). Rossi et al. (2018), Garrett et al. (2019) and Völker et al. (2018) also asked participants about the perceived distance (in minutes) from their home address to blue space. Gilchrist et al. (2015) measured visibility of blue space by asking office workers if they had a view of a water body from their office window (yes/no) while Garrett et al. (2019) also asked participants if they had a view of blue space from their home (yes/no). Finally, Korpela et al. (2010) asked people to rate different types of environments in relation to personal importance, with one category comprising waterside environments.

Other studies used unique tools to measure blue space exposure. Nutsford et al. (2016) developed the Vertical Visibility Index, which considered how much blue space (and other outdoor space) was visible from participants' home addresses within a 15km buffer. Helbich et al. (2019) employed artificial intelligence deep learning techniques to develop Streetscope technology which mapped and coded satellite images of the natural and built environments to determine exposure to blue space through a process called "image segmentation". Benita et al. (2019) had participants wear sensors which connected to Wi-Fi access points to determine location, and data were then assigned to land use maps.

Only one study included an assessment of the quality of the blue space in their analyses, asking participants about perceived safety, perceptions of wildlife, litter pollution and nearby facilities (Garrett et al., 2019).

3.2.5 Outcomes

We categorised studies based on whether they reported on physical health or mental health, and how blue space exposure and health outcomes were measured (Figure 2).

Physical and General Health

Author (Date)	Health Outcome	Health Measurement	Blue Space Exposure Measurement
Halonen et al. (2014)	Obesity	📝	📍
Rossi et al. (2018)	Obesity*	⚕	🕒
Witten et al. (2008)	Obesity*	⚕	📍
Wood et al. (2016)	Obesity*	⚕	📍
Crouse et al. (2018)	Mortality*	⚕	✓
Zijlema et al. (2019)	Mortality*	⚕	📍 ✓
Nieuwenhuijsen et al. (2018)	Mortality*	⚕	%
Abelt and McLafferty (2017)	Adverse Birth Outcomes	⚕	✓
Tillmann et al. (2018)	HRQOL	📝★	%
Wheeler et al. (2012)	General Health*	📝	📍
Garrett el al. (2019)	General Health*	📝★	🕒
Völker et al. (2018)	General Health (physical)*	📝★	🕒
Triguero-Mas et al. (2015)	General Health*	📝★	✓

Mental Health

Author (Date)	Health Outcome	Health Measurement	Blue Space Exposure Measurement
Völker et al. (2018)	Mental Health*	📝★	🕒
Garrett el al. (2019)	Wellbeing*	📝★	🕒
Triguero-Mas et al. (2015)	Mental Health	📝★	✓
	Depression/Anxiety	📝	
	Visit to Specialist		
	Medication Intake		
Huynh et al. (2013)	Wellbeing	📝★	%
Mavoa et al. (2019)	Wellbeing*	📝★	📍 %
Gilchrist et al. (2015)	Wellbeing	📝★	⋯
White et al. (2017)	Wellbeing*	📝★	📍
Nutsford et al. (2016)	Psychological Distress	📝★	⋯
Korpela et al. (2010)	Restorative Experience	📝	⋯
Helbich et al. (2019)	Depressive Symptoms	📝★	⋯
Dzhambov (2018)	Depressive Symptoms and Anxiety	📝★	✓
Gascon et al. (2018)	Depressive Symptoms	⚕	✓
Amoly et al. (2014)	Emotional Functioning	📝★	🕒
Boers el al. (2018)	Major Mental Illness	⚕	%
Benita et al. (2019)	Momentary Subjective Wellbeing	📝	⋯

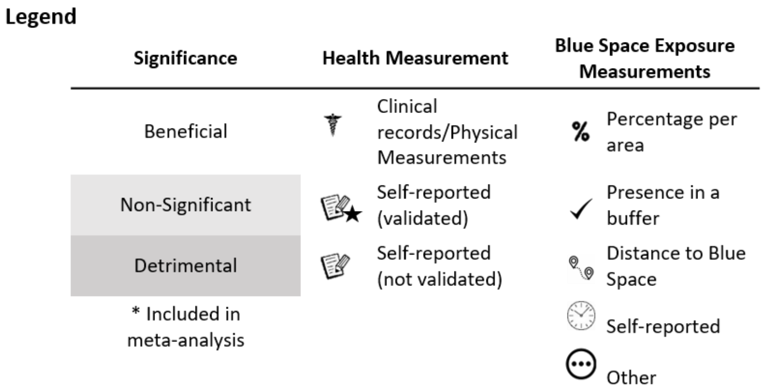

Figure 2 - Included studies showing variation in measurement of blue space exposure and health outcomes.

Physical health outcomes included obesity, mortality, adverse birth outcomes, physical function and general health. Mental health outcomes included self-reported mental health and wellbeing, diagnosed depression or anxiety, reported visits to mental health specialists, prescriptions of mental health medication, psychological distress, restorative experiences, experiences of depressive symptoms or anxiety, emotional functioning, mental disease and momentary subjective wellbeing. Physical health was the focus of 10 papers, 12 papers reported on mental health, and three measured both physical and mental health outcomes. Measurements of health outcomes varied and included clinical measurements and various validated and non-validated self-reporting tools.

3.3 Quality of evidence

Overall, we found that the majority of the 25 included studies were of good quality (n=17). We rated two study as excellent, five as fair and one as poor. No studies were rated as very poor. The quality assessment did not highlight specific areas of weakness in the field, but instead, studies were downgraded for a range of reasons

(Supplementary material Table S3). We cross-referenced the quality assessment categories with those given by Gascon et al. (2017) for eight articles that were included in both reviews, as a cross-validation. Quality categories were consistent across both reviews (Amoly et al., 2015; Halonen et al., 2014; Huynh et al., 2013; Nutsford et al., 2016; Triguero-Mas et al., 2015; Wheeler et al., 2012; Witten et al., 2008; Wood et al., 2016).

3.4 Health impacts of urban blue space exposure

3.4.1 Physical Health

3.4.1.1 Obesity

Four articles focused on the impacts of blue space on obesity measured using Body Mass Index (BMI), which is calculated using an individual's height and weight. Three articles used trained researchers to take physical measurements of height and weight (Rossi et al., 2018; Witten et al., 2008; Wood et al., 2016), while Halonen et al. (2014) used self-reported assessments of height and weight. These studies were conducted in Florianópolis, Brazil (Rossi et al., 2018) and urban areas of New Zealand (Witten et al., 2008), England (Wood et al., 2016) and Finland (Halonen et al., 2014).

Our meta-analysis of obesity levels suggested that living closer to urban blue space was associated cross-sectionally with lower obesity levels in adults and children (Figure 3). The pooled effect size was small but statistically significant (β = -0.34, 95% CI [-0.19, -0.09], $p < 0.001$). This finding was reinforced by Halonen et al.'s

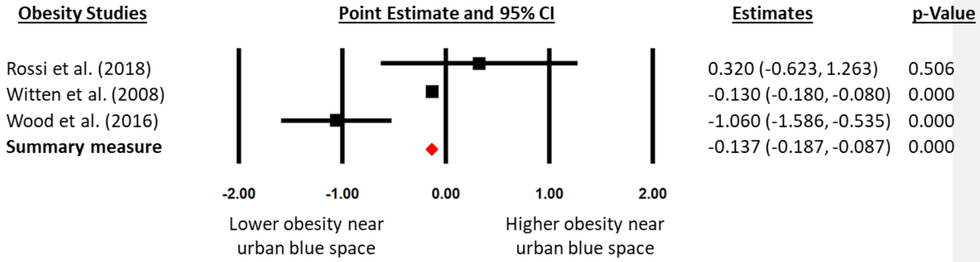

Figure 3 - Forest plot of the relationship between living close to urban blue space and obesity. The area of each block indicates the weight assigned to that study in the meta-analysis.

(2014) longitudinal study over eight years of 15,621 participants which found that participants who lived further away from blue spaces in urban areas of Finland had a greater prospective risk of being overweight.

3.4.1.2 Mortality

Three articles reported on the prospective association of blue space exposure with all-cause mortality risk. These studies were conducted in metropolitan centres in Canada (Crouse et al., 2018), Barcelona, Spain (Nieuwenhuijsen et al., 2018), and Perth, Australia (Zijlema et al., 2019). All-cause mortality data were retrieved from clinical records of registered deaths. The presence of blue space within 500m of peoples' home addresses was significantly associated with 1.4% risk reduction in all-cause mortality (HR = 0.99, 95% CI [0.97, 1.00], $p = 0.038$) based on the three studies, with a combined total of 2,067,382 individuals (Figure 4).

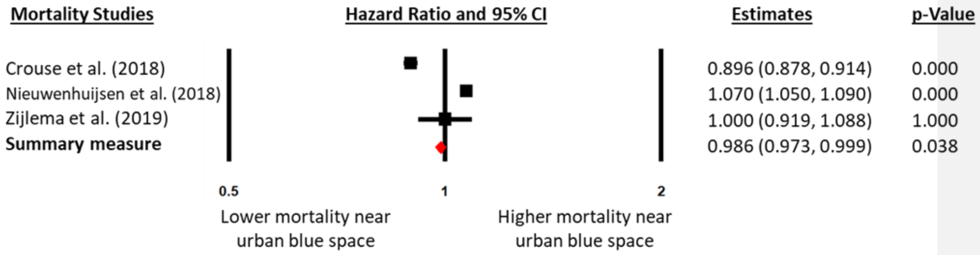

Figure 4 - Forest plot of the relationship between proximity to urban blue space and all-cause mortality. The area of each block indicates the weight assigned to that study in the meta-analysis.

3.4.1.3 General Health

Four studies reported on the relationship between proximity to urban blue space and self-reported general health in adults. These were conducted in Catalonia, Spain (Triguero-Mas et al., 2015), Hong Kong (Garrett et al., 2019), cities in Germany (Völker et al., 2018), and urban areas in the UK (Wheeler et al., 2012). Three papers used validated questionnaires to measure general health and one paper used census data which asked participants to rate their health over the previous 12 months (Table S4).

A meta-analysis of these four studies suggested that living closer to urban blue space was associated with higher self-reported general health in adults (Figure 5).

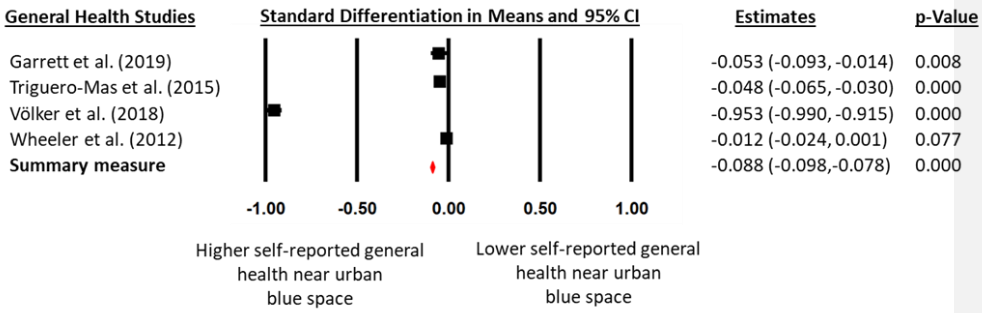

Figure 5 - Forest plot of the relationship between proximity to urban blue space and self-reported general health. The area of each block indicates the weight assigned to that study in the meta-analysis.

The pooled effect size was small but statistically significant (Cohen's d = -0.09, 95% CI [-0.10, -0.08], $p < 0.001$). The figure is negative as people reported poorer general health with increased residential distance from urban blue spaces.

3.4.1.4 Adverse Birth Outcomes

The single study exploring blue space and adverse birth outcomes did not find a statistically significant association between waterfront access and clinically measured birthweight of children born in New York City, USA (N = 183,484) (Abelt and McLafferty, 2017).

3.4.5 Health-Related Quality of Life (HRQoL)

One cross-sectional study measured the impact of blue space exposure on children's HRQOL (N = 851) (Tillmann et al., 2018). The study, conducted in urban Ontario, Canada, used the Paediatric Quality of Life Inventory 4.0 tool to measure children's HRQOL. Results indicated that the percentage of water within 500m of a child's home in urban populations was a negative predictor of HRQOL.

3.4.2 Mental Health

3.4.2.1 Self-reported Mental Health and Wellbeing

Seven studies focused on the impact of urban blue space on self-reported mental health and wellbeing, measured using a range of validated tools, including SF-12 v2 (Völker et al., 2018), WHO-5 Wellbeing Index (Garrett et al., 2019), GHQ-12 (Triguero-Mas et al., 2015), Cantril ladder (Huynh et al., 2013), Personal Wellbeing Index (Mavoa et al., 2019), SWEMWBS (Gilchrist et al., 2015) and data from the UK office of national statistics (White et al., 2017). We conducted a meta-analysis of four studies (Garrett et al., 2019; Mavoa et al., 2019; Völker et al., 2018; White et al., 2017) which all used a similar measures of exposure to blue space in cities in Germany, Hong Kong, Melbourne (Australia), and urban England, respectively. Our meta-analysis found that living closer to urban blue space was associated with higher self-reported mental health and wellbeing in adults (Figure 6). The pooled effect size was small but statistically significant (Cohen's *d* = -0.25, 95% CI [-0.44, -0.07], $p < 0.001$).

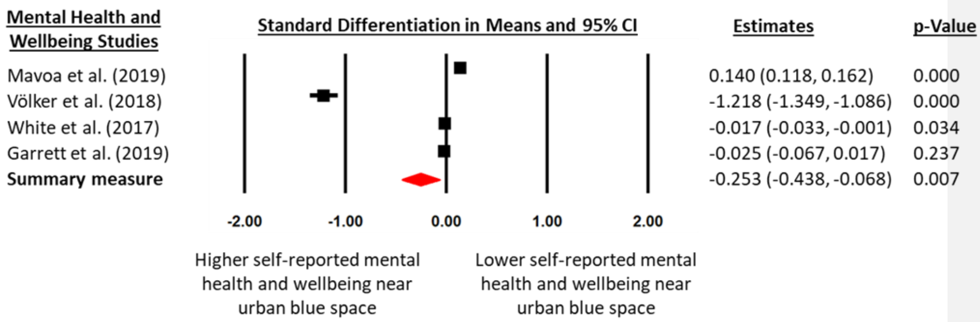

Figure 6 - Forest plot of the relationship between proximity to urban blue space and self-reported mental health. The area of each block indicates the weight assigned to that study in the meta-analysis.

The remaining three studies investigated the relationship between blue space exposure and other mental health outcomes, with conflicting results. Triguero-Mas et al. (2015) asked participants to report if they had ever visited a mental health specialist (yes/no) or taken medication for mental health issues (yes/no), but found no significant association between these health indicators and urban blue space exposure (N = 9,793). Gilchrist et al. (2015) found no evidence to suggest that viewing water from a window was associated with employee wellbeing (N = 366). On the contrary, a study of children and young people in Canada reported a significant linear trend between blue space exposure and positive emotional wellbeing (N = 17,249) (Huynh et al., 2013).

3.4.2.2 Psychological Distress

One cross-sectional study observed that higher levels of visible blue space from home was associated with higher levels of psychological wellbeing in adults living in Wellington, New Zealand (N=442) (Nutsford et al., 2016). They measured psychological distress using the Psychological Distress Scale (K10).

3.4.2.3 Restorative Experience

Korpela et al. (2010) asked people to describe their favourite environments and found that waterside environments were the third most mentioned type of favourite place after built green spaces and urban woodland. They measured people's restorative experiences of these spaces using a multi-item scale of restoration outcomes. People reported stronger restorative experiences in favourite waterside environments than in favourite places in built urban settings (N = 1,273).

3.4.2.4 Depressive Symptoms and Anxiety

Four studies measured the impact of urban blue space on depressive symptoms and anxiety. Helbich et al. (2019) found that people who were exposed to more blue space at street view had significantly fewer depressive symptoms relative to those with lower exposure, as measured with the Geriatric Depression Scale in their study of older people in Beijing, China (N = 1,190). Dzhambov (2018) reported that living close to blue space (<300 m) was associated with lower reports of depressive symptoms and anxiety, as measured by GHQ-12, in both their cross-sectional and longitudinal analyses of university students in Plovdiv, Bulgaria (N = 109). In Garrett et al.'s (2019) study of predominantly older adults in Hong Kong, visiting a blue space more than once a week was associated with a lower risk of depressive symptoms (measured using WHO Wellbeing Index) (N = 1,000). In contrast, Gascon et al. (2018) found no associations between blue space exposure and the prevalence and severity of depressive symptoms and anxiety in Barcelona, Spain, as recorded during interviews with neuropsychologists who enquired about participants' history of diagnosed mental health disorders (N = 958).

3.4.2.5 Emotional Functioning

One cross-sectional study by Amoly et al. (2015) reported on the relationship between urban blue space and emotional functioning in children. They examined the association between green and blue spaces and behavioural development in school children in Barcelona, Spain using a self-reported Strengths and Difficulties Questionnaires (SDQ), which was completed by parents, and the Attention Deficit Hyperactivity Disorder (ADHD) symptom criteria of Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition (ADHD/DSM-IV) (American Psychiatric Association, 2000), which was completed by teachers (N = 2,111). Peer relationship problems were fewer for those who spent more time at the beach. Furthermore, beach attendance was positively associated with prosocial, positive behaviours. There was no consistent pattern of association between contact with blue space and ADHD symptoms.

3.4.2.6 Major Mental Illness

A single study explored whether residential green and blue spaces promoted recovery in people with psychotic disorders in Utrecht, the Netherlands (N = 623) (Boers et al., 2018). Recovery was measured by a person's length of stay in a psychiatric ward and residential proximity to green and blue space were objectively measured for each patient. There was no association between the distance to a blue space and the length of time spent in a psychiatric ward.

3.4.2.7 Momentary Subjective Wellbeing

One included study measured momentary subjective wellness using wearable sensors which were worn by school students in Singapore (N = 59,526) (Benita et al., 2019). The sensor had a button that could be pressed whenever the students felt happy. This study found no association between momentary subjective wellbeing and blue space exposure.

3.5 Heterogeneity

High heterogeneity was present across the four meta-analyses (I^2>75%). We were unable to investigate this formally using meta-regression as too few studies were available to make this meaningful. The heterogeneity is in part expected in this type of research as the majority if studies were largely incommensurable and were therefore not included in the analysis; i.e., there was variation in the measurement of the blue space exposure, measurement of each health outcome, the confounder variables considered, and the analytic procedures undertaken. This heterogeneity should be taken into account when interpreting the pooled effect sizes (Bailar, 1997).

4. Discussion

The purpose of this review was to examine and begin to quantify evidence of the potential salutogenic health impacts of blue spaces in an urban context. We identified 25 eligible studies. We were able to quantify these impacts through four meta-analyses of fourteen studies. We found small but statistically significant effects from good quality studies which suggested a beneficial effect of blue space on obesity (β = -0.34, 95% CI [-0.19, -0.09], $p < 0.001$), all-cause mortality (HR = 0.99, 95% CI [0.97, 1.00] p= 0.038), general health (Cohen's *d* = -0.09, 95% CI [-0.10, -0.08], p< 0.001) and self-reported mental health and wellbeing (Cohen's *d* = -0.25, 95% CI [-0.44, -0.07], p< 0.001). The effect sizes calculated by the meta-analyses were small but statistically significant, thus providing quantitative evidence of the positive impact of urban blue space proximity on health. These are likely to be underestimated due to high heterogeneity. Unlike clinical significance, meaningful significance for environmental exposure is more difficult to define. However, due to increased urbanisation and the prevalence of blue spaces in urban environments, small effect sizes at an individual level collectively create major public health benefits. There was insufficient research on the effects of blue space on the other identified health outcomes for us to carry out further meta-analyses, and so narrative syntheses of these results were presented instead. Overall, the evidence base is still small and is dominated by cross-sectional studies. There is high heterogeneity in the blue space exposure and health outcome assessments. Findings from this review highlight the potential public health value of policies which protect and manage urban blue spaces, and that decision-makers should begin to consider incorporating these benefits into urban planning and water management.

4.1 Comparisons to other literature

Our review adds to the evidence that blue space exposure is beneficial to health, and that, specifically, this benefit is evident in urban environments. To date, research in this area has tended to focus on the health-promoting impacts of the natural environments and green spaces (Bowler et al., 2010; Gascon et al., 2015; James et al., 2015). The impact of green space exposure on all-cause mortality has been the focus of three systematic reviews (Gascon et al., 2016; Rojas-Rueda et al., 2019; Twohig-Bennett and Jones, 2018). The most recent of these included nine longitudinal studies in a quantitative synthesis which used the normalised difference vegetation index (NDVI) to measure exposure and found that the pooled HR for all-cause mortality per increment of 0.1 NDVI within a buffer of 500 m or less of a participant's residence was 0.96 (95% CI [0.94, 0.97]). Our findings for the associations between urban blue space and all-cause mortality are comparable with this (0.99, 95% CI [0.97, 1.00]). Furthermore, our mortality findings are supported by a longitudinal study, which found that the regeneration of the Glasgow Canal, an urban blue space, was associated with reduced mortality rates over 18 years (Tieges et al., 2020).

Twohig-Bennett and Jones (2018) found that increased green space exposure was associated with an increased incidence of good self-reported general health (1.12, 95% CI [1.05, 1.19]). Our findings indicate that the association between blue space exposure and general health has a similar effect size as green space (Cohen's d = -0.09, 95% CI [-0.10, -0.08]). Therefore, blue spaces appear as valuable to public health as green spaces. There is, however, the possibility that the effects might be a result of greenness surrounding particular blue spaces. Conversely, it is also possible that some of the effect reported for green space may come from the presence of blue spaces, as often blue is subsumed within green space. Green space literature has tended to focus on parks, and so canals and rivers, which are present in most cities, are excluded from such research. These findings and associated discussion highlight the need to consider blue space independently of green space when examining the health-promoting capabilities of outdoor environments, as we have shown that blue space can have health benefits that may be distinct and complementary to those provided by green space. Blue spaces are part of the urban fabric of most cities, with 50% of the world's population living within 3 km of a body of freshwater and only 10% living more than 10 km away (Kummu et al., 2011). Therefore, there is a need to harness the health-promoting capacities of blue spaces in urban environments to create healthier cities.

Current thinking has identified several possible pathways that might explain the health benefit of blue spaces (Georgiou et al., 2021). Causal relationships are difficult to discern as the associations between environmental exposures and health are complex (Rojas-Rueda et al., 2019). Blue spaces may encourage physical activity (Jansen et al., 2018), increase social connectivity and interaction (de Bell et al., 2017), reduce stress (Britton et al., 2018) and reduce negative environmental exposure (Burkart et al., 2016; Liu et al., 2018). In addition, it is important to understand mediating and modifying factors. Socio-cultural differences and different climatic factors may promote or limit the use of urban blue spaces (de Keijzer et al., 2019). All studies included in this review adjusted for confounding variables to some degree. However, there is extensive heterogeneity of factors used to adjust the statistical models, making it difficult to isolate the effects of potential confounders (Table S4). The length of time someone has lived near a blue space may also change the relationship between the blue space and their health status. Also, the relationship between urban blue space and health may be bidirectional; perceptions of blue space may affect a person's health and, reversely, their health status may determine how they use the blue space and their perceived responsibility to look after it.

4.2 Incorporating health into urban blue space policy, planning and practice

Traditionally blue space planning and policy has centred around water resource allocation and water risks. Demand for water is projected to increase by 55% by 2050, and so competition between water users for access to water resources will likely increase. Also, cities are increasingly at risk of extreme weather events, including storms, floods and droughts, which are exacerbated by climate change. Finally, pollutants entering the water environment lead to poorer water quality. Understandably, water policy has tended to focus on these concerns. However, these concerns relate considerably to health. This is reinforced by the EU's "Health in All Policies" (HiAP), which highlights that non-health sectors should consider the impact of all policies on health and health equity (EU, 2006).

Blue space should be considered within new urban planning proposals. Blue spaces can be a key part of nature-based solutions: solutions that are inspired by nature, are cost-effective, and synergistically provide environmental, social and economic benefits to help build resilience (Lafortezza et al., 2018). Nature-based solutions, which include water, may deliver additional benefits of health promotion. Where space is limited, micro-blue spaces such as wading fountains could be incorporated into city design. In addition, vacant and derelict land in cities could be repurposed as blue space, which would enhance the urban aesthetic, provide flood risk infrastructure, and simultaneously act as an area of recreation which may promote physical and mental health. The co-benefits of nature-based solutions in urban environments indicate a need to disrupt the silo mentality, which can impede progress. Urban planners, water regulators and the health sector have the opportunity to work together to plan nature-based solutions which have the added benefit of helping alleviate ill health and promote positive health and wellbeing.

Existing green and blue spaces are at risk of being reduced due to densification of cities, and so it is pertinent we maximise the potential health benefits of these environments by granting public access to private spaces and revitalising run-down natural assets. Improving access so that everyone has equitable opportunity to enjoy urban blue spaces is of chief importance, as the absence of access can reinforce existing health inequalities. De Bell et al. (2017) found that those who visit blue spaces tend to have university degrees and better overall health, highlighting that specific demographics may miss out on experiencing blue space. The relevance of natural environments in urban settings for human health and wellbeing and sustainable development of urban areas has given rise to the development of targets for urban green provision at global, national and subnational levels; the importance of the natural environment on health and wellbeing in tackling health inequalities is nationally recognised in Scotland (Scottish Government, 2008). Urban outdoor spaces must be considered in decisions related to resource allocation to ensure more equitable distribution across all of society. However, revitalising run-down, existing blue spaces may prove counter-productive if gentrification occurs, as this would further disadvantage the most underprivileged populations (Kabisch et al., 2016). Rather than top-down interventions, community-led initiatives that support increased use of urban blue spaces for physical activity, recreation and socialisation may improve urban public health (Kabisch et al., 2016). Similarly, strategies which empower communities to contribute to the management and governance of local blue spaces may be beneficial to ensuring that any revitalisation benefits existing populations (Jansson and Randrup, 2020).

The quality of blue space and the amenities located near blue spaces will likely be significant in determining whether they affect health; not all urban blue spaces are clean or desirable. Only one study assessed the quality of the urban blue space being investigated (Garrett et al., 2019). Researchers have explored the impact of poor perceptions and satisfaction of neighbourhoods and how this influences health (Leslie and Cerin, 2008). Furthermore, the perceived aesthetics, biodiversity, walkability, facilities and safety may predict usage of green spaces (McCormack et al., 2010). Perceptions of blue space could be measured in a similar way, using self-reported assessments of perceptions of the safety, cleanliness, and aesthetics of blue spaces or could be objectively assessed by trained auditors or through use of blue environmental assessment tools, such as those developed by BlueHealth (Mishra et al., 2020). Such assessments could be adopted by urban planners when evaluating current or proposing future urban blue spaces. They could also be developed into citizen science projects to engage communities (Jansson and Randrup, 2020).

4.3 Future research

To substantially advance understanding on the relationship between urban blue space and health, future research is required. The current cross-sectional evidence justifies future longitudinal studies which would allow for refining the direction of causality of the relationships and the mechanisms underlying the associations between urban blue spaces and health. Also, future study design should look to include other environmental exposures in their analysis, like green space, which would allow for a more meaningful interpretation of the nuances of the interplay between blue and green space exposure.

Specificity in how urban blue space is defined and measured may assist with future research in this area. Studies that objectively measured blue space exposure have used presence, distance and percentage of blue space. There is no universally accepted standardisation of appropriate buffer sizes for either green or blue spaces (World Health Organization, 2016). Although standardised measurements allow for easier comparison across studies, they can often overlook cultural and climatic differences. Therefore, different measurement tools may be appropriate in different contexts. Further advances in GPS and geotechnology, including automated satellite image classification, will allow for developing innovative assessment techniques of blue space exposure in the future. However, researchers should be wary that objectively measuring the availability of blue space can lead to the inclusion of areas which are inaccessible or undesirable to humans.

Research has shown that the presence of and access to urban blue space does not necessarily equate to usage (Tillmann et al., 2018). Who is exposed to blue spaces, the extent of the exposure and the determining factors influencing the use of blue spaces could be addressed in future studies. Additionally, future investigations should explore peoples' willingness to travel, perhaps if the area in which they live lacks urban blue space. Views of blue space may have stronger relationships with health than proximity alone and so this is also an important exposure to acknowledge going forward (Dempsey et al., 2018).

Blue spaces may affect specific populations' health more than others. Wheeler et al., (2015) found that the benefits of blue spaces were greater in areas with lower socioeconomic status. More research is needed to explore this and other potential effect modifiers. Furthermore, there is a need for sustained interdisciplinary qualitative research to understand peoples' lived experiences of urban blue spaces, including their personal, symbolic and cultural significance and how these factors can be health-promoting and health-limiting (Bell et al., 2018; Foley and Kistemann, 2015; Völker and Kistemann, 2011).

Urban planners and decision-makers need to know what types of blue space are worth investing in and how their investment will be instrumental in health promotion. Differentiating between types, quality and size of blue space is worthy of attention as different urban blue spaces (canals vs coasts vs rivers vs harbours) may have different relationships with health outcomes. Furthermore, none of the included articles discussed the potential salutogenic benefits of micro, anthropogenic blue spaces, such as urban wading fountains. There is anecdotal evidence of their salutogenic benefits regarding relaxation and leisure. The paucity of literature on these "micro" urban blue spaces, combined with their often reasonable scale in the urban landscape, suggests that they should be the focus of future studies.

More primary research, using standardised and validated tools to measure health outcomes, is required to advance the knowledge around urban blue space and health. No included studies investigated the associations between exposure to blue space and non-communicable diseases such as diabetes, cardiovascular or respiratory diseases. Such diseases are the leading cause of deaths globally (World Health Organization, 2018). It is important that we explore whether blue spaces in urban environments may help alleviate this burden of disease. In addition, the majority of health outcome data within the included studies were self-reported and employed a wide variety of methods. While self-reporting is often used successfully to evaluate mental health variables such as wellbeing and depressive symptomatology, in other mental health and physical health areas, using validated clinical measures is also often helpful.

4.4 Strengths and limitations of this review

We adopted rigorous systematic review methods and followed the guidelines of PRISMA (Moher et al., 2009). Three reviewers worked collaboratively on the search of electronic bibliographic databases, and we also carried out a thorough secondary hand search of relevant reference lists. We limited the search to publications written in English, potentially leading to some studies being excluded. The majority of studies were conducted in Anglo-Saxon and European countries, possibly contributing to an unintentional "cultural bias". Studies were categorised by blue space exposure, and only those with comparable measurements of distance to blue space were included in the meta-analysis. Environmental exposure is difficult to measure and so although these studies measured distance differently, we deemed them adequately comparable. Results should be interpreted with caution as it is possible that the effect size is under-estimated as studies with smaller sample sizes and shorter follow up periods tend to report negative or non-significant results (Deeks, 2011). We were unable to conduct a full sensitivity and publication bias analysis due to the low number of studies available.

5. Conclusion

Urban planning must be informed by the evidence for the effectiveness of urban changes on human health and wellbeing. Our review and meta-analysis has synthesised the quantitative evidence on the mental and physical health implications of blue spaces for people living in urban environments. Overall, there is a small evidence base of good-quality studies. The findings suggest that urban blue spaces can have salutogenic health benefits, with small but significant positive effects on obesity, self-rated general health, mental health and wellbeing as well as reduced risk of premature all-cause mortality. These effect sizes are comparable to the health-promoting capacity of green space. When scaled to the population level, these effect sizes may have a wide-reaching public health impact. Blue spaces are an integral part of most cities and therefore worthy of further exploration. In the context of the growing worldwide concern for the burdens of non-communicable diseases and mental illness, exposure to urban blue spaces may offer a solution, as part of broader preventative and restorative public health and urban planning policies, to improve urban population health.

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Supplemental Material

Table S1 - PRISMA report

#	Item	Guidance	On page #	Author Comments
Title				
1	Title	Identify the report as a systematic review, or systematic review and meta-analysis, as appropriate.	1	Urban blue spaces and human health: a systematic review and meta-analysis of quantitative studies
Abstract				
2	Structured summary	Provide a structured summary including, as applicable: • Background; • Objectives; • Data sources; • Study eligibility criteria, participants, and interventions; • Study appraisal and synthesis methods; • Results; • Limitations; conclusions and implications of key findings; • Systematic review registration number.	1	Provided in Abstract
Introduction				
3	Rationale	Describe the rationale for the review in the context of what is already known.	1	1. Background

#	Item	Guidance	On page #	Author Comments
4	Objectives	Provide an explicit Population-Intervention-Comparator-Outcome-Study Design (PICOS) or Population-Exposure-Comparator-Outcome-Study Design (PECOS) statement as appropriate, detailing the following in relation to the research questions being asked: • Participants • Interventions / Exposures (as appropriate) • Comparisons • Outcomes • Study design	3	2.1 Search Strategy
Methods				
5	Protocol and registration	Indicate if a review protocol exists, if and where it can be accessed (e.g. web address), and registration information including registration number (if available).	3	Lines 101
6	Eligibility criteria	Specify study characteristics (e.g. PICOS/PECOS, length of exposure) and report characteristics (e.g. years considered, language, publication status) used as criteria for eligibility, giving rationale.	3	2.2 Inclusion Criteria
7	Information sources	Describe all information sources (e.g. databases with dates of coverage, contact with study authors to identify additional studies) in the search, and date last searched.	2	Lines 115-119.
8	Search	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	41	Table S2
9	Study selection	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).	4	2.3 Study selection, data extraction and analysis

#	Item	Guidance	On page #	Author Comments
10	Data collection process	Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.	4	2.3 Study selection, data extraction and analysis
11	Data items	List and define all variables for which data were sought (e.g., PICOS/PECOS, funding sources) and any assumptions and simplifications made.	4	2.3 Study selection, data extraction and analysis
12	Risk of bias in individual studies	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis.	4	2.4 Quality appraisal and synthesis of evidence
13	Summary measures	State the principal summary measures (e.g., risk ratio, difference in means).	Table 1	
14	Synthesis of results	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., I^2) for each meta-analysis.	4	2.3 Study selection, data extraction and analysis
15	Risk of bias across studies	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	4	2.4 Quality appraisal and synthesis of evidence
16	Additional analyses	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	n/a	
Results				
17	Study selection	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, illustrated with a PRISMA flow diagram.	5	3.1 Study selection Figure 1

#	Item	Guidance	On page #	Author Comments
18	Study characteristics	For each study, present in a summary table the characteristics for which data were extracted (e.g., study size, PICOS/PECOS, follow-up period) and provide the citations.	7-15	Table 1
19	Risk of bias within studies	Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12).	18	3.3 Quality of evidence
20	Results of individual studies	For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot (unless such a plot would be misleading)	5-18	3.2 Characteristics of included studies
21	Synthesis of results	Present results of each meta-analysis done, including confidence intervals and measures of consistency.	19-21	Meta-analysis for four health outcomes: Obesity, Mortality, General Health, Mental Health
22	Risk of bias across studies	Present results of any assessment of risk of bias across studies (see Item 15).	42	Table S3
23	Additional analysis	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	n/a	
Discussion				
24	Summary of evidence	Summarise the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., researchers, users, and policy makers).	23-27	4. Discussion
25	Limitations	Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias).	27	4.3 Strengths and limitations of this review
26	Conclusions	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	27	5. Conclusion

#	Item	Guidance	On page #	Author Comments
Funding				
27	Funding	Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.		Removed for peer review

Table S2 - Database search strategy example

Database	Search
PubMed and MEDLINE	(((((health[Title/Abstract] OR “quality of life”[Title/Abstract] OR wellbeing[Title/Abstract] OR well-being[Title/Abstract] OR “mental health”[Title/Abstract] OR depression[Title/Abstract] OR anxiety[Title/Abstract] OR "life expectancy"[Title/Abstract] OR happy[Title/Abstract] OR happi*[Title/Abstract] OR “cardiovascular disease*”[Title/Abstract] OR “non-communicable disease*”[Title/Abstract] OR “heart disease*”[Title/Abstract] OR coronary[Title/Abstract] OR CHD[Title/Abstract] OR respiratory[Title/Abstract] OR “cognitive function*”[Title/Abstract] OR cognition[Title/Abstract] OR stress[Title/Abstract] OR "Heart Rate"[Title/Abstract] OR "blood pressure”[Title/Abstract] OR “cholesterol”[Title/Abstract] OR “diabetes”[Title/Abstract] OR cancer[Title/Abstract] OR “chronic obstructive pulmonary disease”[Title/Abstract] OR “chronic disease”[Title/Abstract] OR mortality[Title/Abstract] OR death*[Title/Abstract] OR “sedentary”[Title/Abstract] OR “body mass index”[Title/Abstract] OR “BMI”[Title/Abstract] OR obesity[Title/Abstract] OR overweight[Title/Abstract] OR “over weight”[Title/Abstract] OR over-weight[Title/Abstract] OR disease*[Title/Abstract] OR “healthy weight”[Title/Abstract] OR “waist circumference”[Title/Abstract] OR “body fat”[Title/Abstract] OR “waist to hip”[Title/Abstract])) AND (urban*[Title/Abstract] OR city[Title/Abstract] OR cities[Title/Abstract]

	OR peri-urban[Title/Abstract] OR “inner city”[Title/Abstract] OR inner-city[Title/Abstract] OR nonrural[Title/Abstract] OR "non-rural"[Title/Abstract] OR “non rural”[Title/Abstract] OR “metropolitan area*”[Title/Abstract] OR town[Title/Abstract] OR downtown[Title/Abstract])) AND (("blue space"[Title/Abstract] OR ("natural environment"[Title/Abstract] AND water)[Title/Abstract] OR "canal"[Title/Abstract] OR "water*"[Title/Abstract] OR park[Title/Abstract] OR garden*[Title/Abstract] OR (“natural land*”[Title/Abstract] AND water)[Title/Abstract] OR “open space*”[Title/Abstract] OR “natural space*”[Title/Abstract] OR “physical environment*”[Title/Abstract] OR “wild land*”[Title/Abstract] OR “wild space*”[Title/Abstract] OR “wild area*”[Title/Abstract] OR “public land*”[Title/Abstract] OR “public park*”[Title/Abstract] OR “blue infrastructure*”[Title/Abstract] OR waterway*[Title/Abstract] OR canal*[Title/Abstract] OR river*[Title/Abstract] OR stream*[Title/Abstract] OR pond*[Title/Abstract] OR sea[Title/Abstract] OR seas[Title/Abstract] OR beach*[Title/Abstract] OR fountain*[Title/Abstract] OR riparian[Title/Abstract] OR ocean*[Title/Abstract] OR coast*[Title/Abstract] OR marine[Title/Abstract] OR lagoon[Title/Abstract]))) AND Humans[Mesh])

Table S3 - Quality Scores and categories attributed to each included study

Author (Date)	Study Design (0-2)	Confounding factors (0-2)	Statistics (0-1)	Potential Bias (0-1)	Multiplicity (0-1)	Health Measurement (0-2)	Exposure (0-1)	Use of Blue Space (0-1)	Effect Size (0-1)	Lived in the area for 1 year (0-1)	Score (absolute)	Score (%)	Quality Category
Abelt and McLafferty (2017)	1	2	1	1	1	2	1	0	1	0	10	77	Good
Amoly et al. (2014)	1	2	1	1	1	1	0	1	1	0	9	69	Good
Benita et al. (2019)	1	1	1	1	1	2	1	0	1	0	9	69	Good
Boers et al. (2018)	1	2	1	1	1	2	1	0	1	0	10	77	Good
Crouse et al. (2018)	1	1	1	1	1	1	1	0	1	0	8	62	Good
Dzhambov (2018)	2	2	1	1	1	1	0	1	1	0	10	77	Good
Garrett et al. (2019)	1	1	1	1	1	2	1	0	1	0	9	69	Good
Gascon et al. (2018)	1	2	0	0	1	1	0	0	1	0	6	46	Fair
Gilchrist et al. (2015)	1	2	1	1	1	0	1	0	1	1	9	69	Good
Halonen et al. (2014)	2	2	1	1	1	1	1	0	1	1	11	85	Excellent
Helbich et al. (2019)	1	2	1	0	1	1	1	0	1	0	8	62	Good
Huynh et al. (2013)	1	0	1	1	1	0	0	1	1	0	6	46	Fair
Korpela et al. (2010)	1	1	1	1	1	1	1	0	1	0	8	62	Good
Mavoa et al. (2019)	1	1	1	1	1	2	1	0	1	1	10	77	Good
Nieuwenhuijsen et al. (2018)	1	2	1	0	1	1	1	0	1	0	8	62	Good
Nutsford et al. (2016)	1	1	1	1	1	2	0	1	1	0	9	69	Good
Rossi et al. (2018)	1	2	1	1	1	1	1	0	1	0	9	69	Good
Tillmann et al. (2018)	1	2	1	0	1	1	1	0	1	0	8	62	Good
Triguero-Mas et al. (2015)	1	1	1	0	1	1	0	1	1	0	7	54	Fair
Völker, et al. (2018)	1	1	1	0	1	0	1	0	1	0	6	46	Poor
Wheeler, et al. (2012)	1	2	1	1	1	1	1	1	1	0	10	77	Good
White et al. (2017)	1	2	1	1	1	2	1	0	1	0	10	77	Good
Witten et al. (2008)	1	1	1	0	1	2	1	0	1	0	8	62	Fair
Wood et al. (2016)	1	2	1	1	1	2	1	0	1	1	11	85	Excellent
Zijlema et al. (2019)	2	1	1	0	1	0	0	1	1	0	7	54	Fair

Study design (0-1)	0 = ecological, 1 = cross-sectional or case-control study, 2 = longitudinal or intervention study
Confounding factors (0-2)	0 = no confounding factors considered, 1 = confounding factors considered but some key confounders omitted, 2 = careful consideration of confounders
Statistics (0-1)	0 = flaws in or inappropriate statistical testing or interpretation of statistical tests that may have affected results, 1 = appropriate statistical testing and interpretation of tests
Potential bias (0-1)	0 = other study design or conduct issues that may have led to bias, 1 = no other serious study flaws
Multiplicity (0-1)	0 = exposure of interest one of the many variables being tested, 1 = exposure of interest the main variable tested
Outcome assessment (0-2)	0 = self-reported non-validated questionnaires, 1 = self-reported validated questionnaires, 2 = interviews conducted by experts or clinical records, or physical measurements
Blue exposure assessment (0-1)	0 = self-reported or based on regional residence, 1 = satellite system or land-cover map based
Use of blue space	0 = not measured and/or not included in the analysis, 1=measured and included in the analysis
Effect size (0-1)	0= incomplete information, 1=complete information (estimate, confidence level, p value etc.)
Participants have been living at least 1 year in the studied area (0-1)	0 = no or not clearly specified, 1= yes

(Gascon et al., 2017)

Table S4 - Characteristics of included studies.

Author (Date)	Context	Study Design	Population Sampling (participants)	N	Intervention/blue space exposure	How is the blue space measured?	Health outcome measured	How is health measured?	Analysis	Adjustments	Results	Significance
Abelt and McLafferty (2017)	New York City, USA	Cross-sectional	New mothers	103,484	Coastal Blue Space	Census tract centroid situated within 800m of publicly accessible waterfront (Yes/No)	Adverse Birth Outcomes	Clinical records of birthweight	Mixed-effects linear and logistic regression models	Birthweight, gestation (weeks), parity, and sex, and the characteristics of the mother including education, marital status, nativity, race/ethnicity, and risk behaviours (drinking and smoking), receipt of medical assistance, maternal age.	No significant association found between term birth weight and access to waterfront locations	Non-significant
Amoly et al. (2014)	Barcelona, Spain	Cross-sectional	children (7-10years)	2,111	Coastal Blue Space	Self-reported - BREATHE parental questionnaire asking about annual beach attendance. 0.5% and 1.7% lived within 300 m and 500 m of the beach respectively. Therefore, it was not feasible to use proximity to blue spaces within analyses.	Emotional Functioning	Self-reported - Strengths and Difficulties Questionnaires (SDQ) rated by parents, and ADHD symptom criteria of Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition (ADHD/DSM-IV) rated by teachers	Quasi-Poisson mixed-effects models	Age, sex, income, education, work status, household structure, deprivation level, frequency of green space visit frequency.	Children who spent more days at the beach had lower scores for SDQ (fewer behavioural problems). Peer relationship problems were fewer for those who spent more time at the beach. Children who spent more days at the beach also had better prosocial behaviour, and therefore better behavioural development. No association found for beach attendance and	Beneficial

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											ADHD symptoms.	
Benita et al. (2019)	Singapore	Cross-sectional	Students (7-18 years)	59,526	Blue Space	Self-reported (Point of interest developed using Machine Learning techniques. SENSg sensors connect to MAC address of the Wi-Fi access points)	Momentary subjective wellbeing	Self-reported - SENSg sensor worn and pressed whenever participants felt happy.	Poisson regression models and Zero Inflated Poisson (ZIP) regression model, Zero-inflated negative binomial (ZINB) regression model	Environmental and personal variables	No significant association found between proximity to blue space and momentary subjective wellbeing.	Non-significant
Boers et al. (2018)	Utrecht, Netherlands	Cross-sectional	11 to 94 years	623	Blue Space	Percentage blue space within 300m buffer of participants' home address	Mental Disease	Clinical Records, patients with schizophrenia spectrum and other psychotic disorders' according to the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV).	Multivariate regression analysis (two models)	Gender, age, urbanicity, SES	No significant associations found between percentage blue space exposure and patients admitted to psychiatric wards or the length of stay in the hospitals.	Non-significant
Crouse et al. (2018)	Canada - 30 largest census metropolitan areas.	Cross-sectional	Adults (25-89 years)	1,265,515	Blue Space	Presence of blue space within 250m of participants' home address (Yes/No)	Mortality	Clinical Records of registered deaths from Canadian mortality database	Cox proportional hazards models	Adjusted for other factors; aboriginal identity, visible minority status, marital status, education, employment, income. Also adjusted for exposure to ambient air pollution and distance from green space.	Reduced risk of mortality with living within 250m of water compared with living further away (all causes of death, except with external/accidental causes)	Beneficial

Dzhambov (2018)	Plovdiv, Bulgaria	Longitudinal	University students	109	Blue Space	Presence of blue space within 100m, 300m, 500m and 1000m of participants' home address.	Depressive Symptoms and Anxiety	Self-reported questionnaire - GHQ-12	Cross-sectional single mediation models and longitudinal cross-lagged panel mediation models	age, gender, ethnicity, duration of residence, average time spent at home a day, and perceived economic status (0 to 5)	Living closer to blue space (<300 m) was significantly associated with lower GHQ-12 in both the cross-sectional and longitudinal analyses.	Beneficial
Garrett et al. (2019)	Hong Kong	Cross-sectional	Adults (18-70 but 80% respondents were >50 years)	1000	Blue Space	Self-Reported (View of Blue Space from home (Y/N); Frequency of visits to blue space and walking time to such spaces (minutes) through a questionnaire)	General Health Wellbeing Depressive Symptoms	Self-reported - Questionnaire using SF12 for general health, WHO-5 Wellbeing Index for wellbeing. Also asked how they felt after a recent trip to a blue space.	Linear modelling with binomial error structure.	view of blue space, walking distance to blue space, commute, blue space visit, green space visit, district, physical functioning, age, access to garden, occupation, income, sex, children, marital status, dog ownership, physically active,	Having a view of blue space from home was positively associated with people self-reporting 'good' health. No significant association was found between blue space exposure, or walking distance, and self-reported health. Visiting a blue space more than once a week was associated with better subjective wellbeing and a lower risk of depressive symptoms.	Beneficial Non-significant Beneficial
Gascon et al. (2018)	Barcelona, Spain	Cross-sectional	Adults	958	Blue Space	Presence of blue space within buffers of 100, 300 m and 500 m of participants' home address (Yes/No)	Depressive Symptoms	Self-reported - Interview with trained neuropsychologist asking about participants' history of doctor-diagnosed anxiety and depressive disorders and intake of related medication	Logistic regression models	gender, age, education, living alone, BMI, smoking status, sleep difficulties, and caregivers' burden.	No significant associations with blue spaces and any of the health outcomes.	Non-significant

Gilchrist et al. (2015)	Scotland (pen-urban business sites)	Cross-sectional	Adults (employees)	366	Blue Space	View of blue space from office window of a business park (only 5% of windows had views of blue space)	Wellbeing	Self-reported - Questionnaire using the short version of the Warwick-Edinburgh Mental Well-being Scale	Multiple regression analyses	gender, age, site, income coping, outdoor activities frequency, job mental demands, job stressfulness and satisfaction with the indoor environment.	No significant association found between viewing blue space from the office window and employee wellbeing.	Non-significant
Halonen et al. (2014)	Finland (urban areas)	Longitudinal	Adults	15621 nonmovers 9696 movers	Blue Space	Distance - from participants' residential neighbourhood to blue space (<250m, 250-499, 500-750, >750m). Not known whether blue space was usable.	Obesity	Self-reported height and weight within the Finnish Public Sector study	Multilevel multinomial logistic regression	Age, sex, level of education, chronic somatic illnesses, entitlement to special reimbursement for the cost of medication for chronic illnesses, smoking habits, alcohol use, and levels of physical activity	People who had not moved house, who were normal weight at baseline, had a higher BMI if they lived more than 750m from a waterfront when compared with those who lived less than 250m from a waterfront.	Beneficial
Helbich et al. (2019)	Beijing, China	Cross-sectional	Older people (60+ years)	1190	Blue Space	Streetscape (Street view data combined with deep learning to develop new exposure assessments)	Depressive Symptoms	Self-reported - Survey, including the Geriatric Depression Scale (GDS-15). Data collected by Renmin University, China, approached at their residential address.	Multilevel regressions	gender, age, education, ethnic minority and local hukou (China-specific variable), marital status, functional ability, chronic disease, pollution.	People exposed to more blue space at street view had significantly lower GDS-15 scores (fewer depressive symptoms) than those in neighbourhoods with a low coverage blue space.	Beneficial

Huynh et al. (2013)	Canada (stratification by rural, small city, metropolitan area)	Cross-sectional	Children (11-16 years)	17249	Blue Space	Percentage of blue space within 5 km buffer from the schools	Wellbeing	Self-reported - Health Behaviour in School-aged Children (HBSC) Survey. Students asked to rank wellbeing using Cantril ladder (worst to best possible life)	Multilevel logistic regression, built incrementally (3 steps)	SES, perceived neighbourhood safety, age, gender, ethnicity, urban/rural	A significant association found between the percentage of blue space and positive emotional wellbeing in small cities and metropolitan areas.	Beneficial
Korpela et al. (2010)	Helsinki and Tampere, Finland	Cross-sectional	Adults (15-75 years)	1273	Blue Space	Self-reported - Participants asked to rate 16 types of urban and natural places and areas concerning their personal importance (5-point Likert scale).	Restorative experience	Self-reported - Primary data collected via postal questionnaire. Multi-item scales of restoration outcomes and general health questions.	ANCOVA	Satisfaction with Life Scale, The Nature Orientedness Scale, Daily Hassles and Uplifts Scale, Frequency of visiting the favourite place, the length of stay, hobbies involving nature and importance of nature in childhood	Restorative experiences in favourite waterside environments were stronger than in favourite places in built urban settings.	Beneficial
Mavoa et al. (2019)	Melbourne, Australia	Cross-sectional	Adults (18+)	4912	Blue Space	Distance to the coast (m) Area of blue space per buffer (400m, 800m, 1600m) around the home address.	Wellbeing	Self-reported - Personal wellbeing Index (derived from the Australian Unity wellbeing Index) - 7Qs using 11 point scale, converted to %	Adjusted multivariable linear regression models	age, sex, income, education, work status, household type, neighbourhood IRSD, and greenspace visit frequency	No significant relationship found between distance to the coast and subjective wellbeing. Also, no significant relationship found between the percentage of blue space around the home and subjective wellbeing.	Non-significant

Nieuwenhuijsen et al. (2018)	Barcelona, Spain	Cross-sectional	Adults	792,649	Blue Space	Percentage blue space per census tract area	Mortality	Clinical Records of mortality data extracted from Sistema d'Informació pel Desenvolupament de la Investigació en Atenció Primària (SIDIAP) database	Cox proportional hazards regression models	sex, age and smoking, census level socioeconomic status (not individual).	Increased risk of mortality with an increase in the percentage of blue space in a neighbourhood.	Detrimental
Nutsford et al. (2016)	Wellington, New Zealand	Cross-sectional	Adults (15+ years)	442	Blue Space	Vertical Visibility Index(VVI), which accounts for the slope, aspect, distance and elevation of visible areas relative to the observer location, based on four land cover maps and for a buffer of 15 km using residential meshblocks	Psychological Distress	Psychological Distress Scale (K10)	Analytical regression models, controlled for individual and area covariates	SES, population density, crime rates, housing quality index (HQI) Individual level: sex, age, income Others: missing teeth (SES proxy) as an outcome (test	Increased visibility (10%) of blue space was significantly associated with lower psychological distress.	Beneficial
Rossi et al. (2018)	Florianópolis, Brazil	Cross-sectional	Children (7-14 years)	2,152	Coastal Blue Space	Self-reported - Questionnaire detailing the frequency of use of, and perceived distance from home to places for physical activity and active leisure, including coasts.	Obesity	Clinical measurement of weight and height and waist circumference. Children measured by researchers in line with WHO guidelines.	Univariate and multivariate linear regression	age, sex, monthly family income and mothers' and fathers' educational levels, public/private school.	Children in low-income groups, living at an intermediate distance from beaches was associated with lower BMI, but no significance found for shorter distances or longer distances, or children from higher-income areas.	Beneficial

Tillmann et al. (2018)	Ontario, Canada. Categorised as urban/suburban/rural	Cross-sectional	Children (8-14 years)	851	Blue Space	Percentage within 500m circular buffer of a child's home address. Water only accounted for 1% of space for urban/suburban.	Health-related quality of life	Self-reported - Paediatric Quality of Life Inventory 4.0 (PedsQL)	Step-wise linear regression	Gender, age, visible minority (white vs non-white), lone parent household, live in more than one home, siblings present, parental education, parental employment and household income.	The percentage of water within 500m of a child's home in urban and suburban populations was a negative predictor of HRQOL.	Detrimental
Triguero-Mas et al. (2015)	Catalonia, Spain. Only densely populated areas were included	Cross-sectional	Adults (34-64 years)	8793	Blue Space	Presence of blue space within 100m, 300m, 500m and 1000m of participants' home address (Yes/No)	General Health Perceived risk of poor mental health Perceived depression/anxiety (Y/N) Visited a mental health specialist (Y/N) Intake of various mental health medications (Y/N)	Self-reported - through interview. SF-36 used for general health, GHQ-12 for mental health, and asked about other health outcomes with options to answer yes/no.	Logistic regression models with adjustment for covariates	gender, age, education completed, birthplace, type of health insurance, marital status, indicators of household and neighbourhood SES.	No significant associations were found between the presence of blue space surrounding participants' home address and general health, mental health, perceived depression or anxiety, whether they had visited a mental health specialist or intake of mental health medication.	Non-significant
Völker et al. (2018)	Bielefeld, Germany (low % blue space) and Gelsenkirchen (higher % blue space)	Cross-sectional	Adults	1041	Blue Space	Self-reported - Questionnaire detailing perceived distance from water (minutes) Frequency of visits to urban blue space (>3 times per week, 1-3 times per week, 1-2 times per	General Health and Mental Health	A self-reported questionnaire posted to residents, using SF-12v2 for physical and mental health outcomes	Three-step linear multiple regression model	Age, gender, SES (education, qualifications, net household income), local green space	More frequent use of blue spaces was associated with better self-assessed mental health in Gelsenkirchen, while no significant association was found between the use of blue space and walking distance to blue space	Beneficial Non-significant

						month, <1 time per month, never)					and physical health outcomes.	
Wheeler et al. (2012)	The UK - Rural/urban comparison	Cross-sectional	Not Specified	32482 CAUs	Coastal Blue Space	Distance between the population-weighted centroid and the coast (> 50 km, 20–50 km, 5–20 km, 1–5 km, < 1 km)	General Health	Self-reported from census data for England, single question asking to rate health over the past 12 months.	Linear regression models for urban, town/fringe and rural	Age, sex, green space density and socio-economic confounders	Participants living less than 1 km from the coast had better self-reported general health than those living more than 50 km away.	Beneficial
White et al. (2017)	England - focus on urban/peri-urban esidents	Cross-sectional	Adults	7272	Coastal Blue Space	Distance between the population-weighted centroid and the coast (near (<20km) vs far (>20km)) Self-reported - frequency of visit to natural environment questionnaire	Wellbeing	Self-reported - Secondary data from Monitoring Engagement with the Natural Environment (MENE) survey. Subjective wellbeing questions were developed by the UK's Office of National Statistics	Binary logistic regression models	Area level; deprivation; Individual-level - age, gender, socio-economic status, employment status, marital status, children in the household, illness/disability, ethnicity, dog ownership; Time-related – year, season, day of the week 'today' or 'yesterday'.	No significant association was found for the proximity to the coast and eudaimonic wellbeing.	Non-significant
Witten et al. (2008)	New Zealand (adjusted for urban/rural)	Cross-sectional	Adults (15+)	11,233	Coastal Blue Space	Distance to beaches, using travel time from the population-weighted centroid to beach access points,	Obesity	Clinical measurements of height and weight. Secondary data from NZHS	Four-stage models	Ethnicity, sex, age, education, social class (work), receipt of benefits, working/not working and household	Respondents living in neighbourhoods with the shortest distance to the beach had lower normalised BMI.	Beneficial

						following the road network				income, deprivation index (NZDep 2001), rural/urban classification		
Wood et al. (2016)	England - Rural/urban comparison	Cross-sectional	children aged 10 - 11	1,475,617	Coastal Blue Space	Distance between the MSOA population-weighted centroid and the coast	Obesity	Clinical measurement. Secondary data from the National Child Measurement Programme (NCMP)	Regression analyses, stratified by urban/rural category	Rural/Urban, potential greenspace, 2010 Index of Multiple Deprivation, other age groups, ethnicity	In urban conurbations, there was a higher prevalence of childhood obesity within 1-5km and 5-20km from the coast, but no significance was found for shorter distances, <1km and longer distances >20km.	Non-significant
Zijlema et al. (2019)	Perth, Australia	Longitudinal	Older men (65+)	9218	Blue Space	Distance to above-ground rivers and lakes (up to 1000m) The number and total area size (hectare) of waterbody within 500m and 1000m buffer.	Mortality	Clinical records of registered deaths from Western Australia Data Linkage System	Cox regression analysis	Age, marital status, country of birth, highest obtained educational degree, and smoking status obtained at baseline by questionnaires, SES based upon the Australian Bureau of Statistics Index of Relative Socio-economic Advantage and Disadvantage 2011	Associations between blue space and mortality were inconsistent, showing non-linear beneficial and harmful associations across different models for differing exposures.	Non-significant

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Author Statement

This statement is to certify that all authors have seen and approved the final version of the manuscript being submitted. This is the authors' original work. It has not been published elsewhere.