"Freshwater blue space and population health: An emerging research agenda"

Craig McDougall*, Nick Hanley**, Richard Quilliam* and David Oliver*

* University of Stirling, School of Biological and Environmental Sciences

** University Of Glasgow, Institute of Biodiversity, Animal Health and Comparative Medicine.

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Abstract

Growing evidence suggests that access and exposure to water bodies or blue spaces can provide a variety of health and well-being benefits. Attempts to quantify these "blue-health" benefits have largely focused on coastal environments, with freshwater blue spaces receiving far less attention despite over 50 % of the global population living within three km of a body of freshwater and populations living in landlocked areas having limited coastal access. This critical review identifies opportunities to improve our understanding of the relationship between freshwater blue space and health and well-being, and outlines key recommendations to broaden the portfolio of emerging research needs associated with the field of blue-health. Recognising fundamental distinctions in relationships between health outcomes and access and exposure to freshwater versus coastal blue space is critical. Furthermore, research to determine the mechanisms that link exposure to freshwater blue space with tangible health outcomes is needed, and in particular an understanding of how such mechanisms vary across the wide spectrum of freshwater environments present in landscapes. Current methods for quantifying access and exposure to freshwater blue space often fail to account for the unique spatial properties of freshwater and come with a variety of limitations. Based on the findings of this review, a suite of research needs are proposed, which can be categorised into three broad themes: (i) establishing a freshwater blue-health methodological framework; (ii) advancing the empirical freshwater blue-health evidence base; and (iii) promoting freshwater blue-health opportunities. When taken together, these research themes offer opportunities to advance current understanding and better integrate freshwater blue space into the wider nature-health research agenda.

Key words: Blue-health; Green space; Public health; Nature exposure; Health-promotion

1.0 Introduction

Interest in the relationship between access and exposure to the natural environment and human health is growing globally (Frumkin et al., 2017; Hartig et al., 2014). Nature-health research has mainly focused on exposure to green space, which has been associated with a number of positive physical and mental health outcomes (Twohig-Bennett and Jones, 2018). This growing evidence base has seen green space provision become an established component of public health and landscape planning policies across the globe (Rutt and Gulsrud, 2016; Wolch et al., 2014). The health-promoting potential of water bodies or blue spaces has received less attention in comparison, despite a small but growing body of evidence suggesting that access and exposure to blue space can provide a variety of health and well-being benefits (Gascon et al., 2017; Völker and Kistemann et al., 2011).

Although the term 'blue space' has emerged fairly recently, the health and well-being benefits of human-water interactions have been studied for decades across a number of disciplines including environmental psychology (Herzog, 1985; Kaplan and Kaplan, 1989) and human geography (Gesler, 1992; Gesler, 1996). In research concerned with nature and population health, blue space is often excluded (O'Callaghan-Gordo et al., 2020) or classified as green space (van den Berg et al., 2016). However, the establishment of a number of large-scale research programmes (e.g. Depledge and Bird, 2009; Grellier et al., 2017) coupled with a renewed interest in water-health relations in human geography (Foley and Kistemann, 2015) has seen the study of blue space and health shift from a by-product of therapeutic landscape and environmental psychology research towards an established academic field in its own right.

Blue space is generally understood to encompass both freshwater and marine settings (Grellier et al., 2017; Foley and Kistemann, 2015). However, with the exception of large or saline lakes and estuaries where freshwater and marine settings merge, these two environments substantially differ in their physical and hydrological properties and the ecosystem services and amenity values they provide. Furthermore, experiences at freshwater blue space are also likely to consist of different smells, sounds, views and opportunities for recreation than experiences in coastal environments (Mavoa et al., 2019). Current research attempting to quantify the health and well-being benefits of access and exposure to blue space (henceforth blue-health benefits) has largely focused on coastal environments, with freshwater blue spaces receiving far less attention (Gascon et al., 2017). Living in close proximity to the coast has shown an association with greater physical and mental health (Hooyberg et al., 2020; Pasanen et al., 2019; Wheeler et al., 2012) and being able to see the coast from one's home has also been associated with positive effects on mental well-being (Dempsey et al., 2018).

A review of 36 research articles exploring human-freshwater interactions identified that freshwater has a variety of salutogenic properties that can induce health and well-being benefits (Völker and Kistemann et al., 2011), although the data used for this review were mainly comprised of experimental and qualitative studies. This has exposed a significant gap in research that explores the benefits of access and exposure to freshwater from a population health perspective. Although some studies have suggested that access and exposure to freshwater blue space can provide benefits to population health (Pasanen et al., 2019; Pearson et al., 2019; MacKerron and Mourato, 2013; Garrett et al., 2019a), this is not always the case (White et al., 2013; Bezold et al., 2018; Mavoa et al., 2019). The volume and spatial coverage of freshwater is substantially smaller than marine environments; however, investigating the health-promoting potential of freshwater blue space is imperative as over 50 % of the global population live within three km of a body of freshwater and populations living in landlocked areas have limited coastal access (Kummu et al., 2011). Therefore, a better understanding of the relationship between access and exposure to freshwater blue space and indicators of health, and the mechanisms underlying these relationships, are fundamental to supporting a more holistic assessment of blue-health.

This critical review aims to identify opportunities to improve understanding of the relationship between freshwater blue space, health and well-being and thus broaden the portfolio of emerging research needs associated with the field of blue-health. Specifically, the objectives of this review are to (i) evaluate current issues in freshwater blue-health thinking; (ii) critically appraise the contrasting empirical methods adopted to quantify access and exposure to freshwater blue space; and (iii) propose recommendations for novel avenues of future research to advance our understanding of freshwater blue-health.

2.0 Issues in current freshwater blue-health thinking

2.1 Understanding pathways to positive health outcomes

The underlying mechanisms or "pathways" that link access and exposure to natural environments and tangible health outcomes have often been overlooked (Dzhambov et al., 2018). The most commonly cited pathways to improved health via access and exposure to the natural environment are stress reduction and restoration, social interaction, improved air quality and physical activity (Hartig et al., 2014). Grellier et al. (2017) hypothesise that health and well-being benefits of blue space will follow pathways similar to other natural environments; however, blue spaces have a number of distinctive health-promoting and therapeutic properties, e.g. opportunities for physical immersion and water-based activities (Foley, 2015).

There is a growing need to better understand the interaction between nature-health pathways and freshwater blue space (Mavoa et al., 2019) (Table 1). Access and exposure to freshwater blue space may reduce stress and provide cognitive restoration as aquatic environments are perceived to be highly restorative (Maund et al., 2019; Wilkie and Stavridou, 2013; Wang et al., 2016; White et al., 2010) and relaxing (Grassini et al., 2019). Furthermore, water is an important and highly valued aesthetic component in terms of landscape preference (Velarde et al., 2007; Faggi et al., 2013; Kaltenborn and Bjerke; 2002; Burmil et al., 1999). The presence of freshwater alone may induce health benefits by improving a number of environmental attributes, e.g. improving soundscapes by buffering anthropogenic noise (Jeon et al., 2012; Axelsson et al., 2014) and providing restorative or pleasant sounds, such as flowing water or bird song (White et al., 2010; De Coensel et al., 2011). The presence of freshwater can also enhance thermal comfort by reducing the urban heat island effect (Gunawardena et al., 2017) and provide a variety of ecosystem services, including carbon absorption (Apostolaki et al., 2019).

Social interaction (de Bell et al., 2017; Pitt, 2018; Völker and Kistestemann, 2015) and physical activity (Vert et al., 2019; Jansen et al., 2017) are expected to increase with greater access, exposure and usage of freshwater blue space; however, the importance of these pathways in facilitating tangible health outcomes is still relatively unknown. For coastal blue space, physical activity has been shown to be a key pathway in facilitating positive mental health outcomes, however, further research to understand the different mechanisms that cause freshwater blue space to positively influence health is required (Pasanen et al., 2019). Investigating the relationship between individual pathways and their contribution to specific health outcomes can assist health officials, landscape planners and policymakers in designing and managing blue space to optimise the provision of health and well-being benefits (Gascon et al., 2018). Improved understanding of how different types of engagement with freshwater interact with each health pathway, and the strength of these interactions relative to green space and coastal blue space can underpin effective nature-based health interventions, advancing the wider nature-health research agenda.

2.2 Classifying freshwater blue space

While the term 'blue space' is generally well understood in current nature-health literature, the treatment of coastal and freshwater environments in studies concerned with access and exposure to blue space and health varies widely. Access and exposure to freshwater and coastal blue space can be tested against health outcomes and reported as individual categories (Choe et al., 2018; Wheeler et al., 2012; Pasanen et al., 2019; Garret et al., 2019a) or as a combined "blue space" category (de Vries et al., 2016; Garret et al., 2019b; Huynh et al., 2013). The study of blue space can relate specifically to freshwater if, for example, the study location is landlocked (Dzhambov et al., 2018). Variations in blue space definitions and how blue-health findings are reported make comparisons among studies challenging and limit opportunities for evidence synthesis via meta-analyses and systematic review (Taylor and Hochuli. 2017). While combining freshwater and coastal blue space may be appropriate in order to address some research questions, the approach can be problematic, particularly when attempting to draw conclusions related to access and exposure to freshwater specifically. As exposure to coastal blue space may have a stronger health and well-being effect than exposure to freshwater (Garrett et al., 2019a) and as the physical properties of coastal waters can dominate the combined blue space category (Nutsford et al., 2016), caution should be taken when assuming that combined blue space findings are transferable to the freshwater evidence base. In order to better understand how access and exposure to freshwater blue space impacts health and well-being, blue space categories need to be clearly defined, whilst the relationships between health and access and exposure to freshwater and coastal blue spaces need to be reported independently.

2.3 Considering multiple freshwater blue space typologies

There is currently little understanding of how different typologies of freshwater blue space (e.g. lakes, rivers, canals, wetlands, ponds, streams, waterfalls and even fountains) interact with health pathways and consequently, how different typologies can impact health and well-being (Mavoa et al., 2019). Previous research suggests different freshwater typologies may have varying potential for stress reduction and restoration, for example, humans prefer views of rivers, lakes and ponds compared to more swampy waterscapes, such as creeks or bogs (Herzog, 1985). To date, research directly investigating interactions between different freshwater blue space typologies and the environmental quality, social interaction and physical activity health pathways has been sparse. For the environmental quality pathway, larger water bodies are expected to provide greater effects on surrounding temperatures (Wu et al., 2018) and the cooling effect of lakes is often higher than that of rivers (Du et al., 2016). Different freshwater typologies will likely vary in their ability to buffer noise and impact soundscapes, as the sound of water is mainly driven by hydrology, i.e. the volume and speed of water flow (Putland and Mesinger, 2020). Consequently, flowing rivers may have a more significant effect on soundscapes than bodies of relatively still freshwater (Wysocki et al., 2007).

Types of freshwater also vary in their ability to facilitate certain opportunities for physical activity and social interaction. Swimming and paddling are often associated with lakes (Angradi et al., 2018) and outdoor swimming is more likely to occur in lakes than narrow waterways (Lankia et al., 2019). Indeed swimming is often prohibited in urban waterways and canals due to health risks associated with immersion in these bodies of water (Pitt, 2018). An improved understanding of how access and exposure to different freshwater typologies impact health and well-being will likely assist in developing site-specific health interventions and integrating a variety of freshwater blue space typologies into public health strategies. Consequently, recognising the mechanisms that affect the health-promoting capabilities of different freshwater blue space typologies and how these vary across different socio-demographic groups is a key priority for future research.

2.4 Freshwater blue space quality

The perceived quality of the natural environment can impact how that environment is used (Giles-Corti, 2005; Akpinar, 2016) and poor environmental quality is a deterrent of use for both children (McCracken et al., 2016) and adults (Wright Wendel et al., 2012). Research focussing on the role of access often fails to consider the quality of freshwater blue space with little attention given to characteristics, such as accessibility, parking facilities, chemical and bacteriological water quality, recreational opportunities, or other salutogenic properties (Pitt, 2018). Water quality can influence the likelihood of swimming (Lankia et al., 2019), boating (Curtis et al., 2017) and impact the experience of anglers (Pulford et al., 2017). However, the majority of visitors to inland water bodies in England, do not make direct contact with water (Elliot et al., 2018) and improved water quality does not necessarily enhance the cultural ecosystem services offered by freshwater blue space (Ziv et al., 2016). Blue-health benefits commonly occur in terrestrial locations, e.g. due to non-water based physical activity (Vert et al., 2019), reduced psychological distress from viewing water (Nutsford et al., 2016) and social interaction in waterside environments (de Bell et al., 2017). Furthermore, waterside features, such as high quality paths (Verbič et al., 2016) and easily accessible waterside spaces (McDougall et al., 2020) can enhance the overall experience at a range of different freshwater blue space typologies. Consequently, it is clear that measures of freshwater blue space quality must account for both terrestrial attributes and traditional indicators of water quality.

A number of dedicated systems (Ariza et al., 2010; Palazón et al., 2019) and a robust international framework exists for assessing the quality of coastal environments and beaches, including beach certification schemes such as the "Blue Flag" (Lucrezi et al., 2015). Whilst some indicators of coastal and beach quality may be transferable to certain freshwater environments, such as large lakes with beaches and shorelines, many are specific to marine settings and are, therefore, inadequate for assessing freshwater blue space quality. Currently, the BlueHealth Environmental Assessment Tool (BEAT) is the only dedicated tool for assessing the quality of coastal and freshwater blue space (Mishra et al., 2020). BEAT uses a questionnaire-based approach to examine physical, social, aesthetic and environmental aspects of blue space, which relate to opportunities for improved health and well-being. While BEAT is highly suitable for assisting policymakers in designing and managing blue spaces to facilitate public health benefits, the tool requires site visits and questionnaires, thus making it challenging to implement at a population health scale. Moving forward, there is scope to establish ex-situ indicators to quantify blue space quality that can be readily combined with geographic information system (GIS) based approaches. Ex-situ indicators can be complemented by existing spatial data sources such as area-level socio-economic data (Rigolon and Németh, 2018) or the presence of surrounding services and green / open spaces, which are useful indicators of blue-health opportunities (Mishra et al., 2020). Combining freshwater blue space quality data, alongside metrics of access and exposure and health outcomes, would improve our understanding of which elements of freshwater blue space are most important for the provision of blue-health benefits.

3.0 Quantifying access and exposure to freshwater blue space: A critical appraisal

Quantifying access and exposure to freshwater blue space is a crucial component of studies that attempt to relate these variables to health outcomes. Commonly, access and exposure are measured using GIS and combined with individual or area-level health data (e.g. Bezold et al., 2018; Pasanen et al., 2019; Mavoa et al., 2019; Pearson et al., 2019; Wheeler et al., 2015; White et al., 2013). Assessing the capability of these methods to account for the unique physical and spatial properties of freshwater blue space would benefit future research.

3.1 Proximity-based approaches

Proximity-based approaches (e.g. Pearson et al., 2019; Hooyberg et al., 2020; Pasanen et al., 2019; White et al., 2013) are concerned with the distance relative to the blue space and can be divided into two key approaches: (i) determining the distance to the nearest blue space from a particular point (commonly the residence); and (ii) identifying the presence of a blue space within a defined distance or "buffer". Proximity buffers are commonly applied around the residence, although, there may be some merit in considering proximity to blue space in other locations such as schools, hospitals or workplaces, in order to capture the health effects of access and exposure to blue space in non-residential contexts (Koohsari et al., 2015). Proximity can be calculated as a linear distance or as a network distance. Linear distance approaches calculate the shortest distance from a selected location to the edge of the nearest blue space or buffer boundary, whereas network distance calculates the shortest distance from a selected location to the edge of the nearest blue space or buffer boundary along a street network, simulating walkability (Fig.1). Network distance may be more appropriate for research focused on health outcomes that require access and visitation such as physical activity (Labib et al., 2020) or when investigating distance to freshwater blue space in urbanised areas with complex street networks. Network distance approaches may be particularly useful when considering freshwater blue space with inaccessible sections, as linear methods cannot consider this issue (Fig. 1). Linear distance methods may be more appropriate when considering health benefits that can occur irrespective of access, i.e. viewing blue space from a distance or environmental improvements such as noise reduction and temperature mitigation.

A variety of different buffer sizes have been adopted in order to quantify differences in access and exposure to freshwater blue space among populations (Bezold et al. 2018; Dzhambov et al. 2018). Heterogeneity among buffer sizes makes comparing the results of studies and evidence synthesis challenging: the adoption of standardised distance buffers would benefit future freshwater blue space research (Gascon et al., 2017). Standardised buffer distances should be underpinned by empirical evidence and will likely differ from those adopted for coastal blue space, as much smaller distances influence the usage and visitation of freshwater blue space (Völker et al., 2018) and as these distances may vary across different freshwater typologies (Elliot et al., 2020). The adoption of differing buffer distances in coastal and freshwater blue space research reinforces the variance in scale of both resources and further highlights the risks of combining the findings of studies that examine the health effect of access and exposure to coastal and freshwater collectively.

3.2 Area-based approaches

Area-based methods use land cover data to determine the percentage of surface water within a predefined area or administrative boundary, such as a zip code area or census tract (Pearson et al., 2019; Alcock et al., 2015; de Vries et al., 2003; Garrett et al., 2019a). Such methods indicate both the presence and quantity of blue space within an area, which can assist in answering research questions concerning the effect of varying levels of blue space exposure on health. However, the use of area-based methods to quantify exposure and access to freshwater blue space comes with a number of limitations. Area-based methods are better suited to larger bodies of freshwater and certain freshwater typologies such as lakes, which are likely to have greater surface areas (Fig. 2). Such methods may, therefore, underestimate the salutogenic effects of typologies with lower surfaces areas such as rivers and canals, which also offer valuable opportunities for health and well-being (Vert et al., 2019; Pitt, 2018). There is an absence of empirical evidence to justify the notion that access and exposure to certain freshwater typologies are likely to result in greater positive health outcomes than others. Moreover, land cover data is commonly used to identify the presence of freshwater (de Vries et al., 2016) and narrow water bodies (e.g. river corridors and canals) are more likely to be misclassified than larger and more spatially explicit bodies of freshwater, highlighting a further bias. If sufficient data are available, future research may benefit from considering the percentage of surface area covered by freshwater relative to the number of freshwater blue spaces or the perimeter of freshwater, which can account for the presence of different freshwater typologies and begin to address issues related to their misrepresentation.

The adoption of administrative zones when quantifying exposure to freshwater blue space can also be problematic as administrative zones vary in size (Wheeler et al., 2015). Area-based methods represent blue space as a percentage, therefore, freshwater blue spaces of equal size may be deemed to have different health-promoting capabilities depending on the size of the administrative zone it is located within (Fig. 3). As administrative zones are often based on population density, the physical properties of certain blue spaces are likely to be favoured over others. Freshwater blue spaces in densely populated urban areas, such as rivers and canals, are likely to be in smaller administrative zones, whilst lakes and wetlands are less likely to be present in densely populated areas due to their physical properties and are more likely to be located on the urban fringe (Liu et al., 2007). Consequently, the use of administrative zones may underrepresent exposure and access to large lakes, which are important for providing benefits to mental health (Pearson et al., 2019). Administrative zones also notably differ in size across countries (Labib et al., 2020) making international transferability of area-based research and comparison among studies challenging.

3.3 Visibility-based approaches

Visibility-based methods consider topographic and built landscape features in order to determine what areas are likely to be visible to humans from a certain point in the landscape, commonly a household (Qiang et al., 2019). Visible exposure to blue space aligns closely with the stress reduction and restoration health pathway and relates to improved health without actual visitation, as positive health outcomes can be obtained from viewing water from a distance (Nutsford et al., 2016). Incorporating visibility-based methods into freshwater blue-health research may be challenging as freshwater and vegetation (or green space) are often intertwined in landscapes. Indeed, when a blue space becomes a green space and vice versa is often unclear, with no criteria yet defined to aid our understanding of this transition. This issue may be further complicated as definitions of blue space tend to include waterside space and vegetation (Grellier et al., 2017). Why the relationship between blue and green space has been somewhat overlooked in research is unclear but may relate to: (i) methodological issues of unpacking complex interactions between these spatial zones; or (ii) that most blue space research has focused on the coast, thus providing a relatively more defined blue-green split. Generally, the distinct physical properties of coastal landscapes make defining coastal blue space interaction simpler than for freshwater blue space typologies where interactions between water and vegetation are more common.

Acquiring sufficient and appropriate quality vegetation data and accounting for the seasonal, semi-transparent and non-uniform characteristics of vegetation is a key challenge of visibility-based approaches (Murgoitio et al., 2014). Previous studies of blue space visibility have excluded the effect of vegetation in their analysis (Dempsey et al., 2018; Qiang et al., 2019). It may be the case that vegetation has negligible effects on coastal visibility, however, given that vegetation can substantially reduce human views of freshwater (McDougall et al., 2020) it is imperative that future studies attempting to quantify freshwater visibility account for vegetation. Quantifying freshwater visibility in non-residential settings such places of work or education is needed in order to provide a more realistic representation of total freshwater exposure. Determining freshwater visibility throughout one's daily activities could be assisted by innovative approaches such as analysing street view imagery (Helbich et al., 2019) or utilising camera-based methods (Pearson et al., 2017).

3.4 Self-reported access and exposure

Self-reported methods provide insight into actual blue space usage and engagement, which cannot be achieved using objective measures of access and exposure alone, such as understanding the importance of certain freshwater blue space features in facilitating health outcomes (de Bell et al., 2017). Such methods can be useful for understanding relationships between different types of freshwater blue space and health, which are often difficult to consider due to a lack of available data (Mavoa et al., 2019). Self-reported methods also provide an understanding of blue space exposure in non-residential contexts and allow for multiple types of exposure to be considered. The latter can include: (i) indirect exposure, e.g. views of blue space from the residence; (ii) incidental exposure, e.g. contact with a blue space during daily life activities such as commuting; and (iii) intentional exposure, e.g. deliberately visiting a blue space (Garrett et al., 2019b). While self-reported methods offer a number of interesting research opportunities, these methods have some limitations. Attaining a representative sample of a study area or study population can be challenging (Völker et al., 2018; Garrett et al., 2019b). To date, studies using self-reported methods have been relatively limited in their sample size in comparison to studies that use objective quantifications of access and exposure (i.e. Alcock et al., 2015; Pasanen et al., 2019). As self-reported methods often rely on respondents to identify the presence of blue space and quantify exposure to these spaces, there is some scope for human error and subjectivity, which may introduce bias and limit comparability among studies.

4.0 Recommendations for future research

Research concerned with blue space and health has largely focused on coastal environments. Freshwater blue space has received substantially less research attention and consequently, there are significant gaps in our understanding of the health-promoting capabilities of these spaces. In order to fully understand the role of blue space as a public health resource a concerted effort is required for greater and more nuanced consideration of freshwater blue space in future research. Thus, a suite of research recommendations have been identified that, when taken together, offer opportunities to advance current understanding and better integrate freshwater blue space into the wider blue-health research agenda (Table 2). Primarily, there is a need to: (i) establish a methodological framework for freshwater blue-health research; (ii) broaden and advance the current freshwater blue-health empirical evidence base; and (iii) promote and sustain opportunities for freshwater blue-health.

4.1 Developing methodological framework for freshwater blue-health research

Establishing a methodological framework to underpin future research that accounts for the unique characteristics of human-freshwater interactions is a precursor to a better understanding of the relationship between freshwater blue space access and exposure and population health. Such a framework, promoting scale-appropriate and empirically tested methods, can complement conceptual research on the salutogenic benefits of freshwater conducted by Völker and Kistemann (2011) and begin to integrate freshwater blue-health evidence into the public health and landscape planning discourse.

Opportunities for evidence synthesis and meta-analyses can be increased by clearly defining the spatial dimensions of freshwater blue space and the freshwater typologies considered within each study. By testing and reporting exposure to freshwater and coastal blue space, there is an opportunity not only to better understand the relationship between exposure and access to freshwater blue space and health, but to also understand the strength of this relationship relative to coastal blue space, which is a crucial research need (Pasanen et al., 2019). This is currently hindered by a lack of consensus on the most suitable approach to quantify access and exposure in the freshwater blue-health literature. Establishing multiple standardised metrics for quantifying access and exposure is recommended; however, these should be grounded in empirical evidence and allow for a variety of research questions to be tested. Such methods should not only account for the quantity of freshwater, but also consider varying qualities of waterside space, which is essential for understanding many freshwater blue space interactions (Elliot et al., 2018; Vert et al., 2019).

Developing exposure and accessibility metrics that are able to account for freshwater blue spaces of varying scale, quality and perceived importance within the same study area is a significant challenge. One option is to identify freshwater blue spaces that may have substantial importance and ensure these spaces are analysed independently, as demonstrated by Pearson et al., (2017) for the "Great Lakes". Multiscale approaches that use multiple methods to quantify accessibility and exposure have been proposed for green and blue space (Labib et al., 2020) and such approaches are likely to help to account for the varying scale and unique spatial characteristics of freshwater.

4.2 Broadening and advancing the freshwater blue-health evidence base

The ecosystem services offered by freshwater blue spaces vary substantially based on climatic and social contexts (Sterner et al., 2020). However, freshwater and coastal blue space research is predominantly carried out in developed industrialised countries (Gascon et al., 2017). Despite recent studies in developed areas of Asia (Garret et al., 2019b; Helbich et al., 2019), further work is required to examine the effects of access and exposure to freshwater blue space in more diverse geographies in order to globalise the evidence base. Underrepresented human geographies that merit further study include areas where freshwater has deep cultural and religious significance e.g. the Ganges River catchment (Sharma et al., 2019), and low-income countries, where research has been sparse. An improved knowledge of freshwater blue-health in diverse physical geographies such as areas where freshwaters regularly freeze, are visibly contaminated with, for example, plastics or where water quality is generally unsafe for recreation will further advance the evidence base. Furthermore, research focusing specifically on access and exposure to estuaries, where freshwater and marine environments merge, and unique lakes that share oceanic characteristics, such as size, expansive views (e.g. Lake Malawi, Malawi and Lake Michigan, USA) and salinity (e.g. Great Salt Lake, USA and Lake Urmia, Iran) offers potential to expand current understanding of both freshwater and coastal blue-health and explicate the blurred lines that arise from classifying blue space as two distinct categories.

With few studies having investigated the relationship between access and exposure to freshwater blue space and health, there is clearly a need for more empirical research. Randomised control trial experiments, such as clinical trials of blue space exposure can support larger GIS-based research and advance current understanding of freshwater blue-health, but are costly to implement (Frumkin et al., 2017). Natural experiments (also known as quasi-experimental approaches), in which circumstances suitable for experimentation occur without researcher influence, such as observing physical activity levels prior to and after the regeneration of an urban riverside setting (Vert et al., 2019), offer a cost-effective alternative to randomised control trial experiments. If well-designed, natural experiments can be highly effective for eliminating self-selection bias and understanding causation (Greenstone and Gayer, 2009), although such research is often subject to significant logistical challenges (Frumkin et al., 2017). Population health studies focusing on general health outcomes are particularly sparse relative to mental health research and merit greater consideration in future research. Longitudinal study design should be prioritised (Gascon et al., 2017) as longitudinal research can allow causation to be established and negates issues of self-selection, which is often present with cross sectional study designs (de Keijzer et al., 2016). Cross sectional studies would be improved by operating within an established framework of methods as outlined above, negating issues of self-selection by adopting residential sorting approaches to model neighbourhood demand for blue space (Klaiber and Phaneuf, 2010) and integrating data on blue space quality.

By establishing an understanding of how frequency and duration of freshwater blue space exposure and the type of activity carried out in or around blue space relate to health outcomes, there are opportunities to quantitatively understand dose-response relationships (Shannahan et al., 2015; White et al., 2019). Understanding the so called, "dosage" of nature that is required in order to return tangible health benefits is a key objective of the wider nature-health research agenda (Frumkin et al., 2017); however, very little is known about dosage in a freshwater blue space context. Furthermore, an improved understanding of the relationship between specific health pathways and different physical and mental health outcomes and the strength of these relationships relative to green space and coastal blue space is required. Such research can be supported, for example, by structural equation modelling, which has proved to be a particularly effective methodology for quantifying the role of different pathways in supporting positive health outcomes as a result of exposure to natural environments (Dzhambov et al., 2018; Yang et al., 2020).

A number of novel research opportunities have become available through emerging technology. The use of virtual reality technology can advance experimental research by simulating a variety of senses at freshwater blue spaces, which may be particularly useful for comparing blue-health opportunities of different freshwater typologies and builds upon environmental psychology research that utilised static images of water (Herzog, 1985; White et al., 2010). Furthermore, the exploitation of Big Data may provide useful avenues for research. The use of global positioning system (GPS) data that can be acquired from fitness wearables and activity tracking applications may also provide new insight for understanding physical activity levels surrounding freshwater blue space. Such methods can deliver accurate high resolution data on actual exposure to complement high resolution spatial data which is used to infer exposure, but falls short of understanding how people engage with nearby blue space. Furthermore, natural language processing of text from social media posts, e.g. Flickr, represents a novel approach for understanding how freshwater blue spaces are used and valued among populations (Figueroa-Alfaro and Tang, 2017; Gosal et al., 2019).

4.3 Promoting freshwater blue-health opportunities

In addition to growing the freshwater blue-health evidence base, there is a parallel need to communicate these findings to policymakers and the general public effectively. Establishing communication pathways between research and public health professionals is useful for exploring opportunities to integrate freshwater blue-health into ongoing public health strategies. A clear priority for research is to provide guidance on managing, conserving and in some cases developing freshwater blue spaces in order to fully exploit their health-promoting capacity. However, this cannot be achieved without a detailed understanding of how different characteristics and types of freshwater blue space interact with health and well-being. Policymakers may benefit from the use of in-situ assessment tools such as BEAT, which provides a highly practical resource for evidence-based planning and management to maximise the health-promoting potential of freshwater blue spaces. Furthermore, a wealth of interdisciplinary research opportunities exist in order to complement the provision of freshwater blue-health benefits with synergistic outcomes. This would necessitate the consideration of economic, social and environmental issues to enable a more holistic approach to future decision-making that accounts for the diverse needs of freshwater ecosystems. In particular, the integration of environmental economics methods, such as stated and revealed preference approaches, can assist in understanding preferences among the general public (Hanley et al., 2019) and different water users on how best to manage these spaces. Crucially, these approaches allow monetary values to be attached to policy decisions meaning the highest value investments in terms of positive health outcomes and cost-effectiveness can be assessed. However, economic valuation approaches may be unable to capture many qualitative elements of human-blue space interactions (Foley et al., 2019).

Longer-term research priorities should be framed around ensuring freshwater blue-health opportunities are available to all. Research to understand barriers of access to blue space and consequently, the provision of blue-health benefits is limited and may require a variety of qualitative approaches. Barriers to access may occur due to socio-economic factors such as housing status, which may lead to unfamiliarity with the amenities in an area (Haeffner et al., 2017) or more nuanced issues like fear of accessing waterside spaces due to an inability to swim (Pitt, 2019). The impact of swimming ability on perceived access to freshwater blue space may be a particularly useful area of study as socio-economic status could be a significant driver of swimming ability (Irwin et al., 2009; Pharr et al., 2018). Finally, exploring the wider socio-economic, and sometimes unintended, consequences of improving and managing freshwater blue spaces is of high importance. For example, access to water tends to increase house prices (Dahal et al., 2019) and consequently, increasing access to freshwater blue space may induce gentrification and the displacement of residents (Vert et al., 2019). The use of public participation geographic information systems (PPGIS) may be particularly useful in remediating these unintended consequences and developing inclusive freshwater blue-health strategies that can cater to the needs of a number of different water-users (Raymond et al., 2016).

5.0 Conclusion

There is emerging evidence that access and exposure to freshwater blue space can provide health and well-being benefits. However, despite growing evidence, freshwater remains under represented in blue-health research. More in-depth understanding of the relationships between population health and freshwater blue space requires moving beyond traditional disciplinary collaborations and approaches. While environmental science and health research agendas have aligned in the past, our understanding of freshwater blue spaces and health and well-being interactions is often partial, or conflicting. This stems from the frequent failure of research to span traditional disciplinary boundaries in order to fully integrate disciplinary paradigms, e.g. due to philosophical, methodological and communication barriers. Moving forward, researchers across multiple and diverse fields face the challenge of refining the empirical methods used to quantify access and exposure to freshwater blue space and addressing a number of conceptual issues in current freshwater blue-health thinking. The evidence base supporting the health and well-being benefits of exposure to freshwater requires further empirical testing and future interdisciplinary research should seek to investigate the role of freshwater blue space within the wider nature and human health research agenda, while continuing to advance the emerging blue-health research field.

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Table 1: Summary of freshwater blue-health pathways

Pathway	Explanation	Exemplar reference
Stress reduction / restoration	Perceived to have high restorative potential Opportunities for immersion within water Often perceived as relaxing, attractive and calming	Ulrich, 1991; White et al., 2010; Grassini et al., 2019;
Environmental improvement	Enhance thermal comfort and reduce urban heat island Improve soundscapes and buffer anthropogenic noise Provide ecosystem services, e.g. carbon absorption	Gunawardena et al., 2017; Jeon et al., 2012; Apostolaki et al., 2019
Physical activity (PA)	Unique opportunities for PA e.g. swimming and fishing Water-based PA preferred outdoors than indoors Encourage non-water based physical activity	Foley, 2015; Perchoux et al., 2015; Vert et al., 2019
Social interaction	Opportunities for planned and unplanned social contact More relaxed ambience than urban areas Opportunities for group exercise and leisure	Pitt, 2018; Völker and Kistestemann, 2015; Thomas, 2015;

Table 2: Overview of key research recommendations

Establishing a methodological framework	Advancing the blue-health evidence base	Promoting freshwater blue-health opportunities
Define the spatial dimensions of freshwater blue space considered in research	Broaden research landscape to consider diverse climatic and human geographies	Develop communication pathways between research and public health professionals
Establish standardised metrics for quantifying access and exposure	Further empirical research with focus on general health	Provide blue-health focused guidance for managing freshwater sites
Report results for freshwater and coastal blue space exposure independently	Prioritise longitudinal research to establish causation	Understand barriers of accessing freshwater blue space
Adopt multiscale approaches to quantify access and exposure	Utilise big data from social media or activity tracking applications	Explore wider socio-economic consequences of blue-health strategies

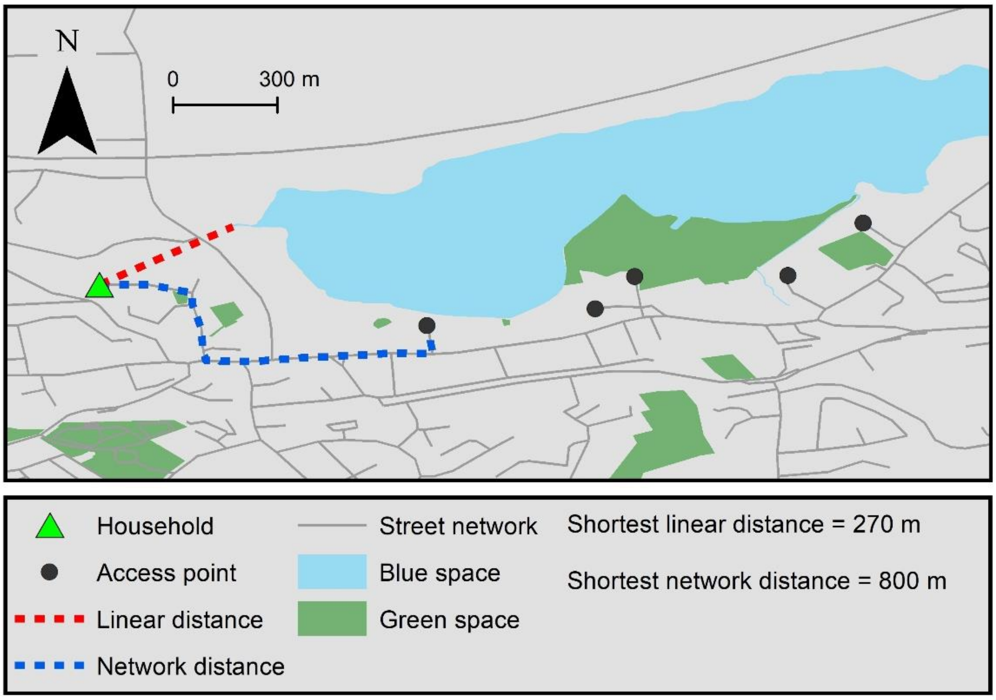

Fig.1: Summary of linear and network distance approaches for quantifying access to blue space

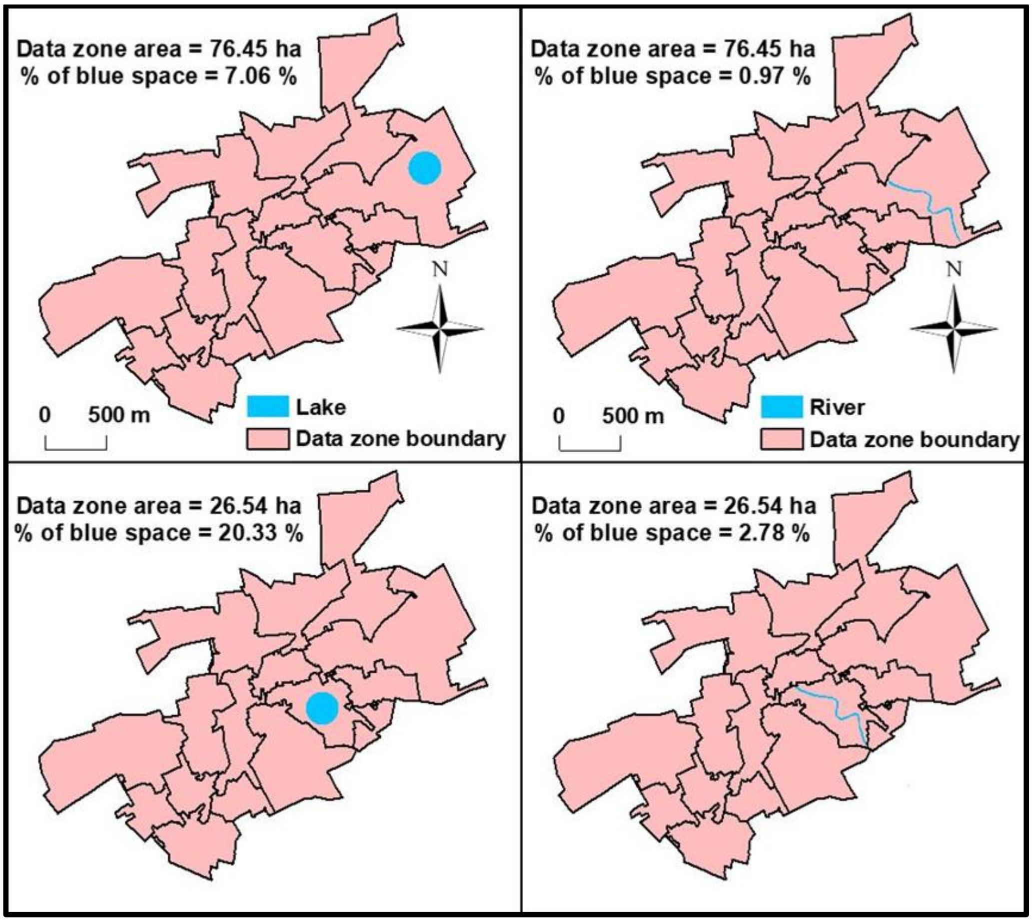

Fig. 2: Area-based representations of freshwater blue space are dependent on blue space typology (e.g. river or lake) and the size of the administrative (data zone) boundary