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BlueHealth: a study programme protocol for mapping and quantifying the potential benefits to public health and well-being from Europe's blue spaces

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TITLE PAGE

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BlueHealth: a study programme protocol for mapping and quantifying the potential benefits to public health and well-being from Europe's blue spaces

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Competing interests statement

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Ethics approval

Throughout the BlueHealth project, ethics review and approval are obtained for all aspects of the study by the relevant local ethics committees before any work is conducted. Stakeholder engagement also involves citizens in many aspects of the project throughout.

ABSTRACT

Introduction

Proximity and access to water have long been central to human culture and accordingly deliver countless societal benefits. Over 200 million people live on Europe's coastline, and aquatic environments are the top recreational destination in the region. In terms of public health, interactions with 'blue space' (e.g. coasts, rivers, lakes) are often considered solely in terms of risk (e.g. drowning, microbial pollution). Exposure to blue space can, however, promote health and well-being and prevent disease, although underlying mechanisms are poorly understood.

Aims and methods

The BlueHealth project aims to understand the relationships between exposure to blue space and health and well-being, to map and quantify the public health impacts of changes to both natural blue spaces and associated urban infrastructure in Europe, and to provide evidence-based information to policy makers on how to maximise health benefits associated with interventions in and around aquatic environments. To achieve these aims, an evidence base will be created through systematic reviews, analyses of secondary datasets, and analyses of new data collected through a bespoke international survey and a wide range of community-level interventions. We will also explore how to deliver the benefits associated with blue spaces to those without direct access through the use of virtual reality. Scenarios will be developed that allow the evaluation of health impacts in plausible future societal contexts and changing environments. BlueHealth will develop key inputs into policy-making and land/water-use planning towards more salutogenic and sustainable uses of blue space, particularly in urban areas.

Conclusions

Through mapping and quantifying the benefits of blue space to health and well-being of the European population, BlueHealth will support consideration of state-of-the-art evidence on health and well-being in the planning and development of Europe's blue infrastructure.

ARTICLE SUMMARY

Strengths and limitations of this study

- BlueHealth (www.bluehealth2020.eu) is the first study programme to explore systematically the benefits to human health and well-being associated with interacting with blue space across Europe.
- BlueHealth examines possible complex mechanisms underlying relationships between blue spaces and public health using a variety of methods drawn from several disciplines.
- The project uses novel tools and methods to evaluate the changing characteristics and states of blue spaces associated with interventions made to urban infrastructure as well as with climate and other environmental change.
- BlueHealth will produce clear guidance to decision makers and other stakeholders on how to achieve maximum health benefits when making changes to urban and other infrastructure located in, on and around water.
- The breadth of approaches and methods used in BlueHealth in different geopolitical and demographic contexts ensures broad applicability of the findings in decision making processes in Europe and elsewhere.

INTRODUCTION

Proximity and access to water have been central to human settlement throughout history.[1] As well as providing sources of drinking water and food, water and the 'blue space' around it facilitate transport, commerce and power generation, and afford recreation and tourism. Consequently, many of the world's largest cities are situated by water, and an extensive network of urban 'blue infrastructure' (e.g. canals, harbour walls) has been developed to secure the benefits, and mitigate concomitant risks. Cities globally are undergoing rapid change. Urban coastal populations are growing,[2] and many cities have seen extensive post-industrial transformation of canals and riversides,[3–5] docks,[6–8] ports,[9,10] harbours,[11–14] and other types of waterfront,[15,16] following changes in global trading patterns. Although environmental, social and economic impacts of waterside regeneration have been explored (e.g.[17,18]), its potential implications in terms of public health and well-being have only recently been scientifically investigated (e.g.[19–22]). This is in contrast to green spaces (such as urban parks, woodlands, and street trees), where a significant evidence-base supports their role in health protection and disease prevention.[23] Twentieth century trends in population growth and urbanisation in coastal areas globally are forecast to continue through this century.[2] Since increasingly large populations exploit or otherwise experience bodies of water through work and recreation in urban settings, human contact with blue environments is increasingly mediated by blue infrastructure.

The scientific understanding of health hazards and risks associated with water is well-developed. For example, certain aquatic habitats support vectors of diseases (such as malaria, yellow fever and dengue[24–26]), and can be sources of human exposure both to microbes responsible for infectious diseases (such as cholera[27] and typhoid[28]) and to a range of chemical pollutants.[29] Water is a hazard in itself: drowning is the third most common cause of unintentional death globally;[30] various complex health risks may result from flooding and its aftermath.[31–33] Activities carried out recreationally in blue spaces are associated with health impacts unrelated to water itself, such as increased risk of sunburn and skin cancer from sunbathing.[34] Many of these risks are amplified by the effects of environmental degradation and climate change. Far less is known about the public health and individual well-being benefits of interactions with blue spaces and infrastructures built in, on and around them.

Epidemiological evidence suggests that people living near—or having views of—the coast are generally healthier,[21,35] experience fewer symptoms of mental distress,[36,37] and more satisfied with their lives[38] than those living inland. Longitudinal evidence suggests that mental and physical health are typically better in people for periods spent living closer to the sea.[39] The positive effects of living near the coast seem particularly pronounced for those with the highest levels of socio-economic deprivation,[21] suggesting less health inequalities in such locations. Little is known about whether these effects are specific to coastal environments, or if other blue spaces (e.g. rivers, lakes, canals etc.) confer similar benefits on health. Preliminary evidence suggests that several pathways may account for the positive relationship between health and well-being and exposure to blue space. Firstly, people feel happier[38,40] and less stressed[41] in blue space settings than in other outdoor locations (replicated under laboratory conditions[42]). Secondly, those living near blue spaces spend more time in them than those living further away.[43] Thirdly, coastal inhabitants are more likely to meet national guidelines for physical activity than those inland.[44] Also, blue spaces are seen as particularly important places to participate in positive social interactions with friends and family[45] and are more widely used for health and well-being purposes than green spaces.[21,46] Lastly, water bodies can contribute to mitigating the urban heat island effect,[47] which is especially important as average summer temperatures rise and heat-related morbidity and mortality increase.[48]

As urban green spaces are increasingly encroached upon by construction,[49] and as populations near large water bodies increase in size, urban blue spaces may become increasingly important sites for recreation. The incorporation of evidence on the salutogenic effects of certain exposures to blue spaces into urban planning and development of urban infrastructure could contribute to tackling key public health challenges,[50,51] from reducing the incidence of non-communicable diseases associated with sedentary lifestyles and stress to reducing morbidity and mortality related to increasing temperatures.[52–54]

Research on relationships between exposure to blue spaces and health is less well-established than that conducted on green spaces and health,[55] and particularly little evidence exists regarding effects of blue spaces other than coastlines. In Europe, research has been conducted in only a few countries and results have been inconclusive, largely due to low statistical power.[56] The overarching goal of the BlueHealth project (www.bluehealth2020.eu) is to fill these gaps.

Over its four-and-a-half year duration, this pan-European project aims to understand better associations between exposure to blue space and health and well-being through a large-scale systematic programme of interdisciplinary research that investigates exposure to blue space and its effects on health and well-being in various geographical, climatic, socioeconomic and cultural contexts across Europe. Furthermore, it aims to quantify the public health impacts of existing and novel interventions and policy initiatives connected to blue space environments, and will develop tools that support decision making on future investments in Europe's blue infrastructure with health promotion in mind.

METHODS

BlueHealth conceptual model

We hypothesise that many benefits to health and well-being from exposure to blue space follow pathways similar to those identified for green space (e.g.[57–61]). We hypothesise that they differ since research suggests that people are particularly motivated to spend time in blue spaces compared to green, grey or mixed blue/green spaces, and that affordances exploited in blue spaces may be particularly beneficial, even relative to green or mixed spaces.[41,62,63] Through an iterative process of literature review and discussion, we created an influence diagram—the BlueHealth Conceptual Model (Figure 1)—that begins to answer the question "What causal chains link drivers of urban infrastructural change to impacts on public health and well-being?" in terms of what could be feasibly explored within BlueHealth.

The Conceptual Model posits that changes made to urban infrastructure and planning will be influenced by future changes in climate, particularly extreme events, as well as responding to a number of cross-cutting issues such as demographic, economic, technological and historical/cultural/geopolitical factors (e.g. Europe's Blue Growth agenda[64]). These changes might impact on the amount and relative distribution of blue space 'available' to the public, or on its character. They may change a population's contact (direct and indirect exposure) with blue spaces, as well as types of activities conducted therein. We consider that changes in exposure to blue space will influence the determinants of health, in terms of stress, physical activity, social contact and place attachment, climate change mitigation and adaptation, and, subsequently, on the states of health and well-being that impact on quality of life, on health care systems and on society at large. We also recognise that these impacts will vary across and within different populations, and across climate zones.

Building an evidence base

To answer the question posed above, the project will build a robust evidence base on the impacts of exposure to blue space on health and well-being, through reviews of existing evidence, analyses of available secondary data, and collection and analysis of a multitude of novel datasets

by way of a pan-European online panel survey, community-level interventions and application of virtual reality.

Reviews

Despite several extensive reviews of health and (urban) green space (e.g.[59,61,65–69]), we know of only one scoping review examining the relationships between health, well-being and blue spaces,[20] and one review on the health impacts of green and blue space that highlighted the insufficient data available on the association between mental health and blue space.[67] BlueHealth will build on these preliminary reviews by employing best practice evidence synthesis guidelines to conduct three broader and up-to-date reviews of the literature and international practice.

The first review will provide a systematic synthesis of the evidence on the relationships between urban blue spaces and the benefits to health and well-being, answering the question: "To what extent, and through what mechanisms, is exposure to urban blue space associated with opportunities for health and well-being promotion and disease prevention?" The results of this review focus the collection of primary and secondary data in the project and guide analytical strategies of them.

The second review will seek to answer the question: "What facets of urban blue infrastructure design and project implementation best promote health and well-being?" This review will examine the effectiveness of plans and, particularly, built environment projects at enhancing public health and well-being. Project documentation, information on planning and implementation processes, and current condition and usage will be evaluated in each case. A set of BlueHealth Criteria will be based on the outcomes of this review; subsequently, these can be used to evaluate new policies and plans in terms of their potential impact on public health. Since much of the evidence is documented in unpublished reports and the professional press, the review will focus on those projects which have, for example, won international design competitions or prizes.

The third review will answer the question: "To what extent, and through what mechanisms, do indoor artificial recreations of blue (and other natural) environments impact on health and well-

being." It will systematically consider effects on health and well-being of blue environments recreated indoors, including the use of aquaria,[70] photographs and paintings, and virtual reality (VR). The outcomes of this review will enable the focused development of VR studies conducted within BlueHealth.

Secondary data analysis

Analyses of secondary data will be carried out to further understanding of how blue space affects health and well-being. Previous analyses of secondary data have been country-specific and suffered from comparability issues due to differences in exposure assessment, outcome measures, adjustment for confounders, and analytical methods. We will conduct coordinated research on key European datasets that contain common health outcomes (e.g. GHQ12,[71] SF-36,[72] Global Life Satisfaction[73]), allowing for consistent operationalisation of exposure to blue space (i.e. residential proximity), including the UK Understanding Society survey,[74] the *Enquesta de Salut de Catalunya* ('Health Survey of Catalonia'),[75] and the Swedish Skåne Public Health Questionnaire.[76] Metrics of residential proximity (based on previous research[44,56]) will be assigned using the European Environment Agency's Urban Atlas.[77] Analysis of these data using a common protocol will allow for comparisons of large samples in three European countries.

Primary data collection and analysis

BlueHealth International Survey

A bespoke BlueHealth International Survey (BIS) is being developed to collect primary data on a large sample of the European populations' recreational experiences of blue spaces and reported health and well-being status. The survey will collect large, nationally-representative samples of individuals, stratified on age, sex, region, and employment status, in 14 European countries (Bulgaria, Czech Republic, Estonia, Finland, France, Germany, Greece, Ireland, Italy, Portugal, Spain, Sweden, The Netherlands, United Kingdom), which represent a range of climatic, geographic and cultural contexts, have coastlines on the Atlantic, the North Sea, the Mediterranean, the Black Sea or the Baltic—or are landlocked—and several feature high numbers of lakes and include Europe's largest rivers. For comparability with existing evidence, questionnaire items have been chiefly drawn from national surveys and European

projects.[55,78] Outcome measures include validated pre-translated health and well-being measures such as the WHO-5 Well-being Index,[79] and items in the European Social Survey.[80]

The BIS will facilitate cross-sectional analyses of nationally-representative samples across Europe, and will primarily focus on elucidating the potential physical and mental health effects of recreational (as opposed to occupational) experiences in blue spaces. It will also facilitate various economic evaluations. Firstly, a travel-cost method will be used to ascribe monetary values to visits using data collected on distances travelled, time taken and mode of transport used to get from a starting point to different blue space destinations. Secondly, economic values will be assigned to levels of physical activity undertaken within different blue environments, using existing protocols.[81,82] Thirdly, a contingent behaviour approach will be used to gauge public reactions to the EU's updated Bathing Water Standards and associated signage, introduced in 2015/16. Water quality at 15,363 designated coastal and 6,473 inland bathing water sites across the EU is now scored in terms of a four-point classification, namely Excellent, Good, Sufficient, and Poor. We will investigate how willingness to visit bathing sites is affected by the classifications and signage, thereby informing us of how bathing water quality may affect recreational choice.

Community-level interventions

At the local scale, we will evaluate impacts on health and well-being of changes to blue infrastructure and recreational behaviour in a range of community-level interventions (CLIs), across a variety of cultural and climatic contexts. A total of 13 CLIs will be carried out across eight European countries (Table 1). Ten CLIs are classed as *environmental interventions*, wherein a tangible change to an aspect of the (urban) blue infrastructure will take place during the course of the project. The impacts of these interventions on the health and well-being of local residents and users will be monitored. In five of these CLIs, the interventions are being made according to existing plans made by third parties. In the other five, we have the opportunity to make novel alterations to the environment to test specific hypotheses. We refer to these as 'urban acupuncture' interventions,[83] by which we mean relatively small-scale interventions made at underused, inaccessible or negatively perceived sites, that may confer disproportionately large positive impacts on the use or enjoyment of those places by given populations. Each urban

acupuncture intervention will be context-specific, and designed, co-created and installed with the cooperation of key stakeholders, including local landscape architects, engineers and planners, and local residents. The economic costs of the interventions will be monitored to enable estimation of the cost-effectiveness of each in increasing salutogenic use of each space. The other three CLIs are classed as *behavioural interventions*, meaning that they aim to change the way people interact with existing (urban) blue infrastructures. These include promotion of lunchtime walking for office workers in Barcelona (Spain) and Thessaloniki (Greece), and school swimming lessons for children of immigrant families that recently moved to Malmö (Sweden).

Type of CLI	Name	Location	Nature of intervention	Evaluation timing	Evaluation tools
Environmental interventions (interventions made to the environment)	Appia Antica Park	Rome, Italy	Improve information on access to, and use of, an urban park	Cross-section of users versus non-users	BCLS, BEAT, BSGIS
	Urban beach regeneration	Plymouth, UK	Regeneration of, and improved access to, an urban beach in a deprived part of the city	Pre-, post (3 months) & delayed post (9 months)	BCLS, BBAT, BEAT + a pre intervention contingent valuation exercise (i.e. willingness to pay for the regeneration);
	Besòs River access	Montcada i Reixac, Spain	Provision of access to an urban riverside path	Pre- and post	BEAT, SOPARC, BCLS
	het Nieuwe Diep access	Amsterdam, the Netherlands	Regeneration of, and improved access to, an urban beach	Pre- and post	BCLS, BBAT, BEAT
	Marazion dune cycle path	Cornwall, UK	Urban acupuncture	Pre- and post	BSGIS, BEAT, BCLS
	Anne Kanal	Tartu, Estonia	Urban acupuncture	Pre- and post	BSGIS, BEAT, BCLS
	Tallinn urban shoreline	Tallinn, Estonia	Urban acupuncture	Pre- and post	BSGIS, BEAT, BCLS
	Rio de Couros urban stream	Guimarães, Portugal	Urban acupuncture	Pre- and post	BSGIS, BEAT, BCLS
	Ribban beach park	Malmö, Sweden	Urban acupuncture	Pre- and post	BSGIS, BEAT, BCLS
	Modernist fountain renovation	Rubí, Spain	Local volunteer renovation of historic fountain	Qualitative	BEAT, BSGIS
Behavioural interventions (interventions made to population behaviour)	Walking office workers	Barcelona, Spain	Trial	Walking group versus control	BPAT
	Walking office workers	Thessaloniki, Greece	Trial	Walking group versus control	BPAT
	School swimming lessons	Malmö, Sweden	Observational, difference in difference	Pre- and post	Swimming ability

BBAT: BlueHealth Behavioural Assessment Tool BCLS: BlueHealth Community-Level Survey BEAT: BlueHealth Environmental Assessment Tool; BPAT: BlueHealth Physiological Assessment Tool BSGIS: BlueHealth SoftGIS

Table 1 - Summary of BlueHealth community-level interventions (CLI)

Five evaluation tools are being developed to assess aspects the CLIs:

1) The BlueHealth Community Level Survey (BCLS) is a shorter site-specific version of the BIS. It will be used with local communities before and after environmental interventions. The inclusion of items common to the BCLS and BIS allow the integration of findings from CLIs with higher level data from the same country.
2) The BlueHealth Environmental Assessment Tool (BEAT) will be used in all CLIs to assess objective environmental conditions (terrestrial and aquatic) and specific features of blue infrastructure at each site. The BEAT will be used at least twice in the environmental interventions to document change before and after their implementation. The tool includes evaluation of water quality, accessibility, litter and vandalism, signage etc.
3) The BlueHealth SoftGIS (BSGIS) tool will use participatory mapping [84] to understand how local residents use the blue spaces in the cities under study. One limitation of all pre-post intervention work is knowing whether changes are site-related, or reflect more general changes in attitudes and behaviours. Enabling local residents to comment on their experiences in local blue spaces will provide a more rounded picture of the importance and relevance of changes made at these sites.
4) The BlueHealth Behavioural Assessment Tool (BBAT), will be used to systematically observe and record how people behave and interact in different areas at relevant CLI sites. Observations made pre- and post-intervention provide information on how behaviour has changed as a result, and inform us about any affordances generated for specific user groups.
5) The BlueHealth Physiological Assessment Tool (BPAT) will be used in the Thessaloniki and Barcelona behavioural interventions (and adapted for use in VR studies). A variety of physiological measures will be collected from participants pre- and post-intervention to investigate short-term effects of spending time in and around blue space on stress and well-being.

Virtual reality

BlueHealth will employ innovative virtual reality (VR) technology in two distinct ways. Firstly, we will create computer-generated imagery of each urban acupuncture site for use by planners and stakeholders in order to optimise the intervention prior to implementation. Using VR with stakeholders in the design phase provides the opportunity to obtain a realistic impression of the proposed intervention, allowing better informed discussion. Secondly, we aim to deliver health and well-being benefits of blue space to individuals unable to access outdoor environments,

either because they are undergoing medical treatment or because they are prevented from visiting blue space due to age, ill health, disability, or environmental conditions. This will require research that builds on the current evidence.[42,85,86] We will further investigate the efficacy of VR blue spaces in the reduction of stress and discomfort during medical procedures such as dental treatment.[85,87] In parallel, we will examine how interactive VR technology and/or the ability to choose visit locations can be used in residential care settings to enable older people to, for instance, 'visit' blue space locations of their own choosing more frequently.

The VR-environments and in-situ protocols will be developed in collaboration with stakeholders and user-groups, to ensure desirability and feasibility. Piloting testing, within controlled laboratory settings, will be conducted prior to in-situ testing to investigate the psycho-biological pathways between virtual blue space exposure and health and well-being outcomes in key target groups.[88] Such work will enable us to explore the underlying mechanisms that are often hard to demonstrate in real-world settings.

Informing urban planning policy and long-term strategy

The BlueHealth evidence base will provide information on how changes to urban blue infrastructure and societal behaviours can maximise benefits to health and well-being associated with blue space. In order to best inform planning over a longer timescale—and to identify optimal blue infrastructure intervention strategies—a number of ideal-typical visions of the future (2050) will be elaborated based on plausible and health-relevant changes in demographic, economic, societal, technological, ecological and political spheres.[89] Five such BlueHealth Futures will be designed to explore the potential ramifications of rapidly changing environments and climate in the context of social and environmental inequalities and demographic change which are particularly pertinent to the health benefits and risks of interactions with urban blue infrastructure (e.g. flooding, water quality, urban heat islands), and to evaluate the effects of adaptive strategies. For this purpose, environmental and societal trends on a global, European and national scale will be scaled down to their relevance on an urban level. Having identified the future developments that will most significantly affect public health, the BlueHealth Futures can be used to identify promising policy options and strategies for influencing them. This will be

done with identified inter-sector stakeholders from government, business, academia, and citizen organisations.

Finally, a BlueHealth decision support tool (DST) will be developed with ongoing stakeholder input and engagement. Building on similar DSTs on urban green infrastructure, the BlueHealth DST will provide policymakers with a novel means approach planning of blue infrastructure—in the face of climate and other environmental change—with both health promotion and the management of potential health risks in mind.

DISCUSSION

The principal aim of the BlueHealth Project is to quantify the impacts on population health and well-being of existing and novel environmental interventions (as well as individual level behavioural initiatives) connected to blue space environments, and to identify the opportunities and obstacles for efficient policy-making and cross-sectoral collaboration in this area.

Assessments of the health and well-being (and environmental) co-benefits, risks, trade-offs, and costs will improve our understanding of the role of urban blue infrastructures in cross-sector health promotion and disease prevention. Many of these infrastructures were originally designed for other policy goals (e.g. transport, flood prevention). However, innovative design and planning can promote health by ensuring that the co-benefits are captured and governance processes should be designed with this broader perspective in mind. For example, given peoples' preferences for blue spaces and their willingness to visit them,[38,90] the evidence suggests that the population uptake of blue infrastructure initiatives that encourage, for instance, greater levels of active recreation, will be particularly high, and thus important for disease prevention and health promotion. The precise conditions of governance needed for such initiatives to be effective are as yet unclear.

We anticipate that the design of this intersectoral, international and multi-disciplinary BlueHealth project, and of the research programme laid out in this article, will provide key evidence to those making decisions on the development and maintenance of Europe's urban blue infrastructures on how to maximise the public health benefits of their policies and projects, to minimise health inequalities across and within populations, and to prepare for future changes in demography and climate. In addition to the evidence base, BlueHealth will produce a number of tools, suitable and available, for incorporation into design, planning and evaluation of interventions and governance processes conducted in, on and around urban blue infrastructure. The legacy of the project—data, evidence, interventions, tools, recommendations, and networks of experts and other stakeholders—will result in decision-making and urban planning that better integrates public health and disease prevention strategies. Given the sizeable investments needed to protect cities against climate change—particularly those on or near blue space—in coming

years, we anticipate that this intersectoral and co-benefit integration could potentially generate large returns in terms of improved population health.

The BlueHealth project is chiefly aimed at the better understanding the *benefits* to health and well-being of non-occupational interaction with blue space in urban settings. Health risks related to recreation or working in environments with water are assessed, but not investigated explicitly in the BlueHealth project. Several occupations are specific to such environments, and many of these present specific risks (e.g. commercial fishing is one of the most hazardous professions globally[91–93]). Since these risks are well understood (compared to the benefits), the BlueHealth project will devote less time to these issues, principally drawing on the existing evidence base on risk when developing the DST.

The pan-European focus of BlueHealth will generate information primarily of relevance to decision-makers across Europe and high-income countries. We are currently uncertain about how the outputs from BlueHealth will transfer to low and middle income countries, in part due to the pace and nature of urban development in these regions, and in part due to the potentially greater risks associated with waterborne disease and other exposures. The concept, and several of the methods, of the BlueHealth project could, however, be readily transferable to other geopolitical contexts. The rapid urban development taking place across the globe requires the construction of urban blue infrastructure on a substantial scale to meet the demands of various sectors. Better understanding of both the risks and benefits associated with this blue infrastructure through a set of developing world case studies might serve to incorporate non-traditional health promotion and disease prevention into development strategies in the fast-growing megapolises of low and middle income countries.

Historically, physical mechanisms have been popularly described as the means by which blue environments—in particular the sea—positively influence health e.g. invigoration of the body and mind through contact with ‘bracing sea air’. Although there is little evidence of these effects, a number of hypothetical biochemical mechanisms have been put forward, including exposures to low levels of airborne microbiota and biogenic products (including phytochemical and particulate allergens), some of which may interact with inflammatory cell signalling pathways to benefit human health.[94] Currently, the empirical evidence for such mechanisms is relatively

limited, and there are currently no plans to investigate these issues in detail with the scope of BlueHealth. Rather, BlueHealth has purposely been focused on those recreational, cultural and ecosystem services interactions with the blue environment to which we expect the majority of health benefits might be attributed.

CONCLUSIONS

The BlueHealth project will build an evidence base that maps and quantifies relationships between exposures to blue space and benefits to health and well-being, and will determine underlying mechanisms. Knowledge and tools developed in the project will provide key inputs to planning and policy relating to blue space, further stimulating the integration of environmental and health considerations into decision-making, such that blue infrastructure is developed across Europe with public health in mind.

AUTHOR CONTRIBUTIONS

James Grellier (JG), Mathew P White (MPW), Lora E Fleming (LEF) and Lewis R Elliott (LRE) drafted this manuscript on the basis of a grant proposal which was devised and written by MPW, LEF, Maria Albin (MA), Simon Bell (SB), Mireia Gascón (MG), Silvio Gualdi (SG), Laura Mancini (LM), Mark J Nieuwenhuijsen (MJN), Denis A Sarigiannis (DAS), Matilda van den Bosch (MvdB), Tanja Wolf (TW) and Susanne Wuijts (SW). All of the authors made substantial contributions to the Methods section of the draft manuscript, in which the conception and design of aspects of the work for which they are responsible in the BlueHealth project are described. Specifically: JG, LRE and MPW constructed the BlueHealth Conceptual Model; JG, LRE, MPW, MA, MG and MJN wrote the sections on *Reviews* and *Secondary data analysis*; JG, LRE, MPW, SB, MG, SG, LM, MJN and MvdB wrote sections on *Primary data collection and analysis*; and TW, SW and DAS rewrote the section on *Informing urban planning policy and long-term strategy*. All co-authors also contributed to the writing of the *Introduction* and *Discussion* sections. JG subsequently prepared a final version of the manuscript based on co-author contributions. All authors then read the final version, approved it for submission for publication and agree to be accountable for all aspects of the work.

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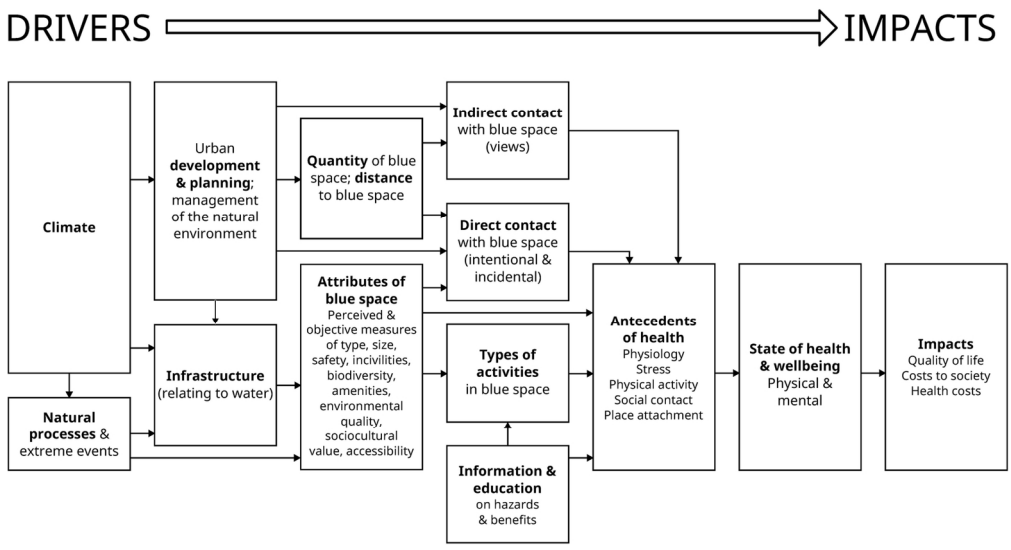
FIGURES

Figure 1

BlueHealth Conceptual Framework: an influence diagram describing the causal chain between drivers and impacts under investigation in the BlueHealth project



BlueHealth Conceptual Framework: an influence diagram describing the causal chain between drivers and impacts under investigation in the BlueHealth project

Figure 1

146x91mm (300 x 300 DPI)

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BlueHealth: a study programme protocol for mapping and quantifying the potential benefits to public health and well-being from Europe's blue spaces

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TITLE PAGE

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BlueHealth: a study programme protocol for mapping and quantifying the potential benefits to public health and well-being from Europe's blue spaces

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Competing interests statement

All authors report grants from European Union Horizon 2020 programme (grant number 666773), during the conduct of the study.

Ethics approval

Throughout the BlueHealth project, ethics review and approval are obtained for all aspects of the study by the relevant local ethics committees before any work is conducted. Stakeholder engagement also involves citizens in many aspects of the project throughout.

ABSTRACT

Introduction

Proximity and access to water have long been central to human culture and accordingly deliver countless societal benefits. Over 200 million people live on Europe's coastline, and aquatic environments are the top recreational destination in the region. In terms of public health, interactions with 'blue space' (e.g. coasts, rivers, lakes) are often considered solely in terms of risk (e.g. drowning, microbial pollution). Exposure to blue space can, however, promote health and well-being and prevent disease, although underlying mechanisms are poorly understood.

Aims and methods

The BlueHealth project aims to understand the relationships between exposure to blue space and health and well-being, to map and quantify the public health impacts of changes to both natural blue spaces and associated urban infrastructure in Europe, and to provide evidence-based information to policy makers on how to maximise health benefits associated with interventions in and around aquatic environments. To achieve these aims, an evidence base will be created through systematic reviews, analyses of secondary datasets, and analyses of new data collected through a bespoke international survey and a wide range of community-level interventions. We will also explore how to deliver the benefits associated with blue spaces to those without direct access through the use of virtual reality. Scenarios will be developed that allow the evaluation of health impacts in plausible future societal contexts and changing environments. BlueHealth will develop key inputs into policy-making and land/water-use planning towards more salutogenic and sustainable uses of blue space, particularly in urban areas.

Ethics and dissemination

Ethical approvals are obtained for all relevant aspects of the study prior to any work being conducted. Results of BlueHealth studies will be published with open access and anonymised data will be made available in open data repositories. Project results will constitute key inputs to urban planning and public health policy.

ARTICLE SUMMARY

Strengths and limitations of this study

- BlueHealth (www.bluehealth2020.eu) is the first study programme to explore systematically the benefits to human health and well-being associated with interacting with blue space across Europe.
- BlueHealth uses a variety of methods drawn from several disciplines to examine possible complex mechanisms underlying relationships between blue spaces and public health.
- The project uses novel tools and methods to evaluate the changing characteristics and states of blue spaces associated with interventions made to urban infrastructure as well as with climate and other environmental change.
- Although BlueHealth is looking at some risks associated with blue spaces, the project is chiefly focused on benefits to health; findings will therefore need to be integrated with existing and ongoing research relating to risks in order to fully understand potential trade-offs.
- Although the breadth of approaches and methods used in BlueHealth in different geopolitical and demographic contexts ensures broad applicability of the findings in decision making processes in Europe, it is uncertain how the project outputs might transfer to low and middle income countries.

INTRODUCTION

Proximity and access to water have been central to human settlement throughout history.[1] As well as providing sources of drinking water and food, water and the 'blue space' around it facilitate transport, commerce and power generation, and afford recreation and tourism. Consequently, many of the world's largest cities are situated by water, and an extensive network of urban 'blue infrastructure' (e.g. canals, harbour walls) has been developed to secure the benefits, and mitigate concomitant risks. Cities globally are undergoing rapid change. Urban coastal populations are growing,[2] and many cities have seen extensive post-industrial transformation of canals and riversides,[3–5] docks,[6–8] ports,[9,10] harbours,[11–14] and other types of waterfront,[15,16] following changes in global trading patterns. Although environmental, social and economic impacts of waterside regeneration have been explored (e.g.[17,18]), its potential implications in terms of public health and well-being have only recently been scientifically investigated (e.g.[19–22]). This is in contrast to green spaces (such as urban parks, woodlands, and street trees), where a significant evidence-base supports their role in health protection and disease prevention.[23] Twentieth century trends in population growth and urbanisation in coastal areas globally are forecast to continue through this century.[2] Since increasingly large populations exploit or otherwise experience bodies of water through work and recreation in urban settings, human contact with blue environments is increasingly mediated by blue infrastructure.

The scientific understanding of health hazards and risks associated with water is well-developed. For example, certain aquatic habitats support vectors of diseases (such as malaria, yellow fever and dengue[24–26]), and can be sources of human exposure both to microbes responsible for infectious diseases (such as cholera[27] and typhoid[28]) and to a range of chemical pollutants.[29] Water is a hazard in itself: drowning is the third most common cause of unintentional death globally;[30] various complex health risks may result from flooding and its aftermath.[31–33] Activities carried out recreationally in blue spaces are associated with health impacts unrelated to water itself, such as increased risk of sunburn and skin cancer from sunbathing.[34] Many of these risks are amplified by the effects of environmental degradation and climate change. Far less is known about the public health and individual well-being benefits of interactions with blue spaces and infrastructures built in, on and around them.

Epidemiological evidence suggests that people living near—or having views of—the coast are generally healthier,[21,35] experience fewer symptoms of mental distress,[36,37] and more satisfied with their lives[38] than those living inland. Longitudinal evidence suggests that mental and physical health are typically better in people for periods spent living closer to the sea.[39] The positive effects of living near the coast seem particularly pronounced for those with the highest levels of socio-economic deprivation,[21] suggesting less health inequalities in such locations. Little is known about whether these effects are specific to coastal environments, or if other blue spaces (e.g. rivers, lakes, canals etc.) confer similar benefits on health. Preliminary evidence suggests that several pathways may account for the positive relationship between health and well-being and exposure to blue space. Firstly, people feel happier[38,40] and less stressed[41] in blue space settings than in other outdoor locations (replicated under laboratory conditions[42]). Secondly, those living near blue spaces spend more time in them than those living further away.[43] Thirdly, coastal inhabitants are more likely to meet national guidelines for physical activity than those inland.[44] Also, blue spaces are seen as particularly important places to participate in positive social interactions with friends and family[45] and are more widely used for health and well-being purposes than green spaces.[21,46] Lastly, water bodies can contribute to mitigating the urban heat island effect,[47] which is especially important as average summer temperatures rise and heat-related morbidity and mortality increase.[48]

As urban green spaces are increasingly encroached upon by construction,[49] and as populations near large water bodies increase in size, urban blue spaces may become increasingly important sites for recreation. The incorporation of evidence on the salutogenic effects of certain exposures to blue spaces into urban planning and development of urban infrastructure could contribute to tackling key public health challenges,[50,51] from reducing the incidence of non-communicable diseases associated with sedentary lifestyles and stress to reducing morbidity and mortality related to increasing temperatures.[52–54]

Research on relationships between exposure to blue spaces and health is less well-established than that conducted on green spaces and health,[55] and particularly little evidence exists regarding effects of blue spaces other than coastlines. In Europe, research has been conducted in only a few countries and results have been inconclusive, largely due to low statistical power.[56] The overarching goal of the BlueHealth project (www.bluehealth2020.eu) is to fill these gaps.

Over its four-and-a-half year duration, this pan-European project aims to understand better associations between exposure to blue space and health and well-being through a large-scale systematic programme of interdisciplinary research that investigates exposure to blue space and its effects on health and well-being in various geographical, climatic, socioeconomic and cultural contexts across Europe. Furthermore, it aims to quantify the public health impacts of existing and novel interventions and policy initiatives connected to blue space environments, and will develop tools that support decision making on future investments in Europe's blue infrastructure with health promotion in mind.

METHODS AND ANALYSIS

BlueHealth conceptual model

Within the scope of BlueHealth we define blue spaces as outdoor environments—either natural or manmade—that prominently feature water and are accessible to humans either proximally (being in, on, or near water) or distally/virtually (being able to see, hear or otherwise sense water). We hypothesise that many benefits to health and well-being from exposure to blue space follow pathways similar to those identified for green space (e.g.[57–61]). We hypothesise that they differ since research suggests that people are particularly motivated to spend time in blue spaces compared to green, grey or mixed blue/green spaces, and that affordances exploited in blue spaces may be particularly beneficial, even relative to green or mixed spaces.[41,62,63] Through an iterative process of literature review and discussion, we created an influence diagram—the BlueHealth Conceptual Model (Figure 1)—that begins to answer the question "What causal chains link drivers of urban infrastructural change to impacts on public health and well-being?" in terms of what could be feasibly explored within BlueHealth.

The Conceptual Model posits that changes made to urban infrastructure and planning will be influenced by future changes in climate, particularly extreme events, as well as responding to a number of cross-cutting issues such as demographic, economic, technological and historical/cultural/geopolitical factors (e.g. Europe's Blue Growth agenda[64]). These changes might impact on the amount and relative distribution of blue space 'available' to the public, or on its character. They may change a population's contact (direct and indirect exposure) with blue spaces, as well as types of activities conducted therein. We consider that changes in exposure to blue space will influence the determinants of health, in terms of stress, physical activity, social contact and place attachment, climate change mitigation and adaptation, and, subsequently, on the states of health and well-being that impact on quality of life, on health care systems and on society at large. We also recognise that these impacts will vary across and within different populations, and across climate zones.

Building an evidence base

To answer the question posed above, the project will build a robust evidence base on the impacts of exposure to blue space on health and well-being, through reviews of existing evidence, analyses of available secondary data, and collection and analysis of a multitude of novel datasets by way of a pan-European online panel survey, community-level interventions and application of virtual reality.

Reviews

Despite several extensive reviews of health and (urban) green space (e.g.[59,61,65–69]), we know of only one scoping review examining the relationships between health, well-being and blue spaces,[20] and one review on the health impacts of green and blue space that highlighted the insufficient data available on the association between mental health and blue space.[67] BlueHealth will build on these preliminary reviews by employing best practice evidence synthesis guidelines to conduct three broader and up-to-date reviews of the literature and international practice.

The first review will provide a systematic synthesis of the evidence on the relationships between urban blue spaces and the benefits to health and well-being, answering the question: "To what extent, and through what mechanisms, is exposure to urban blue space associated with opportunities for health and well-being promotion and disease prevention?" The results of this review focus the collection of primary and secondary data in the project and guide analytical strategies of them.

The second review will seek to answer the question: "What facets of urban blue infrastructure design and project implementation best promote health and well-being?" This review will examine the effectiveness of plans and, particularly, built environment projects at enhancing public health and well-being. Project documentation, information on planning and implementation processes, and current condition and usage will be evaluated in each case. A set of BlueHealth Criteria will be based on the outcomes of this review; subsequently, these can be used to evaluate new policies and plans in terms of their potential impact on public health. Since much of the evidence is documented in unpublished reports and the professional press, the

review will focus on those projects which have, for example, won international design competitions or prizes.

The third review will answer the question: "To what extent, and through what mechanisms, do indoor artificial recreations of blue (and other natural) environments impact on health and well-being." It will systematically consider effects on health and well-being of blue environments recreated indoors, including the use of aquaria,[70] photographs and paintings, and virtual reality (VR). The outcomes of this review will enable the focused development of VR studies conducted within BlueHealth.

Secondary data analysis

Analyses of secondary data will be carried out to further understanding of how blue space affects health and well-being. Previous analyses of secondary data have been country-specific and suffered from comparability issues due to differences in exposure assessment, outcome measures, adjustment for confounders, and analytical methods. We will conduct coordinated research on key European datasets that contain common health outcomes (e.g. GHQ12,[71] SF-36,[72] Global Life Satisfaction[73]), allowing for consistent operationalisation of exposure to blue space (i.e. residential proximity), including the UK Understanding Society survey (~40000 subjects per two-year wave),[74] the *Enquesta de Salut de Catalunya* ('Health Survey of Catalonia') (~8 000 subjects per four-year sample),[75] and the Swedish Skåne Public Health Questionnaire (~28 000 subjects per four-year wave)[76] Survey responses will be geocoded as population-weighted centroids of lower layer super output areas (UK), and residential address (Sweden and Catalonia); various metrics of residential proximity to blue space (based on previous research[44,56]) and area-level average exposures will be assigned using the European Environment Agency's Urban Atlas.[77] Analysis of these data using a common protocol will allow for comparisons of large samples in three European countries.

Primary data collection and analysis

BlueHealth International Survey

A bespoke BlueHealth International Survey (BIS) is being developed to collect primary data on a large sample of the European populations' recreational experiences of blue spaces and reported

health and well-being status. The survey will collect large, nationally-representative samples of individuals, stratified on age, sex, region, and employment status, in 14 European countries (Bulgaria, Czech Republic, Estonia, Finland, France, Germany, Greece, Ireland, Italy, Portugal, Spain, Sweden, The Netherlands, United Kingdom), which represent a range of climatic, geographic and cultural contexts, have coastlines on the Atlantic, the North Sea, the Mediterranean, the Black Sea or the Baltic—or are landlocked—and several feature high numbers of lakes and include Europe's largest rivers. One thousand panel members will be surveyed in each country (except in Bulgaria and Estonia, where 500 individuals will be surveyed). For comparability with existing evidence, questionnaire items have been chiefly drawn from national surveys and European projects.[55,78] Outcome measures include validated pre-translated health and well-being measures such as the WHO-5 Well-being Index,[79] and items in the European Social Survey.[80]

The BIS will facilitate cross-sectional analyses of nationally-representative samples across Europe, and will primarily focus on elucidating the potential physical and mental health effects of recreational (as opposed to occupational) experiences in blue spaces. It will also facilitate various economic evaluations. Firstly, a travel-cost method will be used to ascribe monetary values to visits using data collected on distances travelled, time taken and mode of transport used to get from a starting point to different blue space destinations. Secondly, economic values will be assigned to levels of physical activity undertaken within different blue environments, using existing protocols.[81,82] Thirdly, a contingent behaviour approach will be used to gauge public reactions to the EU's updated Bathing Water Standards and associated signage, introduced in 2015/16. Water quality at 15,363 designated coastal and 6,473 inland bathing water sites across the EU is now scored in terms of a four-point classification, namely Excellent, Good, Sufficient, and Poor. We will investigate how willingness to visit bathing sites is affected by the classifications and signage, thereby informing us of how bathing water quality may affect recreational choice.

Community-level interventions

At the local scale, we will evaluate impacts on health and well-being of changes to blue infrastructure and recreational behaviour in a range of community-level interventions (CLIs). Conducted across eight European countries, these CLIs were selected to encompass a variety of

blue spaces (e.g. coast, rivers, lakes) and a broad range of demographic, socioeconomic, historical/cultural/regional and climatic contexts (Table 1). Ten CLIs are classed as *environmental interventions*, wherein a tangible change to an aspect of the (urban) blue infrastructure will take place during the course of the project. The impacts of these interventions on the health and well-being of local residents and users will be monitored. In five of these CLIs, the interventions are being made according to existing plans made by third parties. In the other five, we have the opportunity to make novel alterations to the environment to test specific hypotheses. We refer to these as 'urban acupuncture' interventions,[83] by which we mean relatively small-scale interventions made at underused, inaccessible or negatively perceived sites, that may confer disproportionately large positive impacts on the use or enjoyment of those places by given populations. Each urban acupuncture intervention will be context-specific, and designed, co-created and installed with the cooperation of key stakeholders, including local landscape architects, engineers and planners, and local residents. The economic costs of the interventions will be monitored to enable estimation of the cost-effectiveness of each in increasing salutogenic use of each space. The other three CLIs are classed as *behavioural interventions*, meaning that they aim to change the way people interact with existing (urban) blue infrastructures. These include promotion of lunchtime walking for office workers in Barcelona (Spain) and Thessaloniki (Greece), and school swimming lessons for children of immigrant families that recently moved to Malmö (Sweden).

Type of CLI	Name	Location	Nature of intervention	Evaluation timing	Evaluation tools
Environmental interventions (interventions made to the environment)	Appia Antica Park	Rome, Italy	Improve information on access to, and use of, an urban park	Cross-section of users versus non-users	BCLS, BEAT, BSGIS
	Urban beach regeneration	Plymouth, UK	Regeneration of, and improved access to, an urban beach in a deprived part of the city	Pre-, post (3 months) & delayed post (9 months)	BCLS, BBAT, BEAT + a pre intervention contingent valuation exercise (i.e. willingness to pay for the regeneration);
	Besòs River access	Montcada i Reixac, Spain	Provision of access to an urban riverside path	Pre- and post	BEAT, SOPARC, BCLS
	het Nieuwe Diep access	Amsterdam, the Netherlands	Regeneration of, and improved access to, an urban beach	Pre- and post	BCLS, BBAT, BEAT
	Marazion dune cycle path	Cornwall, UK	Urban acupuncture	Pre- and post	BSGIS, BEAT, BCLS
	Anne Kanal	Tartu, Estonia	Urban acupuncture	Pre- and post	BSGIS, BEAT, BCLS
	Tallinn urban shoreline	Tallinn, Estonia	Urban acupuncture	Pre- and post	BSGIS, BEAT, BCLS
	Rio de Couros urban stream	Guimarães, Portugal	Urban acupuncture	Pre- and post	BSGIS, BEAT, BCLS
	Ribban beach park	Malmö, Sweden	Urban acupuncture	Pre- and post	BSGIS, BEAT, BCLS

Type of CLI	Name	Location	Nature of intervention	Evaluation timing	Evaluation tools
	Modernist fountain renovation	Rubí, Spain	Local volunteer renovation of historic fountain	Qualitative	BEAT, BSGIS
Behavioural interventions (interventions made to population behaviour)	Walking office workers	Barcelona, Spain	Trial	Walking group versus control	BPAT
	Walking office workers	Thessaloniki, Greece	Trial	Walking group versus control	BPAT
	School swimming lessons	Malmö, Sweden	Observational, difference in difference	Pre- and post	Swimming ability

BBAT: BlueHealth Behavioural Assessment Tool BCLS: BlueHealth Community-Level Survey BEAT: BlueHealth Environmental Assessment Tool; BPAT: BlueHealth Physiological Assessment Tool BSGIS: BlueHealth SoftGIS

Table 1 - Summary of BlueHealth community-level interventions (CLI)

Five evaluation tools are being developed to assess aspects the CLIs:

1) The BlueHealth Community Level Survey (BCLS) is a shorter site-specific version of the BIS. It will be used with local communities before and after environmental interventions. The inclusion of items common to the BCLS and BIS allow the integration of findings from CLIs with higher level data from the same country.
2) The BlueHealth Environmental Assessment Tool (BEAT) will be used in all CLIs to assess objective environmental conditions (terrestrial and aquatic) and specific features of blue infrastructure at each site. The BEAT will be used at least twice in the environmental interventions to document change before and after their implementation. The tool includes evaluation of water quality, accessibility, litter and vandalism, signage etc.
3) The BlueHealth SoftGIS (BSGIS) tool will use participatory mapping [84] to understand how local residents use the blue spaces in the cities under study. One limitation of all pre-post intervention work is knowing whether changes are site-related, or reflect more general changes in attitudes and behaviours. Enabling local residents to comment on their experiences in local blue spaces will provide a more rounded picture of the importance and relevance of changes made at these sites.
4) The BlueHealth Behavioural Assessment Tool (BBAT), will be used to systematically observe and record how people behave and interact in different areas at relevant CLI sites. Observations made pre- and post-intervention provide information on how behaviour has changed as a result, and inform us about any affordances generated for specific user groups.
5) The BlueHealth Physiological Assessment Tool (BPAT) will be used in the Thessaloniki and Barcelona behavioural interventions (and adapted for use in VR studies). A variety of

physiological measures will be collected from participants pre- and post-intervention to investigate short-term effects of spending time in and around blue space on stress and well-being.

Virtual reality

BlueHealth will employ innovative virtual reality (VR) technology in two distinct ways. Firstly, we will create computer-generated imagery of each urban acupuncture site for use by planners and stakeholders in order to optimise the intervention prior to implementation. Using VR with stakeholders in the design phase provides the opportunity to obtain a realistic impression of the proposed intervention, allowing better informed discussion. Secondly, we aim to deliver health and well-being benefits of blue space to individuals unable to access outdoor environments, either because they are undergoing medical treatment or because they are prevented from visiting blue space due to age, ill health, disability, or environmental conditions. This will require research that builds on the current evidence.[42,85,86] We will further investigate the efficacy of VR blue spaces in the reduction of stress and discomfort during medical procedures such as dental treatment.[85,87] In parallel, we will examine how interactive VR technology and/or the ability to choose visit locations can be used in residential care settings to enable older people to, for instance, 'visit' blue space locations of their own choosing more frequently.

The VR-environments and in-situ protocols will be developed in collaboration with stakeholders and user-groups, to ensure desirability and feasibility. Piloting testing, within controlled laboratory settings, will be conducted prior to in-situ testing to investigate the psycho-biological pathways between virtual blue space exposure and health and well-being outcomes in key target groups.[88] Such work will enable us to explore the underlying mechanisms that are often hard to demonstrate in real-world settings.

Informing urban planning policy and long-term strategy

The BlueHealth evidence base will provide information on how changes to urban blue infrastructure and societal behaviours can maximise benefits to health and well-being associated with blue space. In order to best inform planning over a longer timescale—and to identify optimal blue infrastructure intervention strategies—a number of ideal-typical visions of the future (2050) will be elaborated based on plausible and health-relevant changes in demographic,

economic, societal, technological, ecological and political spheres.[89] Five such BlueHealth Futures will be designed to explore the potential ramifications of rapidly changing environments and climate in the context of social and environmental inequalities and demographic change which are particularly pertinent to the health benefits and risks of interactions with urban blue infrastructure (e.g. flooding, water quality, urban heat islands), and to evaluate the effects of adaptive strategies. For this purpose, environmental and societal trends on a global, European and national scale will be scaled down to their relevance on an urban level. Having identified the future developments that will most significantly affect public health, the BlueHealth Futures can be used to identify promising policy options and strategies for influencing them. This will be done with identified inter-sector stakeholders from government, business, academia, and citizen organisations.

Finally, a BlueHealth decision support tool (DST) will be developed with ongoing stakeholder input and engagement. Building on similar DSTs on urban green infrastructure, the BlueHealth DST will provide policymakers with a novel means approach planning of blue infrastructure—in the face of climate and other environmental change—with both health promotion and the management of potential health risks in mind.

DISCUSSION

The principal aim of the BlueHealth Project is to quantify the impacts on population health and well-being of existing and novel environmental interventions (as well as individual level behavioural initiatives) connected to blue space environments, and to identify the opportunities and obstacles for efficient policy-making and cross-sectoral collaboration in this area.

Assessments of the health and well-being (and environmental) co-benefits, risks, trade-offs, and costs will improve our understanding of the role of urban blue infrastructures in cross-sector health promotion and disease prevention. Many of these infrastructures were originally designed for other policy goals (e.g. transport, flood prevention). However, innovative design and planning can promote health by ensuring that the co-benefits are captured and governance processes should be designed with this broader perspective in mind. For example, given peoples' preferences for blue spaces and their willingness to visit them,[38,90] the evidence suggests that the population uptake of blue infrastructure initiatives that encourage, for instance, greater levels of active recreation, will be particularly high, and thus important for disease prevention and health promotion. The precise conditions of governance needed for such initiatives to be effective are as yet unclear.

We anticipate that the design of this intersectoral, international and multi-disciplinary BlueHealth project, and of the research programme laid out in this article, will provide key evidence to those making decisions on the development and maintenance of Europe's urban blue infrastructures on how to maximise the public health benefits of their policies and projects, to minimise health inequalities across and within populations, and to prepare for future changes in demography and climate. In addition to the evidence base, BlueHealth will produce a number of tools, suitable and available, for incorporation into design, planning and evaluation of interventions and governance processes conducted in, on and around urban blue infrastructure. The legacy of the project—data, evidence, interventions, tools, recommendations, and networks of experts and other stakeholders—will result in decision-making and urban planning that better integrates public health and disease prevention strategies. Given the sizeable investments needed to protect cities against climate change—particularly those on or near blue space—in coming

years, we anticipate that this intersectoral and co-benefit integration could potentially generate large returns in terms of improved population health.

Depending on how the BlueHealth DST is developed—which will in large part be based on stakeholder needs identified—this tool could be applied to assess the public health impact of various scenarios concerning changes in infrastructure, climate or other drivers. Considered application of such a tool might be useful in the targeted planning of blue space infrastructure to minimise health inequalities in areas characterised by particular vulnerabilities, including assessing the transformability potential of aspects of urban environments.

The BlueHealth project is chiefly aimed at the better understanding the *benefits* to health and well-being of non-occupational interaction with blue space in urban settings. Health risks related to recreation or working in environments with water are assessed, but not investigated explicitly in the BlueHealth project. Several occupations are specific to such environments, and many of these present specific risks (e.g. commercial fishing is one of the most hazardous professions globally[91–93]). Since these risks are well understood (compared to the benefits), the BlueHealth project will devote less time to these issues, principally drawing on the existing evidence base on risk when developing the DST.

The pan-European focus of BlueHealth will generate information primarily of relevance to decision-makers across Europe and high-income countries. We are currently uncertain about how the outputs from BlueHealth will transfer to low and middle income countries, in part due to the pace and nature of urban development in these regions, and in part due to the potentially greater risks associated with waterborne disease and other exposures. The concept, and several of the methods, of the BlueHealth project could, however, be readily transferable to other geopolitical contexts. The rapid urban development taking place across the globe requires the construction of urban blue infrastructure on a substantial scale to meet the demands of various sectors. Better understanding of both the risks and benefits associated with this blue infrastructure through a set of developing world case studies might serve to incorporate non-traditional health promotion and disease prevention into development strategies in the fast-growing megapolises of low and middle income countries.

Historically, physical mechanisms have been popularly described as the means by which blue environments—in particular the sea—positively influence health e.g. invigoration of the body and mind through contact with 'bracing sea air'. Although there is little evidence of these effects, a number of hypothetical biochemical mechanisms have been put forward, including exposures to low levels of airborne microbiota and biogenic products (including phytochemical and particulate allergens), some of which may interact with inflammatory cell signalling pathways to benefit human health.[94] Currently, the empirical evidence for such mechanisms is relatively limited, and there are currently no plans to investigate these issues in detail with the scope of BlueHealth. Rather, BlueHealth has purposely been focused on those recreational, cultural and ecosystem services interactions with the blue environment to which we expect the majority of health benefits might be attributed.

ETHICS AND DISSEMINATION

Throughout the BlueHealth project, ethics review and approval are obtained for all relevant aspects of the study by the local ethics committees prior to any work being initiated and an ethics expert has been appointed to the project advisory board. So far, ethical approval has been obtained for the BIS and for CLIs taking place in Spain, Italy and the UK. Engagement of stakeholders, including the public, involves citizens in many aspects of the project. Results of all individual studies within the BlueHealth project will be published with open access. After full anonymization and application of any measures necessary to prevent disclosure, data generated in the project will be deposited into open data repositories of the partner institutions, in line with a formal data management plan. Other knowledge and tools developed in the project will be made available via the project website (www.bluehealth2020.eu). Project results will ultimately provide key inputs to planning and policy relating to blue space, further stimulating the integration of environmental and health considerations into decision-making, such that blue infrastructure is developed across Europe with both public health and the environment in mind.

AUTHOR CONTRIBUTIONS

James Grellier (JG), Mathew P White (MPW), Lora E Fleming (LEF) and Lewis R Elliott (LRE) drafted this manuscript on the basis of a grant proposal which was devised and written by MPW, LEF, Maria Albin (MA), Simon Bell (SB), Mireia Gascón (MG), Silvio Gualdi (SG), Laura Mancini (LM), Mark J Nieuwenhuijsen (MJN), Denis A Sarigiannis (DAS), Matilda van den Bosch (MvdB), Tanja Wolf (TW) and Susanne Wuijts (SW). All of the authors made substantial contributions to the Methods section of the draft manuscript, in which the conception and design of aspects of the work for which they are responsible in the BlueHealth project are described. Specifically: JG, LRE and MPW constructed the BlueHealth Conceptual Model; JG, LRE, MPW, MA, MG and MJN wrote the sections on *Reviews* and *Secondary data analysis*; JG, LRE, MPW, SB, MG, SG, LM, MJN and MvdB wrote sections on *Primary data collection and analysis*; and TW, SW and DAS rewrote the section on *Informing urban planning policy and long-term strategy*. All co-authors also contributed to the writing of the *Introduction* and *Discussion* sections. JG subsequently prepared a final version of the manuscript based on co-author contributions. All authors then read the final version, approved it for submission for publication and agree to be accountable for all aspects of the work.

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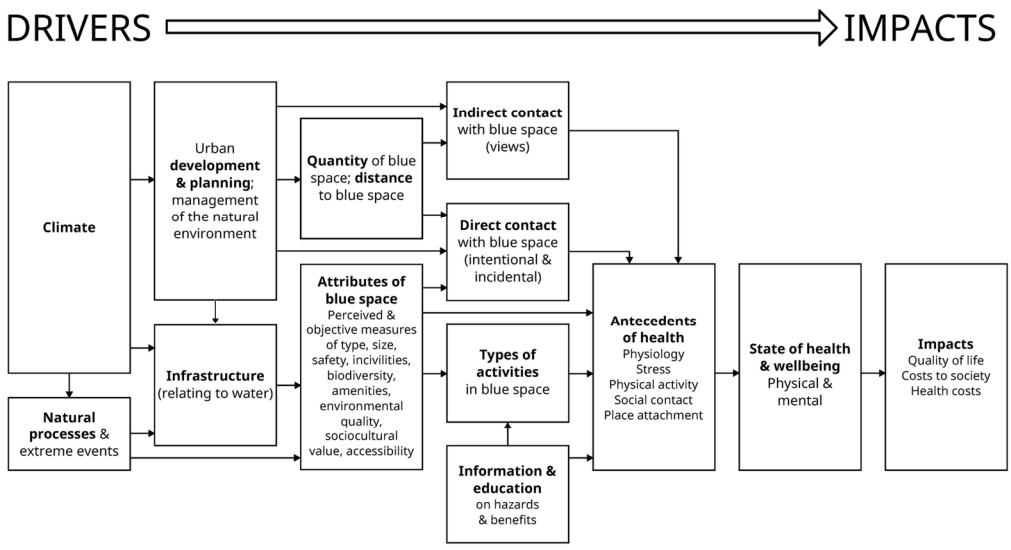
FIGURES

Figure 1

BlueHealth Conceptual Framework: an influence diagram describing the causal chain between drivers and impacts under investigation in the BlueHealth project



BlueHealth Conceptual Framework: an influence diagram describing the causal chain between drivers and impacts under investigation in the BlueHealth project

Figure 1

146x91mm (300 x 300 DPI)