



New frontiers for environmental epidemiology in a changing world



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ABSTRACT

Background: In the next 25 years, transformative changes, in particular the rapid pace of technological development and data availability, will require environmental epidemiologists to prioritize what should (rather than could) be done to most effectively improve population health.

Objectives: In this essay, we map out key driving forces that will shape environmental epidemiology in the next 25 years. We also identify how the field should adapt to best take advantage of coming opportunities and prepare for challenges.

Discussion: Future environmental epidemiologists will face a world shaped by longer lifespans but also larger burdens of chronic health conditions; shifting populations by region and into urban areas; and global environmental change. Rapidly evolving technologies, particularly in sensors and OMICS, will present opportunities for the field. How should it respond? We argue, the field best adapts to a changing world by focusing on healthy aging; evidence gaps, especially in susceptible populations and low-income countries; and by developing approaches to better handle complexity and more formalized analysis.

Conclusions: Environmental epidemiology informing disease prevention will continue to be valuable. However, the field must adapt to remain relevant. In particular, the field must ensure that public health importance drives research questions, while seizing the opportunities presented by new technologies. Environmental epidemiologists of the future will require different, refined skills to work effectively across disciplines, ask the right questions, and implement appropriate study designs in a data-rich world.

1. Introduction

Pekkanen and Pearce described the main challenges in environmental epidemiology in 2001 (Pekkanen and Pearce, 2001). These included complex mixtures of a large number of correlated exposures, small effect sizes which can lead to inconclusive studies in the context of residual confounding, and the need for new methods and inter-disciplinarity to study links between global environmental change and health. They also warned that new technologies, rather than public

health importance, might drive research questions (Pekkanen and Pearce, 2001). Although notable advances have since been made in statistical tools to derive useful information on mixtures of correlated exposures, (Agier et al., 2016; Bobb et al., 2015; Chadeau-Hyam et al., 2013) these, together with the precise measurement of exposures in space and time, remain some of the key challenges in the field today. The rapid pace of technological development and availability of data have made the need more acute to prioritize what should be done for maximum public health benefit over what could be done.

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In Part I of this essay, we map out key driving forces that will shape environmental epidemiology in the next 25 years (a time span roughly overlapping with most of the authors' careers). In Part II, we suggest how the field can leverage these forces to improve population environmental health. Specifically, we suggest ways in which new paradigms, measurement strategies, and analytical approaches can be adapted. Among possible future scenarios, we highlight those which we believe are preferable for achieving public health goals.

1.1. Part I. Forces that will shape the field

1.1.1. Demographics and urbanization

Within the broader context of the epidemiologic transition and economic development, the changing age and geographic distribution of the global population will continue transforming environmental health research priorities. Lifespans have lengthened across the globe, including important gains in low-income countries where life expectancy has improved from 53 years in 1990 to 62 years in 2012 (WHO, 2014). Adults aged 60 and older comprised 8% of the global population in 1940, which grew to 12% by 2013 and is projected to be 21% in 2050 (UN Department of Economic and Social Affairs, 2013). This monumental shift in the global age distribution is due in part to public health interventions, but also presents new health challenges.

There will also be notable shifts in the geographic distribution of the global population. Most of the population growth between now and 2050 is projected to occur in just nine countries with high fertility or already large populations; more than half of the expected growth will be in Africa alone (UN Department of Economic and Social Affairs, 2015). The proportion of the population living in Africa will increase from 16% to 25% between now and 2050, while the proportion in Europe will shrink from 10% to 7% (UN Department of Economic and Social Affairs, 2015). Population growth is projected to remain especially high in the 48 least developed countries, adding to challenges in meeting sustainable development goals (UN Department of Economic and Social Affairs, 2015). There is currently very little data on environmental exposures and their health effects in many countries with the largest population growth. Effects of environmental exposures are likely to differ from those observed in high-income countries, where most environmental health research has been conducted, due to differences in infectious disease burden, access to health services, and material deprivation.

Large-scale migration will add further complexity for environmental epidemiology, presenting challenges for follow-up of study participants and environmental exposure assessment. Individuals living in areas with similar levels of environmental exposures may have highly variable cumulative exposure based on their migration history. For migrants from poorly to better regulated societies, adult health may be influenced by high levels of environmental exposures in early life, exposures which may be particularly difficult to reconstruct. Migration may also present opportunities for using natural experiments to understand how environment shapes health.

The global population continues to shift from rural to urban areas. In 2014, 54% of the population resided in urban areas; this is projected to be 66% by 2050 (UN Department of Economic and Social Affairs, 2014). Nearly 90% of the projected increase in the world's urban population will be concentrated in Asia and Africa, with India, China, and Nigeria accounting for a large share of this growth. Urbanization profoundly shapes (both positively and negatively) environmental exposures (e.g. air pollution, noise, green space) and behaviors (e.g. physical activity, food consumption) and thereby disease risks (Nieuwenhuijsen, 2016).

1.1.2. Global environmental change

Climate change and emerging environmental risks will define much of the future context for environmental epidemiology. Climate change has been identified as “the biggest global health threat of the 21st

century” (Costello et al., 2009). Mean surface temperature is expected to increase by 0.3 to 4.8 °C by 2100, (IPCC, 2013) leading to direct impacts on health from heat stress and flooding, as well as indirect health impacts mediated through infectious diseases, air quality, and food security (Anstey, 2013; Costello et al., 2009; IPCC, 2014; McMichael, 2012; Patz et al., 2016).

Recent reports have elaborated the multiple potential health impacts of climate change (Whitmee et al., 2015). There is strong evidence that heat-related mortality is rising as a result of climate change; the Intergovernmental Panel on Climate Change anticipates an increase in both the frequency and intensity of heat waves under all climate scenarios (IPCC, 2014). The combined effect of global warming and demographic change will expose an increasing number of vulnerable older adults to heat stress (Watts et al., 2015). Health impacts of extreme weather events such as storms and floods are likely to increase this century if no adaptation measures are taken (IPCC, 2014). It is also anticipated that climate change increases the risk of intense droughts in some regions, (IPCC, 2013) affecting agricultural output and, subsequently, increasing food insecurity and malnutrition. Climate change has been identified as one of the greatest challenges for food security (High Level Panel of Experts on Food Security and Nutrition, 2012). Droughts also elevate risks of water-related disease (e.g. *E. coli*, cholera), vector borne disease (e.g. dengue, West Nile Virus), airborne and dust-related disease (e.g. coccidioidomycosis) and mental illness (Stanke et al., 2013). Climate (change) may be an important factor in the dynamics of vector borne disease transmission, including malaria, dengue, and Lyme's disease (Chaves and Koenraadt, 2010; IPCC, 2014). Alongside shifts in land use, climate change appears to be altering the geographic range of vectors that transmit pathogens (e.g. *Aedes albopictus*, *Aedes albopictus*, *Ixodes scapularis*) to humans (Murray, 2013; Ogden and Radojevic, 2014; Proestos et al., 2015).

Chemical exposures will remain an important environmental health concern. Chemical production in 2000 was 1000 times higher than in 1930 (UNEP, 2013). Although chemical production is not a direct measure of population exposure, it is likely that the number of chemicals to which one is exposed will continue to increase in coming decades. Of particular concern are those with short half-lives in the body, now preferred to those with long half-lives for health and environmental reasons, but which contribute to exposure misclassification in traditional studies that rely on spot biomarkers (Perrier et al., 2016).

1.1.3. Technology

Technology with applications to environmental exposure and health outcome assessment is evolving rapidly. Technology will generate new opportunities, particularly in regards to population datasets, e- and m (obile)-health, personal and remote sensor technology, and OMICs data. Below we highlight technologies that lie on the horizon and how they could be applied to environmental epidemiology.

Expanding data availability will allow prediction of diverse population exposures and create new opportunities for exploring novel exposures that have been previously difficult to quantify. Importantly, geo-referenced data are becoming more widely available in low- and middle-income countries, reducing barriers for conducting environmental epidemiology in these countries. Such data include those collected through remote sensing, sensor networks, smartphones, as well as the “internet of things” (i.e., everyday objects with network connectivity). Remote sensing has been used to estimate environmental exposures including air pollution, (Geddes et al., 2016) green space, (Dadvand et al., 2015) and temperature (Dadvand et al., 2014). Opportunities for satellite-based exposure assessment will continue to expand with increasing number of satellites and improved resolution of detection. Quantifying neighborhood attributes will be enhanced by applying developments in image processing to resources such as Google Street View and to ecological momentary assessment based on individuals taking a photograph of their immediate environment from their

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