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Editorial

Urban nature benefits – Opportunities for improvement of health and well-being in times of global change

Nadja Kabisch[1,2,], Dagmar Haase [1,3]*
*E-Mail: *nadja.kabisch@geo.hu-berlin.de*

[1] Humboldt-Universität zu Berlin, Geographisches Institut, Unter den Linden 6, 10099 Berlin, Germany
[2] Helmholtz Centre for Environmental Research-UFZ, Department of Urban and Environmental Sociology
[3] Helmholtz Centre for Environmental Research-UFZ, Department of Computational Landscape Ecology

Abstract
Cities are those places on earth with the highest human population densities in combination with concentrations of built, social, and economic infrastructure. They are those places where climate change and urbanisation impact with severe challenges. Yet they provide opportunities for action on a multitude of variables to influence both health and well-being of the majority of the world's population. The complex and multifaceted nature of these challenges calls for an integrated approach in which urban nature – namely green and blue spaces – should play a major role. Urban nature benefits for health and well-being are in the focus of this short communication.

1. World Urbanisation and Climate Change

1.1 World Urbanisation Trends

Urbanization is understood as population growth and the increase in densification of built-up areas (Haase et al., 2018). Nowadays, more than half of the world's population lives in cities. More than 60 years ago, in 1950, less than on third (30%) of the world's population was defined as urban, and it is projected that in the next 30 years (by 2050),

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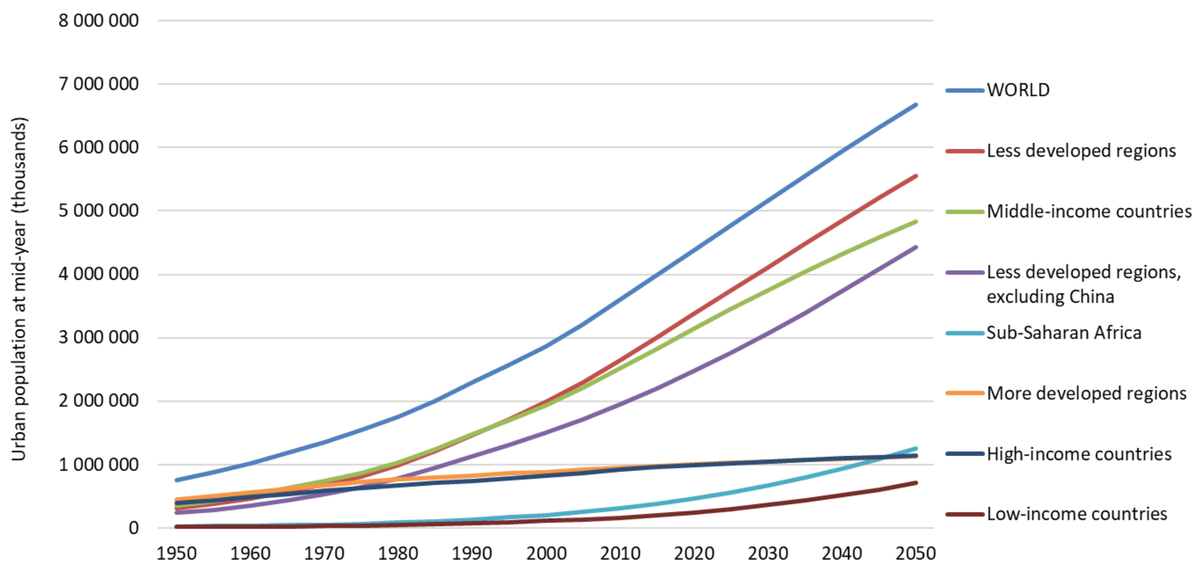

Figure 1. World urban population (in thousands), divided by world regions, for the period of 1950-2050. Data: World Urbanisation Prospects: United Nations, Department of Economic and Social Affairs, Population Division (2018). The 2018 Revision (own graph).

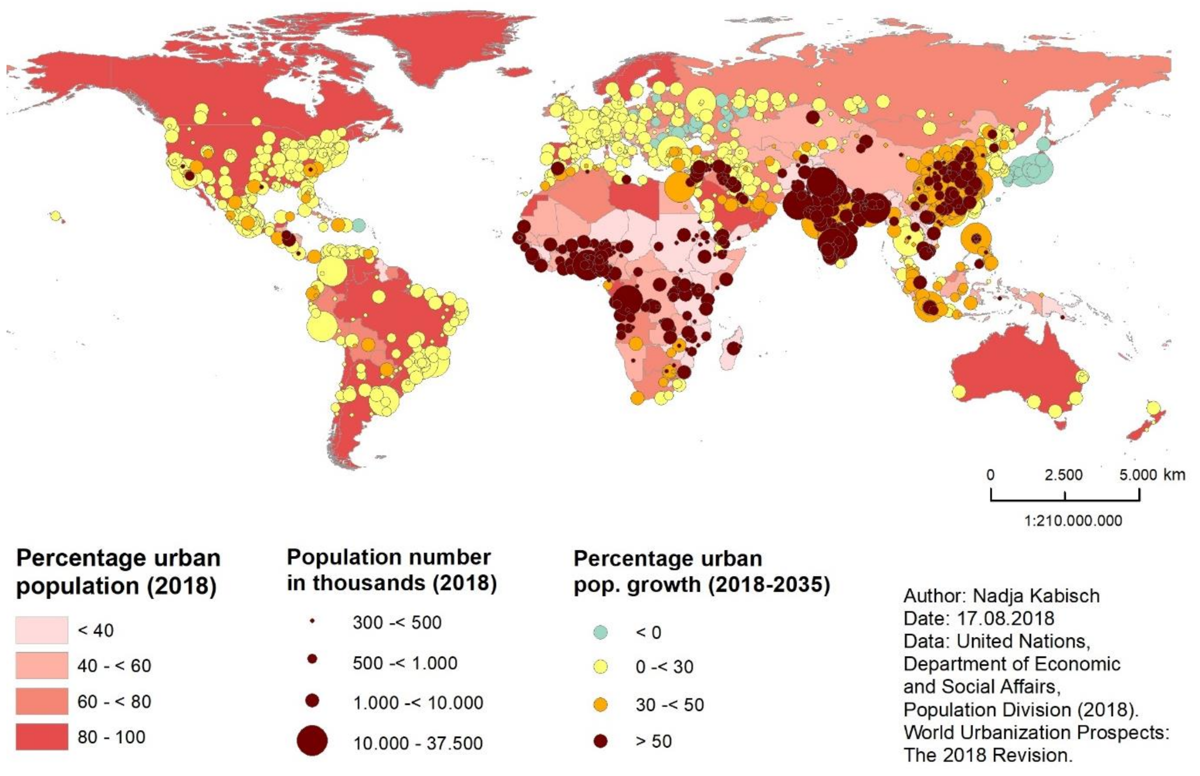

Figure 2: Percentage urban population, population number by size classes and percentage population growth 2018-2035. Data source: United Nations, Department of Economic and Social Affairs, Population Division (2018). World Urbanization Prospects: The 2018 Revision, Online Edition.

around 68% of the world's population will be urban (United Nations -Department of Economic and Social Affairs, 2018, Figure 1). Urban population growth is driven by migration towards cities and peri-urban areas and by natural growth. Although the level of urbanization in less developed world regions of Asia (50%) and Africa (43%) is significantly lower today and more people are still living in rural areas, these global regions will be the ones where urbanisation will occur most rapidly in the coming decades (Figure 2). Projections expect that population growth in Asian and African (mega-)cities will add almost 90% of the overall 2.5 billion to the world's urban population expected for 2050. Today, the most urbanized regions are Northern America (82%), Latin America and the Caribbean (81%), and Europe (74%, see Figure 2 again).

Nearly half of the world's urban population lives in cities with less than half a million inhabitants. In addition, we find a total of 33 megacities each hosting more than 10 million inhabitants. Soon, in 2030 this number will increase to 43 megacities located to the largest extent in developing countries. At current, the largest megacity with 37 million inhabitants is located in a highly developed but strongly ageing country: Tokyo in Japan. Although population growth is the major trend in our urbanising world, we find some declining cities in the last decades. Faced with population losses due to natural disasters or economic decline those are mostly low-fertility countries in the developed world, such as in Asia or Europe (Figure 2).

1.2 Global Climate Change and its impact on cities

In a global study, Scheuer, Haase, & Volk (2017) showed that those areas facing major urban growth are to a large extent also hotspots of climate change. Climate change can profoundly impact on urban environments with heat waves, droughts, extreme rainfall events and resulting stormwater or riverine floods causing severe effects on health and well-being of city residents. Urban areas usually contain high shares of sealed spaces covered with asphalt and brick. Roofs are often dark and less space is left for unsealed green open spaces. These typical urban land cover conditions boost and absorb air temperatures, and may lead to severe surface flooding in case of extreme rainfall events when water cannot infiltrate into the soil and forms large runoff waves. In consequence, urban planning has to deal with challenges such as health of residents being at risk due to excessive heat, and with infrastructure such as drainage systems may not being constructed for extreme events (Kabisch, Korn, Stadler, & Bonn, 2017). Less obvious but remarkable for the long-term urban sustainability and thus also highly relevant for human well-being is the biological response to a changing climate in cities exhibiting a loss of native species and an invasion of infection-prone tropical fauna, e.g. mosquitos (Knapp, Kuehn, Stolle, & Klotz, 2010)

Temperature-related climate extremes such as extensive heat waves are strongly impacting on human health. Heatwaves with severe health impacts were mostly related to excessive mortality rates such as in the case of the 2003 or 2010 summer heat waves in Europe with increased deaths particularly in Paris (ca. 1850 people) or Moscow (ca. 11,000) (Shaposhnikov et al., 2014; Vandentorren et al., 2004). Excessive heat events occur already now frequently in many urban areas worldwide with nearly one-third of the world's population being exposed to thermal conditions with severe health outcomes (Mora et al., 2017). Within the last 50 years, several cities across the globe showed a statistically significant rise in the number of heat waves with the highest number counted in the recent decade (Mishra, Ganguly, Nijssen, & Lettenmaier, 2015). Taken over all sites, the largest number of heat waves has occurred during the most recent decade (2003–2012).

The year 2018 will get known as a year with one of the hottest and driest summers and respective health consequences around the globe, particularly in the Northern hemisphere. In Quebec, Canada, at least 93 people died as a result of the July heat wave including 53 deaths in the city of Montreal (Woods, 2018). Temperatures reached values of even more than 35° C during the first week of July in 2018. In the

US, temperature measurements showed a top value of 48.8 °C in parts of Los Angeles (Woods, 2018). In Europe, the 2018 heat wave reached Scandinavia with constant July-temperatures of above 30 °C. In a comparative analysis of European capital cities, in 2018, Stockholm was the driest city with a precipitation of 76 mm for the period April-July which is less than a half of the rainfall average in this period (165 mm, Figure 3; Behlinger, 2018).

Based on local land cover conditions in urban areas, impacts of climate change are not evenly distributed. Urban greenspaces can significantly lower air temperatures through shading and evapotranspiration and vice versa may counteract heat related mortality. Schinasi, Benmarhnia, & De Roos (2018) found that people living in less green areas had a 5% higher risk of death from heat-related causes compared to those living in greener neighbourhoods. Climate impacts on cities further include the overall traffic-related poor air quality because of the higher ozone concentration in the troposphere and a respective ozone enrichment in the lower atmosphere. Thus, air pollution with particles and NO_x is more severe in these hot areas, increasing the risk of morbidity and mortality.

Impacts from climate change but also urbanisation are in particular severe for vulnerable population groups, such as elderly people, children or low-income populations living near traffic routes or in poor housing conditions with less or now access to urban green spaces (Kabisch, Haase, & Van Den Bosch, 2016).

2. Benefits of urban natural environments for human health

Natural environments such as urban green and blue spaces that include a number of green and blue spaces such as parks, forests, gardens, allotments, street trees, cemeteries or bioswales on the one hand and lakes or rivers on the other may counteract the challenges from urbanisation and climate change through the provision of ecosystem services, i.e. the benefits nature provides to humans. In particular, ecosystem services can provide a number of health opportunities to city residents because exposure to natural environments contributes significantly to human health through mediating pathways

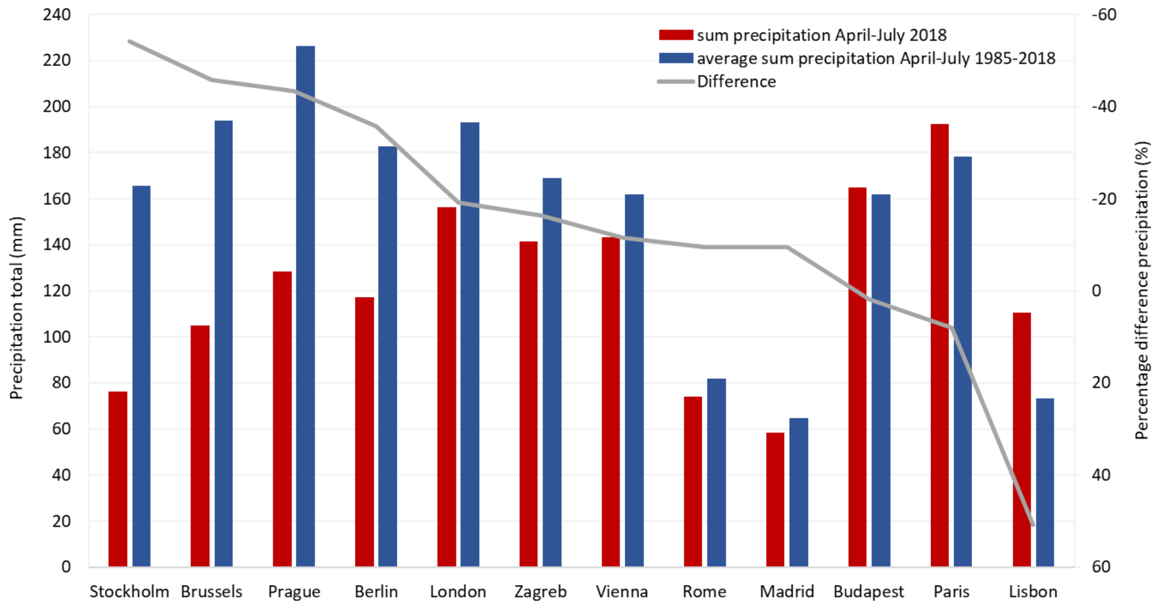

Figure 3. Accumulated precipitation April-July 2018 compared to average precipitation April-July 1985-2018 and percentage difference for selected European capital cities. Data: Meteoblue (https://www.meteoblue.com; Behlinger, 2018).

and direct effects (Haase et al., 2014; Hartig, Mitchell, de Vries, & Frumkin, 2014; Kabisch, van den Bosch, & Lafortezza, 2017) Table 1 shows examples of how urban green and blue spaces provide ecosystem services that are of particular relevance for improving human health in the context of climate change and urbanisation.

Table 1. Examples of health promotion by urban nature - provision of cultural ecosystem services. Photos by: Nadja Kabisch.

Urban nature offers space for many different sport activities, space to engage with nature, and thus, may improve physical and mental health as well as well-being.	
Natural areas provide opportunities to engage in creative play, set self-paced challenges, find quiet retreats, learn about the environment from direct experience, and form emotional bonds with places and the natural world.	
Contact with nature and better access both green and blue spaces improve attention restoration and stress relief.	
Urban nature encourages physical activity, improves mental health and may increases social connectedness particularly for elderly.	

Urban vegetation improves climatic conditions by tree shading, leaf transpiration and the exhalation of essentials.	
Urban green improves air quality and attenuates noise by buffering acoustic waves and by fixing pollutants on the leaf surfaces.	
Urban green decreases energy use in housing estates by cooling in-door temperatures without artificial air conditioning and keeps air temperature moderate in times of cold days without heating.	
Urban green mitigates rainfall and coastal flooding and helps to moderate extreme precipitation events in cities.	

3. Pathways through which urban nature can affect health in the context of challenges from climate change and urbanisation

The pathways of the provision of ecosystem services by urban green and blue spaces and how they may be linked to improvements of health is shown in Figure 4 with a particular focus on children and elderly people, as vulnerable groups in cities. These pathways can act to either encourage healthy activity and behaviours like physical activity or social interaction through the provision of cultural ecosystem services (Rall, Bieling, Zytynska, & Haase, 2017), or to decrease risk factors such as air pollution or urban heat through the provision of regulating ecosystem services (heat mitigation by the leafs of the vegetation, tree crown shade, noise buffering or limited car traffic).

How the provision of these ecosystem services translates into significant health outcome effects was analysed through a systematic literature review of scientific research by Kabisch et al. (2017). The results showed that the health outcomes differ between sub-groups of children and elderly residents: Health outcomes of children mainly addressed birth outcomes, mental health (particularly ADHD), obesity and overweight, asthma, and allergy. Health outcomes of the elderly mainly addressed heat and air pollution-related mortality, but also mental health and perceived general health.

A basic finding of the review is that there is a tendency for a positive association between urban green and blue spaces and reduced environmental risk factors due to increasing urbanization for both groups. Some particular relationships address the association between green space and mental health and behavioural issues in children. Relatively consistent results convincingly show that exposure to green space is associated with reduced aggressive behaviours and improved cognitive development among children (Amoly et al., 2014; Younan et al., 2016). Access and use of urban green space is also related to an improved perceived health of elderly people. Nevertheless, the overview of the diversity of studies also revealed that general evidence is rather weak and that results from different individual studies are to some degree inconclusive (Kabisch, van den Bosch, et al., 2017). These inconclusive studies mainly concerned the relationship between green space availability and overweight in children (Kabisch et al., 2016; Schüle, Fromme, & Bolte, 2016). Here, most of the factors explaining health outcomes were related to individual socio-environmental factors as confounders such as income or social status of parents, rather than the availability of or exposure to urban green and blue spaces. Socioeconomic confounding variables seem also to explain spatial distribution and appearance of infant mortality (Kihal-Talantikite et al., 2013).

One of the main conclusions drawn from the review is that socioeconomic health determinants such as low income, deprivation, unemployment or educational status of parental households are predominant and often seem to

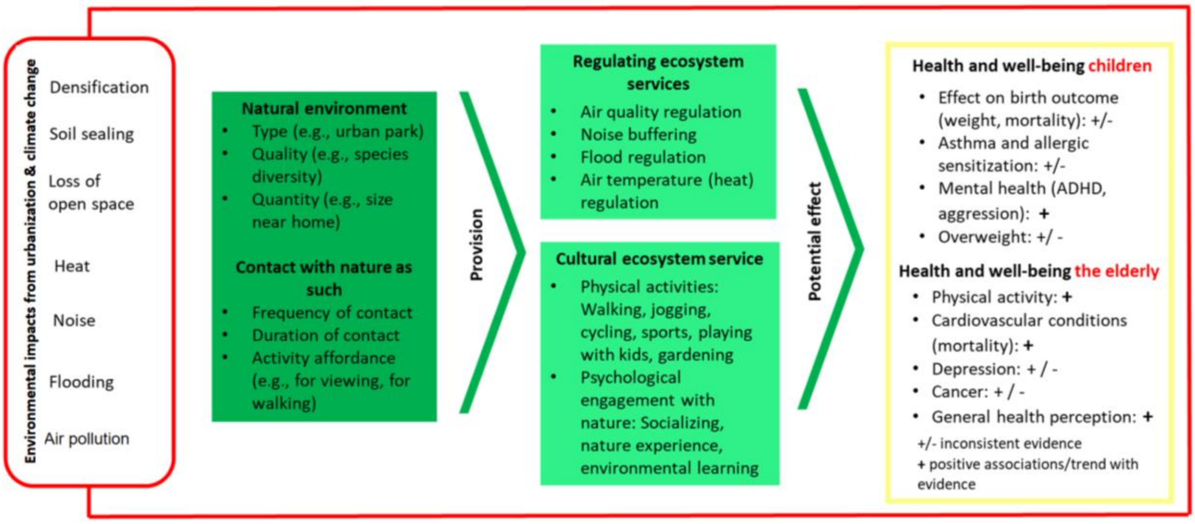

Figure 4. Pathways through which urban nature can affect health in children and elderly in the context of challenges from climate change and urbanisation.

'override' potential health improvement effects of urban nature, at least on a first view. These results demonstrate the inherent complexity and multi-factor dependency between socioeconomic and environmental factors and the health outcomes of children and the elderly. It does further show that it is particularly vulnerable population groups (deprived households such as single parents, children, elderly) who are most effected by the negative effects of climate change, in particular extensive heat, or the direct consequences of urbanisation (lack of green space, air pollution).

4. Left for Future research: A multi-method approach to assess health outcome effects of urban green spaces – the project GreenEquityHEALTH

In times of increasing urbanization and climate change, the topic of urban nature and green urban environments is central for public health and mandatory ingredient of a more resilient and sustainable urban planning. Recent heat waves and long-term hot temperatures made it very obvious that urbanization, particularly in combination with climate change, poses enormous challenges to human health. Green and blue spaces can here become crucially important refuges for people in cities in case they are open, and freely accessible for all population groups or households. Better differentiated and more clearly targeted research can help to integrate the multiple context factors of urban systems under climate change to make qualified recommendations to urban planning. Multi-method and spatially explicit, mapping approaches that show the impacts of global challenges on the urban landscape and its people, and vice versa, on their health outcomes by providing hotspots and coldspots can be very helpful here.

As many studies already show, socioeconomic variables play a major role in health outcomes and may be more important than single environmental factors. However, they do not at all eliminate them. This aspect warrants the inclusion of a combined ecosystem services provisioning and an environmental justice perspective in future studies to research the impact of urban green and blue spaces on public health in the context of ongoing urbanisation and climate change.

In this context, the research project GreenEquityHEALTH (www.greenequityhealth.hu-berlin.de) aims at assessing urban environmental processes related to climate change and urbanisation with a specific focus on public health and socio-environmental justice. In GreenEquityHEALTH, an interdisciplinary multi-method approach is applied to urban parks that includes ecosystem services assessments such as air temperature and air humidity measurements combined with remote sensing data for greenness identification and, simultaneously, social science research methods such as ethnographic observation, people counting, activity mapping, local questionnaire surveys on perceived health and use of green spaces. Linked to spatial maps, this multi-method approach will take into account many different factors to explain potential health outcomes under health relevant conditions of urbanisation and climate change.

The focus of the studies in the research group is on local residents including retired people and children to start from where the reviews ended. The specific aim is to assess the potential of urban green spaces for improving health of city residents. Surveys and measurements focus on selected urban green spaces such as historic old parks but also newly developed parks resulting from brownfield regeneration in two German cities Leipzig and Berlin, two cities that underwent decline and growth with high dynamics and velocity in the last decades. The results of the interdisciplinary on-site monitoring activities, sensor-based modelling and surveys will feed into a multi-criteria assessment tool and specific policy recommendations which will be discussed in transdisciplinary workshops with local planning actors and experts of the project's advisory board. The discussions should focus on how project results can effectively support the improvement of city residents' health and environmental justice in a sustainable climate and health-sensitive urban planning. Together with the results, recommendations will be disseminated in a form of fact sheets and policy briefs using the networks of IUCN and WHO but will also feed the development of site-specific strategies and city-level targets in the case studies.

Overall, the research planned in GreenEquityHEALTH will generate significant new knowledge in interdisciplinary sustainability sciences combining research on urban ecology, urban geography, governance research, public health and urban sociology. It will contribute to the understanding and application of the Sustainable Development Goals (SDGs) of the United Nations on urbanization development and planning particularly in growing large cities. Considering environmental justice and health benefits aspects through nature in cities is of upmost importance for a sustainable and resilient future of the cities and their societies.

Acknowledgements

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International Collaboration to improve Urban Environmental Health and Sustainability: the Healthy-Polis Consortium

Sotiris Vardoulakis[1], Jennifer Salmond[2], Kim Dirks[3], Hanna-Andrea Rother[4]
E-Mail: Sotiris.vardoulakis@iom-world.org

[1]Institute of Occupational Medicine, Edinburgh, United Kingdom
[2]School of Environment, University of Auckland, New Zealand
[3]School of Population Health, University of Auckland, New Zealand
[4]Division of Environmental Health, School of Public Health and Family Medicine, University of Cape Town, South Africa

1. Introduction

Over half of the global population currently lives in cities, with rapid urbanisation putting unprecedented pressure on infrastructure and resources and threatening both environmental quality and public health. This pressure is compounded by climate change, which increases the risk of extreme weather events, such as heatwaves, floods and droughts, contributes to water shortages and can exacerbate urban air pollution episodes (Vardoulakis et al., 2016; Salmond et al., 2018). The impacts of environmental degradation are particularly evident in fast-growing cities in low- and middle-income countries (LMIC), where urban infrastructure and public health systems are less resilient to external stressors (Rother et al., 2018). High-income cities are not immune to the challenges of environmental and demographic change, with elderly populations being more vulnerable to both temperature and air pollution extremes.

Well-integrated policies and interventions in urban planning, transport and housing are needed to improve outdoor and indoor air quality, reduce carbon emissions, and deliver substantial public health, environmental, and socioeconomic co-benefits. Such initiatives could also lead to the delivery of several of the UN Sustainable Development Goals and the New Urban Agenda. For example, substantial environmental and health benefits can accrue from low-carbon policies aimed at: (a) reducing carbon emissions by improving energy efficiency in buildings, which enhances thermal comfort for occupants; (b) encouraging active transport (walking and cycling) which reduces dependence on private car use, and improves local air quality as well as physical and mental health; (c) increasing renewable energy generation, which reduces carbon emissions and improves ambient air quality; and (d) increasing and improving green infrastructure in cities, which enhances carbon sequestration, improves air quality and reduces urban heat island intensity. Accounting for the health co-benefits of climate change mitigation strengthens the case for reductions in greenhouse gas (GHG) emissions from many sectors (Haines et al., 2009).

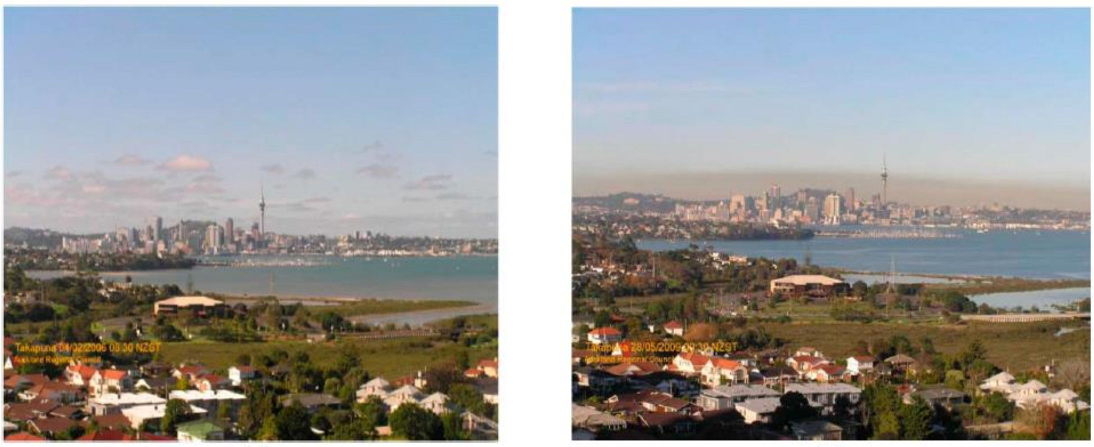
However, the environmental health challenges that cities around the world are facing are very complex and often inter-connected. Therefore, attention should also be paid to the unintended harmful effects of certain carbon reduction policies. For example, home energy efficiency measures could worsen indoor air quality, if steps are not taken to maintain good ventilation (Vardoulakis et al., 2015); and the promotion of active travel has the potential to increase road injuries, if adequate cycling/walking infrastructure is not put in place (Vardoulakis et al., 2018). Therefore, it is essential to address urban environmental health challenges holistically by providing “systems-based” solutions, rather than narrow single-hazard approaches.

Planned urban cities provide a unique space for prevention and reduction of non-communicable diseases (NCDs), particularly asthma, type-2 diabetes and cancer (Rother et al., 2018). In unplanned informal settlements (or “slums”) predominately in LMIC, urban environments are more complex to navigate for conventional adaptation strategies due to the existing social, economic and political forces (e.g., poor infrastructure, violence, crime, lack of sanitation; Smit et al., 2016). Given that “cities” and the communities within experience health inequities and disparities differently, which impacts on adaptation and NCD prevention strategies, research is critical, particularly in LMIC informal settlements, to promote community strengthening for healthy inclusive cities (Oni et al., 2016). Furthermore, research translation and engagement with policy makers are essential for raising awareness of the risks and health burdens from climate-sensitive NCDs and allocating resources for urban planning prevention strategies.

In this context, the Healthy-Polis International Consortium for Urban Environmental Health and Sustainability (www.healthy-polis.org), a global open initiative set up in 2013, aims to : (a) facilitate international, inter-disciplinary collaboration on urban environmental health research, (b) evaluate and promote cost-effective environmental interventions to improve public health in cities, (c) promote innovation and harmonisation in research methods, (d) facilitate dissemination of research outcomes and strengthen knowledge transfer, particularly bridging the gaps between research, policy and practice, and (e) promote capacity and capability building, especially in rapidly urbanising countries.

2. Knowledge transfer and dissemination across disciplines

Healthy-Polis has brought together researchers and practitioners working on a range of relevant disciplines, including environmental science, urban planning, transport engineering, building physics, epidemiology, climatology and public health. The consortium has organised inter-disciplinary meetings, symposia and workshops, often adjacent to large international events, such as the International Conference on Urban Health (Manchester, 2014; Coimbra, 2017), and the International Society for Environmental Epidemiology (ISEE) / International Society for Exposure Science (ISES) Conference (Rome, 2016; Sydney, 2017; Ottawa, 2018). It has also edited special issues of journals on: (a) Challenges and Opportunities for Urban Environmental Health and Sustainability (*Environmental Health*, 2016), which covered the broad area of urbanisation, environmental health and planning; and (b) Urban Climate, Air Pollution and Public Health (*Climate*, 2017), which explored the effects of air pollution and mitigation actions on urban populations in different locations. Some key findings from these special issues are briefly presented in the following sections.



(a) (b)

Figure 1: Auckland, New Zealand, on (a) a clear morning and (b) a brown haze morning (Courtesy Auckland Council) (Dirks et al., 2017).

3. Air pollution and climate change effects and mitigation

Links have been established between urban air pollution and mortality and morbidity in cities around the world. For example, Haque and Singh (2017) examined the health effects of air pollution on urban populations in Kolkata, India, where the burden of respiratory disease currently exceeds that of waterborne illness by a factor of five. In a contrasting geographic location, Dirks et al. (2017) demonstrated the relation between daily mortality and local traffic-related air pollutants in Auckland, New Zealand, a city with relatively good air quality that is affected by brown haze under certain weather conditions (Fig. 1).

Naik et al. (2017) demonstrated significant health and environmental co-benefits from the implementation of low emission zones involving access restrictions for polluting vehicles in West Yorkshire, UK. Xu et al. (2017) showed that exposure to green space in Hong Kong (Fig. 2) was associated with reduced mortality, potentially due to beneficial effects of improved air quality and reduced urban heat islands, leading to increases in exercise and improved mental health in densely populated Hong Kong.

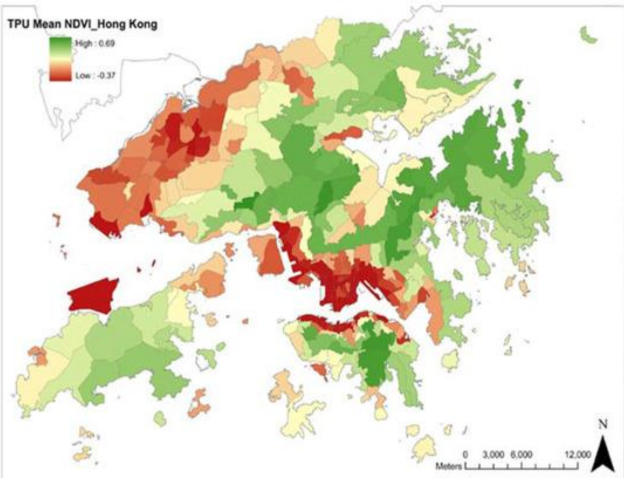


Figure 2: Mean Normalized Difference Vegetation Index (NDVI), a measure of green space coverage, by tertiary planning unit in Hong Kong in 2006 (Xu et al., 2017).

Guariso and Malvestiti (2017) demonstrated that the benefits of increased cycling in Milan, Italy, on public health and the environment, which included increased physical activity and reduced emissions of GHG and air pollutants, had to be carefully evaluated against potential increases in exposure of cyclists to air pollution and road accidents. Their analysis showed that the overall balance for public health was always in favour of cycling.

However, an analysis of the health co-benefits of climate change mitigation in several European and Chinese cities showed mixed results (Sabel et al. 2016). For example, Asikainen et al. (2017) demonstrated that policies which are intended to reduce GHG emissions in Kuopio, Finland, may have resulted in unintended impacts on local air quality, as the increased use of domestic wood burners would likely have resulted in negative impacts on local air quality and health. On the other hand, they found that there are significant economic and health gains to be made by promoting strategies that reduce traffic-related emissions by promoting active travel, such as cycling and walking.

4. Temperature effects on health

Anthropogenic climate change is projected to have a substantial impact on temperature-related mortality in cities around the world (Gasparrini et al., 2017). In an analysis of climates in 246 cities using 18 different climate model scenarios, Milner et al. (2017a) demonstrated that urban populations are projected to be exposed to higher temperatures than currently experienced, particularly in cities of mid to high latitude, in humid temperate and dry climate regions, and with large seasonal variation in temperature. These cities are likely to experience large increases in the hottest month mean temperatures under high GHG emissions trajectories, which will present challenges to current health protection measures.

Although analyses of patterns of changing susceptibility to heat and cold over time indicate that some urban populations have become less susceptible to heat over the last 100 years (Arbuthnott et al., 2016), the health effects of temperature extremes can be significant. This is particularly true in cities given that, in the absence of significant adaptation measures, hot weather is further exacerbated by the Urban Heat Island (UHI) effect (Heaviside et al., 2017), particularly during heatwaves (Mitchell et al., 2016). In the West Midlands (UK), 50% of the heat-related mortality was attributed to the UHI effect during the 2003 European heatwave (Fig. 3) (Heaviside et al., 2016).

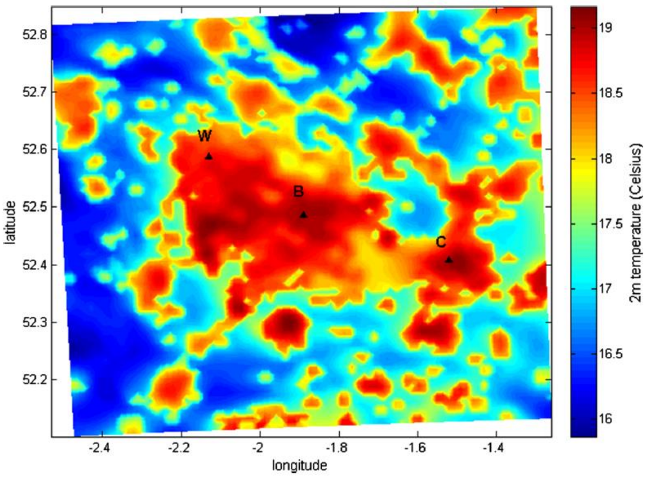


Figure 3: Modelled hourly air temperatures in the West Midlands during the August 2003 heatwave (W, B and C represent the cities of Wolverhampton, Birmingham and Coventry) (Heaviside et al., 2016).

Emergency services, such as ambulance services in cities, can also be affected by temperature extremes, which will be exacerbated by climate change (Mahmood et al., 2017). Specifically, analysis of ambulance call outs in London has showed that ambulance response times decrease when the mean daily temperature drops below 2 °C or rises above 20 °C. However, the susceptibility of urban populations and services to high/low temperatures may change in the future depending on changes in urban infrastructure and the implementation of climate change adaptation plans.

5. Housing, energy efficiency and indoor air quality

There are strong links between housing, energy and wellbeing, and these can be effectively used to determine criteria for assessing housing policy based on causal diagrams developed through stakeholder consultation (Macmillan et al., 2016). However, whilst reductions in GHG emissions through improvements in residential energy efficiency achieved by increased insulation may have appreciable near-term net benefits to health due to better indoor thermal regulation and reduced exposure to outdoor pollutants, these may be offset by increased exposure to air pollution from indoor sources due to reduced ventilation (Milner et al., 2017b). The estimated annual burden of disease caused by exposure to indoor air pollution in EU countries corresponds to a loss of over 2 million healthy life years (Asikainen et al., 2016). Future challenges in many cities include the difficulty of ventilation using outdoor air when it is polluted. Therefore, full consideration should be given to both the near- and long-term benefits and unintended consequences of climate change mitigation measures in the built environment (Vardoulakis et al., 2015).

6. Urbanisation and city planning

Cities are complex systems requiring consideration of many parameters as part of the decision-making process for sustainable urban planning. Examining the consequences of China's massive ongoing migration and rapid urbanisation, Li et al. (2016) discussed action from national to individual to protect and improve health in cities. Analysing urban form indicators and health data in England, Fecht et al. (2016) indicated higher rates of cardiovascular mortality in urban areas with higher densities of road junctions, and discussed implications for urban planning and regeneration strategies.

To assist decision-making, multi-criteria decision analysis can be used to prioritize environmental health hazards, and their mitigation (Woods et al., 2016). Alternative approaches include systems based assessment methods, which have been shown to be effective for water and waste management in cities in India, Mozambique and in Austria (Rietveld et al., 2016). The benefits of a holistic approach have also been demonstrated in Salmond et al. (2016) where the ecosystem services and disservices provided by street trees were considered to provide a framework to optimise net benefits when using tree planting as an urban planning intervention. A range of concepts and methods for addressing the complexity of urban environmental health in the context of urban and transport planning, providing a range of recommendations, is presented in Nieuwenhuijsen (2016).

7. Conclusions

Well-integrated low-carbon urban planning, transport and housing policies can help address the challenges posed by urbanisation, demographic and environmental change, and provide multiple health and socioeconomic co-benefits. Policies such as the promotion of active travel, urban greening, and energy efficiency (combined with optimum ventilation) in buildings, can help prevent non-communicable diseases and reduce health inequalities in cities.

The complexity of urban systems demonstrates the need for ongoing interdisciplinary collaboration to share international knowledge and expertise, build capacity and capability, and develop scalable solutions. This is the objective of Healthy-Polis, which alongside other international initiatives, aims to bring about sustainable transformative change in urban environments.

Healthy-Polis

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The Canadian Urban Environmental Health Research Consortium

Eleanor Setton (Managing Director), Evan Seed (Geospatial Data Lead), Dany Doiron (Data Linkage Lead), Mahdi Shooshtari (Data Scientist), Jeffrey Brook (Scientific Director)
E-Mail: jeff.brook@canue.ca

1. Introduction

How the environment around us affects our health has been an important avenue of research around the world. More than 20 years of growing evidence shows that the environmental characteristics like noise, air quality, climate, greenness, and neighbourhood amenities such as walkability, transit access, and healthy food outlets can influence individual and population health, both positively and negatively. With newly emerging opportunities to use big data for measuring and modelling urban characteristics, well-established retrospective and prospective cohorts and administrative health databases, and the increasing interest of urban planners and public health practitioners in creating healthy cities, a new era in urban environmental health research has arrived in Canada.

The Canadian Institutes for Health Research (CIHR) recognized the potential for expanding environmental health research and convened a series of meetings[1] to assess the strengths, critical issues and opportunities for environmental health research in Canada. The key results included recommendations to break down some of the existing silos of research in the environment and health field; tackle the real-world complexity of interacting and ubiquitous environmental influences; and build research capacity and supporting data platforms[2–4]. During these consultations, CIHR undertook the Environmental Health Signature Initiatives (EHSI) funding program in 2012[5].

In June of 2016, the Canadian Urban Environmental Health Research Consortium (CANUE) [6] was established at the University of Toronto with support from the EHSI, primarily to build a data platform, but also to provide a central “hub” for sharing methods and tools and connect environmental health researchers across Canada and with similar international efforts. In the first six months of operations, a Strategic Plan and associated Implementation Plan were developed by CANUE’s eight Directors and 25 Team Leaders. In brief, CANUE’s mandate is to:

- Build a common, harmonized data and methods platform containing environmental exposure metrics that characterize multiple aspects of urban form spatially and temporally.
- Support research on novel integrated approaches to quantify the combined health effects of multiple harmful and protective characteristics of the physical environment in urbanized areas.
- Identify and communicate the results of real-world applications of integrated approaches that provide specific insight into the physical characteristics of Canadian urban/suburban environments that maximize health.
- Increase awareness of the importance of human health in urban development by training current and future scientists, professionals and public leaders so that they can promote and apply these concepts in their careers.

These goals were developed in recognition of the current state of environmental health research in Canada, where environmental health researchers develop their own exposure metrics on an as-needed basis or make use of existing metrics due to data availability rather than strong theoretical links to the health outcomes of interest. Difficulties in recruiting and retaining staff and students with the required technical expertise to develop appropriate metrics are frequently encountered. Once developed, these metrics are then linked to health data study by study which leads to duplication of effort and are seldom archived for future re-use or sharing.

CANUE has been operating now for just over two years and has made significant progress on our data platform, with a focus on developing measures of environmental factors in six domains: air quality, noise, natural spaces (i.e., greenness, proximity to water), weather and climate, transportation, and neighbourhood factors (i.e., land-use, walkability, socio-economic status). The remainder of this article describes our data strategy, including successes, lessons learned and challenges encountered. More detailed information is available in Canadian Urban Environmental Health Research Consortium et al [7].

2. Data Strategy

CANUE's data platform was designed recognizing that the best-case scenario for environmental health research would be to have a wide range of readily available, comparable exposure metrics at optimal spatial and temporal resolutions linked to large retrospective and prospective cohorts that recorded residential locations over time. Keeping this future state in mind, we have focused on five activity streams: 1) acquiring and developing historic exposure metrics from existing open source and researcher-held data; 2) funding research teams to fill data gaps using novel methods and big data; 3) enriching existing cohorts with residential history; 4) making data linkable via indexing to postal codes; and 5) working with health data stewards to add CANUE data to their holdings to expedite analysis analysis (Figure 1).

2.1 Existing data development

CANUE staff includes several geospatial specialists and a data scientist, who have acquired and processed twelve national data sets to date, using a variety of methods (Table 1). Incoming data have been in a variety of formats, such as ASCII, GRIB2, and Excel. All are converted into standard comma separated text files (.csv) for easy importing into most analytical software applications. In some cases, incoming data are aggregated into summary metrics, such as annual averages based on hourly data. CANUE creates standard metadata and each data provider sets the sharing and use conditions which must be agreed to by data requestors prior to CANUE distributing any data.

Notably, as shown in Table 1, the datasets span many years, some going back as far as the mid-1980s. These historical exposure data allow researchers to take advantage of the very large CanCHEC retrospective cohorts (n ~ 3 million) developed by Statistics Canada using information from each Census of the Canadian population, linkages to federal records providing residential history, vital statistics mortality data and in some cases, cancer registry data [8–10]. Additionally, in Canada, each province and territory is responsible for managing individual health data on all residents, and in some cases, these data are made available for researchers via secure

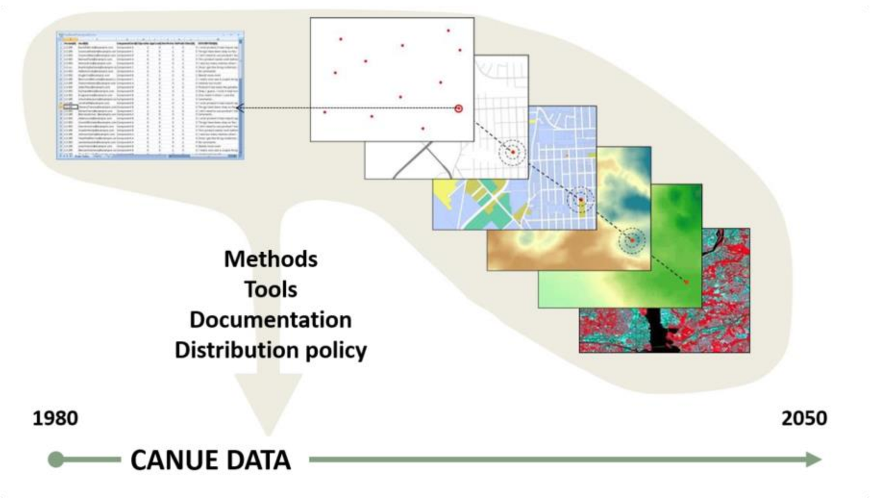

Figure 1: Schematic of the main data products and linkages being compiled through CANUE

systems to protect confidentiality [11–13]. These databases include information on address of residence, hospitalizations, prescription use, physician visits, birth and death records, and in some cases occupation and childhood development indicators. Researchers can request data that represent cross-sectional or retrospective cohorts of interest, with the potential to retrieve records going back to the 1980s.

Now that a large amount of historical data have been processed, we will use (and share) the methods and tools developed (i.e., python, R and MATLAB scripts) to annually update our holdings for all datasets that are in continuous production, such as the Environment and Climate Change Canada air quality and weather models and satellite-based acquisitions.

2.2 Funding new data development

Data teams for each domain were established during the grant application phase of CANUE and receive funds annually to address data gaps and advance exposure science in general. Details on each team's activities are available on the CANUE website (https://canue.ca/research/), and we include a few highlights here. One of the most active areas has been in advancing the use of machine/deep learning with high resolution satellite and ground-level (street view) images to identify a wide range of urban micro-scale characteristics. This is a rapidly emerging field of research with potentially large benefits to urban environmental health studies. For example, CANUE staff are working with numerous data

Table 1. Environmental datasets in distribution

Data set	Spatial Resolution	Temporal coverage	Source*
Annual average nitrogen dioxide concentration	< 100m	1985 - 2012	Researcher provided
Annual average fine particulates concentration	1 km	2000 - 2012	Researcher provided
Annual average ground-level ozone	10km – 21km	2002 - 2015	Environment and Climate Change Canada
Annual average sulphur dioxide concentration	20 km	2007 - 2015	Environment and Climate Change Canada
Annual average, growing season average and annual maximum NDVI**	LandSat (30m) MODIS (250m) AVHRR (1km)	1984 – 2015 2000 – 2015 1985 - 2013	USGS via Google Earth Engine
Annual average nighttime light	1 km	1992 - 2013	DMSP-OLS via Google Earth Engine
Annual weather (35 variables)	Interpolated from observation stations to postal code locations	1985 - 2015	Natural Resources Canada
Material and Social Deprivation Indices	Census dissemination areas	Census years 1991, 1996, 2001, 2006	Institut national de santé publique du Québec
Canadian Marginalization Index	Census dissemination areas	Census years 1991, 1996, 2001, 2006	Researcher provided
Canadian Active Living Index	Census dissemination areas	2006, 2016	Researcher provided

* For complete details and references, see individual metadata files at https://canue.ca/data/

** Normalized Difference Vegetation Index teams to develop metrics of greenness that incorporate satellite data, tree inventories, GIS data and street view image classification, and also to map local climate zones [14] across Canada at 100m resolution from LandSat data, with accuracy assessments based on street view images We have also been developing water balance metrics from basic weather data, including estimates of soil moisture/precipitation surplus and deficit conditions that affect vegetative growth and associated airborne pollen and fungal concentrations. The air quality team is laying the ground work to begin taking in 2.5km resolution hourly air quality data from soon to come GOES/TEMPO satellite [15].

2.3 Enhancing residential history

Canada has invested significant funds in establishing large prospective research cohorts via the Canadian Partnership for Tomorrow Project (CPTP) [16]. Made up of five regional cohorts, CPTP includes over 300,000 Canadians from 30 to 74 years in age. Currently, the residential address of each participant is recorded at the time of recruitment and going forward, but has not been systematically recorded for past years. When looking at chronic health outcomes, the lack of residential history places a substantial limit on the accuracy of exposure assessment for any participants who have moved from one location to another. Health Canada has partnered with Statistics Canada to reconstruct residential history for established cohorts as far back as 1980 using federal government records with a secure data environment. CANUE's Data Linkage Lead is coordinating and facilitating the transfer of information from the cohorts to Statistics Canada for processing. We expect this work to be completed in early 2020, significantly expanding the kinds of studies researchers can conduct (i.e., looking at changes in long-term health outcome for individuals who move from one level of exposure to another) and improving the exposure assessment accuracy for those who have moved over time.

2.4 A common index for linking data

A key step in conducting environmental health research is assigning exposure information based on the spatial locations of study participants. Typically, most administrative health databases and cohorts record individuals' residential addresses, including full 6-digit postal code. In Canada, a single postal code can cover an entire small town, a significant part of a medium-sized town, a single side of a city block in urban areas, or a single large apartment building [17]. The limitation in spatial accuracy notwithstanding, the six-digit postal code is the only practical method for easily linking large spatial environmental datasets with large health databases. The environmental datasets distributed by CANUE are not the entire input data, but consist of data values extracted at the locations of all postal codes nationally, for each year of data. In 1985, there were approximately 580,000 unique postal codes in Canada; by 2016, this increased to 864,000. By providing data values for postal codes, a labour intensive step has been eliminated for researchers and health data stewards as one-to-one linking of exposure and health data via unique postal codes is easily accomplished.

2.5 Expediting analysis

One of the barriers to advancing environmental health research in Canada identified earlier is the 'one-at-a-time' approach, where individual researchers or teams develop their own exposure metrics, then work with a health data steward to gain access and link the exposure and health data for their specific study. An important part of CANUE's mandate is to provide analysis-ready data, and we see this as being accomplished by pre-linking CANUE data to as many of Canada's cohorts and administrative health databases as possible. In this way, researchers can access all the required data in one place. In practice, the CANUE Data Linkage Lead had been working closely with a wide variety of cohorts and provincial health data stewards to establish policies, procedures and processes for taking in CANUE data on a regular basis (i.e., annually), and ensuring re-distribution follows the documented use and sharing conditions. As these relationships become formalized, we are ensuring that future updates of CANUE data can be very quickly incorporated and made available for research use.

3. Successes

In our first two years of operation, our over-riding aim has been to establish 'proof-of-concept' for the CANUE model, given the datasets are large, both spatially and temporally, the health databases are varied, and the research community has complex and sometimes unique data needs as they work to address cutting-edge questions relevant to urban environmental health. In several crucial ways, we have met our aim. Firstly, CANUE data have been available for distribution for one year at the time of writing. In that time, we have received and filled over 40 unique requests for our standard data, as well as 8 requests for specialized data, including monthly satellite estimates of NDVI, calculations of metrics for custom buffer sizes around postal codes, and the extraction of data for custom locations (Figure 2). The average number of datasets requested per user was seven, indicating interest in multiple exposure studies and their associations to various health outcomes. Furthermore, 50 % of studies were at the provincial level, 30 % were Canada-wide, and 20 % were city-specific. In many cases, the full temporal range of data was requested, suggesting research projects were including a longitudinal component. Over 75 unique researchers were named in the data requests, and approximately half of projects requesting data involved students in the research. This certainly bodes well to fostering the next generation of researchers. Secondly, CANUE data are now pre-linked to all five CPTP cohorts, and to the Canadian Longitudinal Study on Aging [18]. Together, these are Canada's largest prospective cohorts and systems are now in place to stream data in on a regular basis. In addition, CIHR has recently issued a competitive funding call for research that makes use of CANUE data linked to health data, indicating that we have established CANUE as a credible

Figure 2: Word Cloud of CANUE Data Users Research Projects
The content of the word cloud in Figure 2 was generated from project summaries completed as part of our data request forms. This allowed us to gather information about what users are doing with the requested data in addition to tracking dataset request frequency – both of which are key data platform evaluation metrics.

source for environmental data, and helping to advance linkage of CANUE data with additional health databases and cohorts. Thirdly, as discussed previously, CANUE has been a key player in facilitating the addition of residential history to the five CPTP cohorts. Our Data Linkage Lead has been the liaison between Statistics Canada and each of the cohort data managers, working through numerous barriers presented by conditions imposed by the ethics boards overseeing each cohort and legal aspects of participant consent.

4. Lessons learned

Our early experience at CANUE has provided valuable lessons learned for moving the consortium forward. Certainly, collaboration is key. Developing a multiple-source environmental exposure data platform for health research involves building partnerships with data providers within Canada (e.g., to access modelled hourly air pollution data from Environment and Climate Change Canada) and internationally (e.g., development of local climate zone mapping in partnership with the World Urban Database Portal and Tools (WUDAPT) project) [19]. Early engagement with data providers has allowed for an iterative process of prioritizing dataset and variable selection with their expert input. Typically, we found that many data developers want to maximize the benefit of their work, including transferring/exchanging knowledge, and realizing professional gains via unanticipated uses of their data along with interdisciplinary collaborations and additional research citations or publications, especially when a trusted 'third-party" organization such as CANUE provides data management.

Value added content and support is critical. Providing documentation, metadata, quality checks, data user guides, FAQs, or consultative advice on data use has proven to be an important criterion in building a core group of data users. This valued added content enhances trust amongst both data users and data providers in that providers are ensured their data are properly managed, cited and referenced and data users can rely on a single source of trusted exposure data. Researchers want guidance on how to use and interpret data particularly when there are multiple similar data sets or metrics that researchers must choose between e.g. greenness metrics compiled at different spatial and temporal scales from different satellite sensors. For example, CANUE has produced a user guide on the process of exposure assignment using postal codes that addresses frequently asked questions (FAQs) typically asked by researchers and similar documentation on satellite derived greenness metrics. In this regard, value added content also facilitates research innovation by supporting researchers to step outside their normal sphere and formulate new hypothesis that advance the science e.g. multiple or cumulative exposure analysis.

Both standardized and customized exposure data are required. There is significant value in having consistent data available to and used by all researchers. Comparisons among different studies are enhanced, reproducibility of results is facilitated, and new metrics can be 'bench-marked' against the standard data. We do recognize, however, there will always be a need for unique exposure metrics that have strong theoretical links to specific health outcomes and populations. There is also value in local data, compared to national data. For example, landuse regression models of various air pollutants have been developed for many Canadian cities. Each model has predictive variables and coefficients specific to the city and we know that these models are not often transferable from one city to another. Each model provides a more accurate estimate of local air quality than a single national model. We see CANUE's role as one of facilitating the development and sharing of meaningful exposure data as they are identified by researchers' needs, rather than becoming a distributor of convenient data.

5. Challenges

As the CANUE data platform continues to expand and evolve, we fully expect there to be challenges around the types of activities we engage in and the environmental exposure data we develop and include in the platform. As we move beyond the proof-of-concept phase, improving the user experience through better data exploration and request/delivery processes will streamline and reduce staff workloads. We are currently implementing a data browser and access portal based on PostgreSQL, MapBox, PHP and other open source applications, which will allow users to visualize CANUE data holdings and generate requests, replacing the current manual systems. However, even at this early stage, the datasets currently in distribution contain over 150 unique variables associated with up to 850,000 postal code locations, for many years. For example, the annual weather and climate data consist of 35 variables for each postal code, in each of 35 years. The design of the data browser is a significant logistical exercise and requires specialized skills to develop and maintain in the future.

In an era of increasingly open data sharing, we are experiencing a shift from data poor to data rich platforms. The process of curating or selecting data is an ongoing challenge with the need to balance user requirements, ease of access and CANUE resources to maintain and manage data. Including data simply because it is available does little to contribute to a successful data platform. There should be some expectation that the data will be used, but it is not always clear at the outset. We need to continually survey emerging research to identify high value exposure metrics that are expected to be in demand, as well as survey our membership to prioritize data development efforts.

Even with careful selection, the CANUE data holdings are growing at a rapid pace and we are already facing issues related to data versions. For example, a better method for processing NDVI from the MODIS satellite was developed during an update, but the output was very slightly different than the original data due to a geographic projection shift. We now need to maintain the old version, in case researchers used it and need to access it in the future, but we have produced an entirely new dataset that is now in distribution. We plan to implement a persistent citation system for each dataset to help with tracking versions. Even at this early stage, it is not hard to foresee similar kinds of issues in the future as new data sources and processing tools become available, and to predict that CANUE will need to have substantial archiving resources and a more robust data management plan than currently exists.

Growing the data platform beyond a core group of CANUE members and users will require additional outreach to engage new data users and improve accessibility of the data platform for current users. As a follow up to data user requests, we will also start tracking data users to better understand their needs and improve data gathering on our part e.g. using follow up surveys with data users.

6. Conclusion

To the best of our knowledge, CANUE is a unique model for developing and distributing environmental exposure data for health research. By the number of data requests filled and successfully pre-linking our data with Canada's major prospective cohorts, we have demonstrated the feasibility of our approach. We have not solved all the issues, and foresee future challenges, but are optimistic that we are on the right track. We have created a critical mass to advance environmental exposure assessment and facilitated numerous new collaborations among researchers who are poised to expand environmental health research in Canada in the coming years.

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Deutsches Ärzteblatt, 2018

Die Zukunft im Blick: 3D-Druck
Umweltbundesamt, 2018

Event Announcements

Hereby we inform you about the conferences and meetings in the disciplines relevant to *Housing and Health*. We request you to validate the correctness of the information. The *WHO Collaboration Centre for Housing and Health* does not take responsibility for the authenticity of the information provided herein.

Healthy Buildings Summit 2018
25th - 27th of October 2018
Seven Springs, PA, USA
Further information: Healthy Buildings Summit 2018

First WHO Global Conference on Air Quality and Health
30th of October - 1st of November 2018
Geneva, Switzerland
Further information: WHO's First Global Conference on Air Pollution and Health
For more information, please contact: ambientair@who.int

Urban Transitions 2018
25th - 27th of November 2018
Sitges, Barcelona, Spain
Further information: Urban Transitions

15th International Conference on Urban Health
26th - 30th of November 2018
Kampala, Uganda
Further information: 15th International Conference on Urban Health

World Forum on Urban Forests
28th of November - 1st of December 2018
Mantova, Italy
Further information: Mantova World Forum Urban Forest

Hitze in der Stadt - kommunale Klimavorsorge
22nd - 23rd of May 2019
Düsseldorf, Germany
Further information: Hitze in der Stadt - kommunale Klimavorsorge

Message Board

In this section we will inform you about activities and projects related to housing and health that are being carried out by WHO or the WHO CC. This may relate to ongoing activities and projects, as well as invitations to participate in data collections or case study projects.

WHO work on indoor, built and urban environments

Launch of WHO Environmental Noise Guidelines

The WHO Environmental Noise Guidelines for the European Region were launched by the WHO Regional Office for Europe on the 10th of October in Basel, Switzerland. The guidelines provide guidance on protecting human health from harmful exposure to environmental noise by setting health-based recommendations on average environmental noise exposure of five relevant sources of environmental noise. These sources are: road traffic noise, railway noise, aircraft noise, wind turbine noise and leisure noise.

The Environmental Noise Guidelines aim to support the legislation and policy-making process on local, national and international level. The WHO guideline values are public health-oriented recommendations, based on scientific evidence of the health effects and on an assessment of achievable noise levels.

For further information, please go here.

International Healthy Cities Conference (Belfast, United Kingdom, 1-4 October 2018)

Healthy Cities is a global movement working to put health high on the social, economic and political agenda of city governments. For 30 years the WHO European Healthy City Network has brought together some 100 flagship cities and approximately 30 national networks. The flagship cities interact directly with WHO/Europe, while the national networks bring together cities in a given Member State. In both cases, WHO provides strategic and technical support as well as capacity-building. Together the flagship cities and national networks cover some 1400 municipalities.

As well as celebrating 30 years of Healthy Cities as a network and a global movement, the Conference has focused on the 6 themes of the new political vision for the WHO European Healthy Cities Network, drafted by the Network’s Political Vision Group: people, place, participation, prosperity, planet and peace. The details of the new phase were also announced, along with the new cohort of designated healthy cities.

For further information, please go to the conference website.

Making the link between transport, health, environment and achieving the SDGs

Everyone has a role to play in implementing the 2030 Agenda for Sustainable Development and reaching the Sustainable Development Goals (SDGs), including governments, intergovernmental organizations, civil society, the private sector and people everywhere.

A new publication, entitled “Making THE (transport, health and environment) link”, presents the results of an analysis of how countries can advance the 2030 Agenda by working through the Transport, Health and Environment Pan-European Programme (THE PEP).

THE PEP contributes to SDG-related efforts by offering countries a unique intersectoral policy platform, and by establishing collaborative partnerships across the 3 sectors with a focus on achieving healthy, clean, zero-emission mobility and transport for all in Europe.

The report can be accessed here.

Global Health Observatory – urban health data

As part of the WHO Global health Observatory database, there is a section of the observatory reflecting the theme of this newsletter – urban settings and health. The observatory provides access to global and national statistics for a range of urban issues.

For details, see the observatory website.

WHO's First Global Conference on Air Pollution and Health

The first Global Conference on Air Pollution and Health will be held at WHO Headquarters in Geneva on 30 October - 1 November 2018.

The conference is being held in collaboration with UN Environment, World Meteorological Organization (WMO), the Secretariat of the UN Framework Convention on Climate Change (UNFCCC), the Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants (CCAC) and the United Nations Economic Commission for Europe (UNECE).

Participants will include Ministers of Health and Environment and other national government representatives; representatives of intergovernmental agencies, health professionals, other sectors (e.g. transport, energy, etc.), as well as from research, academia and civil society.

The conference responds to a World Health Assembly mandate to combat one of the world's most significant causes of premature death, causing some 7 million deaths annually. Air pollution in most cities exceeds recommended WHO Air Quality levels and household air pollution is a leading killer in poor rural and urban homes. Up to 1/3 of deaths from stroke, lung cancer and heart disease are due to air pollution.

Affordable strategies exist to reduce key pollution emissions from the transport, energy, agriculture, waste and housing sectors. Health-conscious strategies can reduce climate change and support Sustainable Development Goals for health, energy and cities.

For more information, go here. Remote participation will be facilitated by webcasting and live-streaming of the sessions.

2018 International lead poisoning prevention week of action

From 21 to 27 October 2018 the international lead poisoning prevention week of action will take place, with a particular focus on eliminating lead paint.

Lead poisoning is preventable, yet the Institute for Health Metrics and Evaluation has estimated that, based on 2016 data, lead exposure accounted for 540 000 deaths and 13.9 million years lost to disability and death due to long-term effects on health, with the highest burden in developing regions.

Of particular concern is the role of lead exposure in the development of intellectual disability in children. Even though there is wide recognition of this problem and many countries have taken action, exposure to lead, particularly in childhood, remains of key concern to health care providers and public health officials worldwide.

Further information can be accessed here.

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Landesgesundheitsamt Baden-Württemberg
im Regierungspräsidium Stuttgart
Baden-Württemberg State Health Office
WHO Collaborating Centre for Housing and Health
Head: Dr. Karlin Stark
Nordbahnhofstrasse 135
70191 Stuttgart

phone +49 (0)711• 904 35000
fax +49 (0)711• 904 35105

who.cc@rps.bwl.de
www.whocc-housing-and-health.de

Editors:
Dr. Snezana Jovanovic, Dr. Katharina Gabriela Cibis
Dr. Guido Fischer, Stefan Kluge