Metrics in Urban Health: Current Developments and Future Prospects

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Abstract

The research community has shown increasing interest in developing and using metrics to determine the relationships between urban living and health. In particular, we have seen a recent exponential increase in efforts aiming to investigate and apply metrics for urban health, especially the health impacts of the social and built environments as well as air pollution. A greater recognition of the need to investigate the impacts and trends of health inequities is also evident through more recent literature. Data availability and accuracy have improved through new affordable technologies for mapping, geographic information systems (GIS), and remote sensing. However, less research has been conducted in low- and middle-income countries where quality data are not always available, and capacity for analyzing available data may be limited. For this increased interest in research and development of metrics to be meaningful, the best available evidence must be accessible to decision makers to improve health impacts through urban policies.

INTRODUCTION

Since 2008, for the first time in human history, a majority of the world has been living in urban areas. The United Nations (UN) estimates that 2 out of 3 people worldwide will live in urban areas by 2050 (97). In 1950, only 1 in 5 people lived in urban areas. Of the estimated daily increase of 187,066 new city dwellers now, 91.5% are in developing countries (95). **Figure 1*a*** shows the trends in the percentage of people living in urban areas. In low-income countries, this change in proportion is more dramatic, from fewer than 1 in 10 to nearly half the population.

Rapid urbanization affects human lives through its impact on the natural environment or its influence on human lifestyles through built and social environments, among other effects. Middle-income countries will witness an increase in urban populations from 2.6 billion in 2015 to 4.2 billion in 2050 (**Figure 1*b***); more than one billion of this increase will occur in lower-middle-income countries. This increasing population pressure on resources in cities in low- and middle-income countries (LMICs) is causing many individuals to be excluded from receiving health and social services, as well as leading to the formation of informal settlements and slums where environments are particularly hazardous for health (122). The number of people living in slums is expected to double from the current levels to two billion in 2050 (120). High-income countries (HICs), for their part, are faced with the challenge of improving infrastructure, environment, and services, especially with regard to the aging populations in cities.

Challenges and Opportunities

Urbanization was identified by the World Health Organization (WHO) as one of the three main demographic challenges for public health in the twenty-first century, the other two being population aging and globalization (116). Researchers are showing an increasing interest in exploring the impacts of living in urban areas on health. Since 2010, a number of international organizations have focused their global reports on child health, maternal health, HIV/AIDS, and health equity in urban settings (87, 102, 104, 122).

So, what is urban health? In a 2005 review paper, urban health was posited to concern "itself with the determinants of health and diseases in urban areas and with the urban context itself as the exposure of interest" (30, p. 342). Three broad categories of theories and mechanisms explain how city living may affect health: the physical environment, the social environment, and the availability of and access to health services (30). People living in cities are, on average, wealthier, more educated, and more densely concentrated than their rural counterparts. These factors are known to be beneficial in improving population health by facilitating the delivery of services to a more aware and health-conscious population (36, 80).

However, certain characteristics of cities make them less conducive for improving population health. Slums, for example, are characterized by extremely overcrowded conditions, limited access to safe drinking water or sanitation, poor housing conditions, and lack of secure tenure (99). In short, slums are recipes for public health disasters, which lead to high inequalities in health between slum and nonslum urban populations (103, 115). The latest estimates indicate that slums account for 3 in 5 people in urban sub-Saharan Africa, 1 in 3 people in urban Asia, and 1 in 4 people in urban Latin America and the Caribbean (97).

High inequalities in health are also evident across socioeconomic levels in urban areas. **Figure 1*c*** shows the gap in under-five mortality rate between the richest and poorest 20% of urban populations, using the latest available data since 2010 for 35 LMICs. The three-letter UN code for countries used in **Figure 1** are mapped to their full names in **Appendix 1** (follow the **Supplemental Material link** from the Annual Reviews home page at **http://www.annualreviews.org**).

Supplemental Material

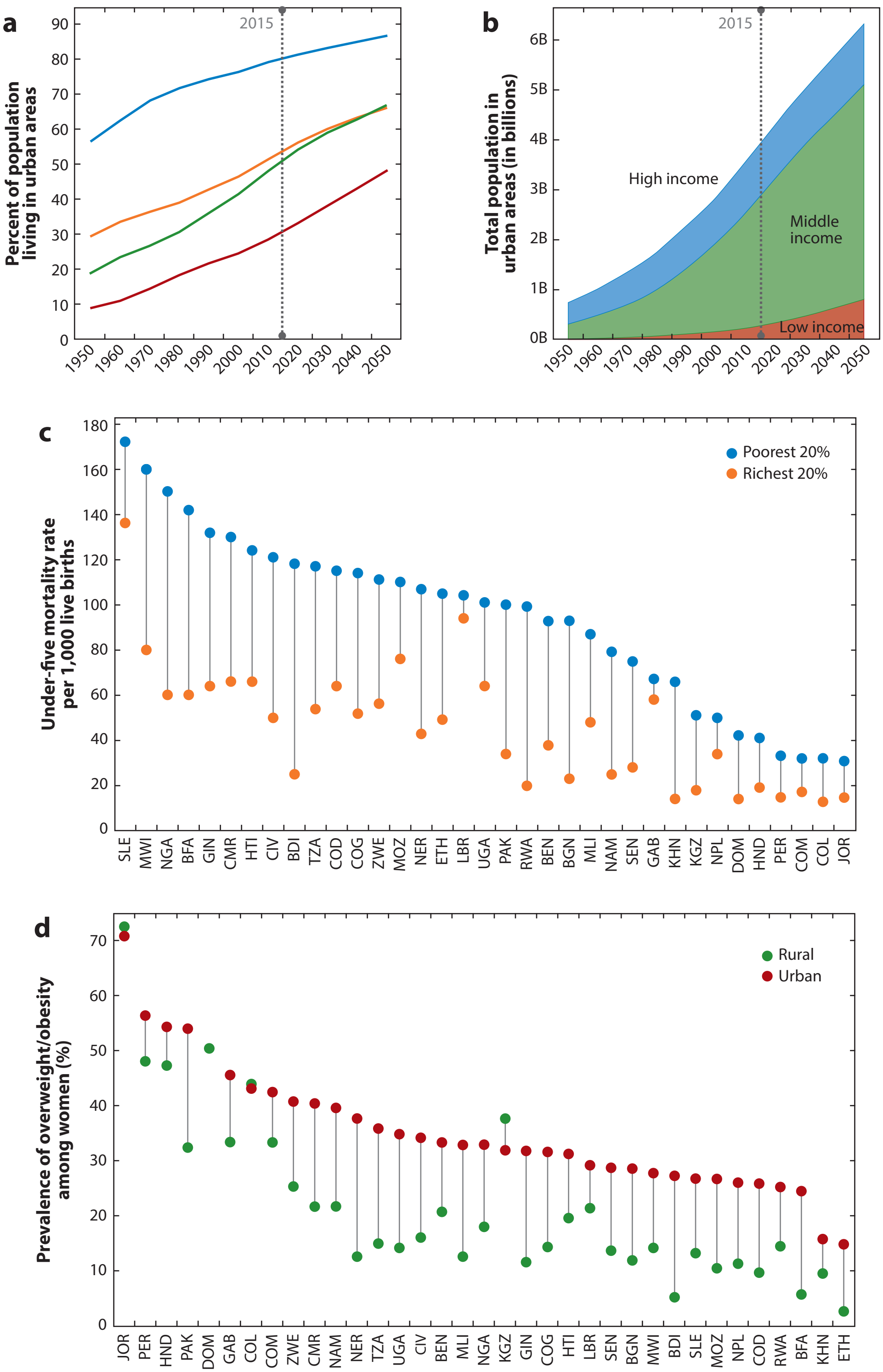

Figure 1

Urban health equity dashboard. (*a*) Urbanization, by income category of countries. (*b*) Total urban population, by income category of countries. (*c*) Urban health inequalities in under-five mortality by socioeconomic levels, select countries. (*d*) Urban–rural inequalities in overweight/obesity among women, select countries. The three-letter UN code for countries used in panels *c* and *d* are mapped to their full names in **Supplemental Appendix 1** (follow the **Supplemental Material link** from the Annual Reviews home page at **http://www.annualreviews.org**). Source: World Urbanization Prospects 2014 Revision, United Nations; WHO Global Health Observatory (latest available data since 2010).

Supplemental Material

There is substantial variation across countries, especially for the poorest populations. The under-five mortality rate for children in the poorest urban populations in Sierra Leone is five times higher than that of their counterparts in Jordan. Within-country inequalities in urban areas are high, as well. Urban children in the poorest 20% of households are more than 4 times as likely to die before their fifth birthday than are children in the richest 20% of households in countries such as Bangladesh, Burundi, Cambodia, and Rwanda.

A previous study of 47 LMICs highlighted that the urban poor have higher rates of stunting and mortality than do their rural counterparts, implying an urgent need for targeted programs as urban population grows (108). Another study investigating urban–rural differentials in child malnutrition in sub-Saharan African countries shows that although, on average, malnutrition is lower in urban areas, urban–rural gaps are abolished in almost all countries when socioeconomic status (SES) is controlled for (28). These health inequalities are, however, not restricted to LMICs. In a study of 15 European cities, the level of avoidable mortality by neighborhood was, in general, positively associated with social deprivation (40).

The WHO and the United Nations Human Settlements Program (UN-HABITAT) have cautioned that the magnitude of health inequalities in urban areas significantly impacts economic and social development as well as peace and security (94, 117). Health inequalities that are systematic, unfair, and avoidable are defined as health inequities (114).

Cities tend to promote an unhealthy lifestyle characterized by sedentary behavior and cheap and convenient diets that depend on processed foods rich in fats and sugar yet are low in essential nutrients (80). These behaviors result in a population that is less physically active and is more likely to be obese, both of which are risk factors for noncommunicable diseases (NCDs). An estimated 3.2 million deaths annually can be attributed to insufficient physical inactivity (58).

The global prevalence of obesity is rising and has been linked with unhealthy lifestyles, diets, and environments. In **Figure 1*d***, using data from 35 LMICs, we can see that the prevalence of overweight and obesity among women is higher in urban areas compared with rural areas for 32 out of 35 countries. More than half of urban women are either overweight or obese in the Dominican Republic, Honduras, Jordan, Pakistan, and Peru. Data from the WHO's Global Health Observatory reveal that obesity is rising in all LMICs where comparable data are available (120).

Furthermore, 90% of people in urban centers breathe air that fails to meet levels deemed safe for their health, according to a WHO survey of 1,600 cities in 91 countries. Outdoor air pollution was estimated to cause 3.7 million premature deaths worldwide in 2012 (119). Climate change–related health hazards are an additional challenge for urban living. Cities will likely experience an increasing frequency of heat waves, severe storms, and infectious diseases. The impacts of such adverse events are amplified for marginalized populations (58).

Lack of social cohesion and a sense of community in cities also result in adverse impacts on population health. A more violent and less safe environment manifests negative impacts. In 2011, the average homicide rate among the 10 largest cities of Brazil—97.6 deaths per 100,000 population—was 3.5 times higher than the national rate (111).

Sustainable Development Goals

The global development community is gearing up to prioritize actions to reduce the negative impacts of our increasingly urbanized world, including those on health, over the next 15 years (**Supplemental Table 1**). In September 2015, officials from 193 UN Member States committed to pursue 17 Sustainable Development Goals (SDGs) with 169 targets between 2016 and 2030. Goal 3 is focused on ensuring healthy lives and promoting well-being for all people at all ages, whereas SDG 11 focuses on creating inclusive, safe, resilient, and sustainable cities (98).

Supplemental Material

SDG 3 builds on the recently concluded Millennium Development Goal (MDG) efforts; three of the eight MDG goals focused on reducing child mortality, maternal mortality, and the burden of HIV/AIDS and malaria (96). As **Supplemental Table 1** shows, SDG 3 covers an extended and comprehensive array of 13 health targets, in addition to issues covered in the MDGs, such as NCDs, road traffic injuries, pollution, and universal health coverage, among others. SDG 11 for cities with 10 targets is a novel consideration. Targets are intended to improve life in cities through action on housing, transport, climate change, and disaster resilience, among other issues.

Supplemental Material

Although SDGs 3 and 11 are not explicitly linked, a number of synergies link their achievements. First, common concerns have been expressed regarding the two goals. For instance, target six for health is focused on road traffic injuries, whereas target two for cities aims to improve transport and road safety. Reducing deaths from air pollution is target nine for health, whereas reducing the adverse environmental impacts of poor air quality is target six for cities. Second, target five for cities is directly aimed at reducing mortality from disasters in cities, with a focus on vulnerable populations. Third, pursuing targets for housing, transport, air pollution, disaster resilience, green spaces, and climate change in cities will directly contribute to the achievement of health targets on NCDs and mental health, road safety, and the reduction in health risks from disasters.

One can clearly see why identifying appropriate metrics and analyzing urban health are critically important: Nothing will change in the absence of evidence (82). However, generating high-quality evidence requires resources that are not always available, especially in LMICs. Over the past decade, international organizations have been emphasizing the relevance of the urban setting in public health, the need to uncover and address health inequities requiring the disaggregation of data at the intraurban level; and the imperative to develop entire domains of measurement to accomplish this goal (6, 68, 100, 106, 110, 114). Local authorities, academia, and civil society have all emphasized the role of cities in improving public health as well as the imperative to make evidence-based decisions.

The objectives of this article are to review the existing scientific literature on the development and use of metrics for analyzing urban health and to identify gaps and future priorities in the field of urban health metrics to inform decision making and achieve local, national, and international goals.

METHODS

Our study methods included (*a*) identifying the objectives of the review; (*b*) defining categories for classifying the research identified in the review; (*c*) systematically reviewing the literature to search for primary studies; (*d*) extracting, synthesizing, and analyzing relevant data; and (*e*) identifying gaps in research and charting a way forward. As stated above, the objectives of this review are based on the parameters defined by the invitation from the *Annual Review of Public Health* but were adapted to focus on contemporary areas of interest, such as air pollution and the built and social environments. The review, therefore, discusses and assesses the use of traditional urban health metrics, ranging from standard health outcome measures to indicators of determinants of health. New metrics and methods of data collection using the latest technology will be analyzed with a view to chart out future prospects in research using metrics for urban health. Particular attention is paid to determine the volume of research in LMICs.

To categorize the areas of research, we adapted the framework proposed by Galea & Vlahov (30). In addition to the "urban" category, we defined a research category for "health." In cases where more than one urban or health issue was being addressed, we categorized the research under the primary issue of concern.

There were five "urban" subcategories: built environment, pollution, social environment, urban climate, and other features. The definitions of these categories were closely aligned with that of Galea & Vlahov. However, the definition of the built environment was expanded to include green spaces and urban infrastructure. Social environment was redefined to include social and economic factors, demographics, and other factors (e.g., culture).

In addition to the above, we created five "health" subcategories. These included general health and health care, infectious diseases, injuries, maternal and child health, and NCDs.

Next, we undertook a systematic search across five major literature databases: Medline, Social Science Citation Index, Embase, ProQuest, and EBSCO. There were no restrictions on dates of search or on language entered in the databases. The following search terms were used to identify relevant abstracts: "urban health AND indicators," "urban health AND measures," "urban health AND metrics," "urban sustainability AND health indicators," "urban sustainability AND health measures," "urban sustainability AND health metrics," "urban planning AND health indicators," "urban planning AND health measures," "urban planning AND health metrics," "urban resilience AND health indicators," "urban resilience AND health measures," "urban resilience AND health metrics," "urban governance AND health indicators," "urban governance AND health measures," "urban governance AND health metrics," "urban liveability AND health indicators," "urban liveability AND health measures," and "urban liveability AND health metrics." Our objective was to capture papers on urban characteristics that utilized metrics to determine their relationship to or their impact on health. Studies that did not explicitly aim to analyze the impacts of urban characteristics on health were excluded. Given the broad scope of the search terms, we did not pursue the snowball technique to follow up on references from the search results.

Figure 2 shows the flow diagram of search, screening, and inclusion of articles. In the case of abstracts, each of the four researchers applied all the following criteria to consider inclusion:

- Study should focus attention on impact of or on urban settings;
- Health must be a key consideration or outcome variable of interest in the study;
- Use of indicators, a model, or framework for indicators should be specified; and
- The full-text articles should be written in English.

A total of 885 full-text articles were retrieved through this process. We noted a limited number of articles in other languages, mostly in Spanish, Portuguese, Chinese, Russian, and French. However, we selected only those written in English, as this was one of the limitations of the researchers. Further criteria were applied to consider exclusion of studies at this stage:

- Studies that were purely comparisons of health in urban and rural areas were excluded if they did not elaborate on how urban areas affected people's health;
- Although neighborhood-level studies are not generalizable to different contexts, they were included if they met all other criteria because they provide insights into particular characteristics of urban areas that may impact health;
- Initial criteria to select abstracts were reapplied when reviewing the full-text article to serve as a double check.

As a result of this exercise, 203 full-text articles were excluded, which resulted in 682 articles selected for the study. In addition to the 682 articles, we conducted a gray literature search restricted to international organization websites to extract global or regional reports or tools relevant to metrics in urban health. This step resulted in the inclusion of 12 documents.

Publications reviewed were classified on the basis of the subcategories of "urban" and "health," as previously defined. We created a database of each study's key characteristics for analysis and

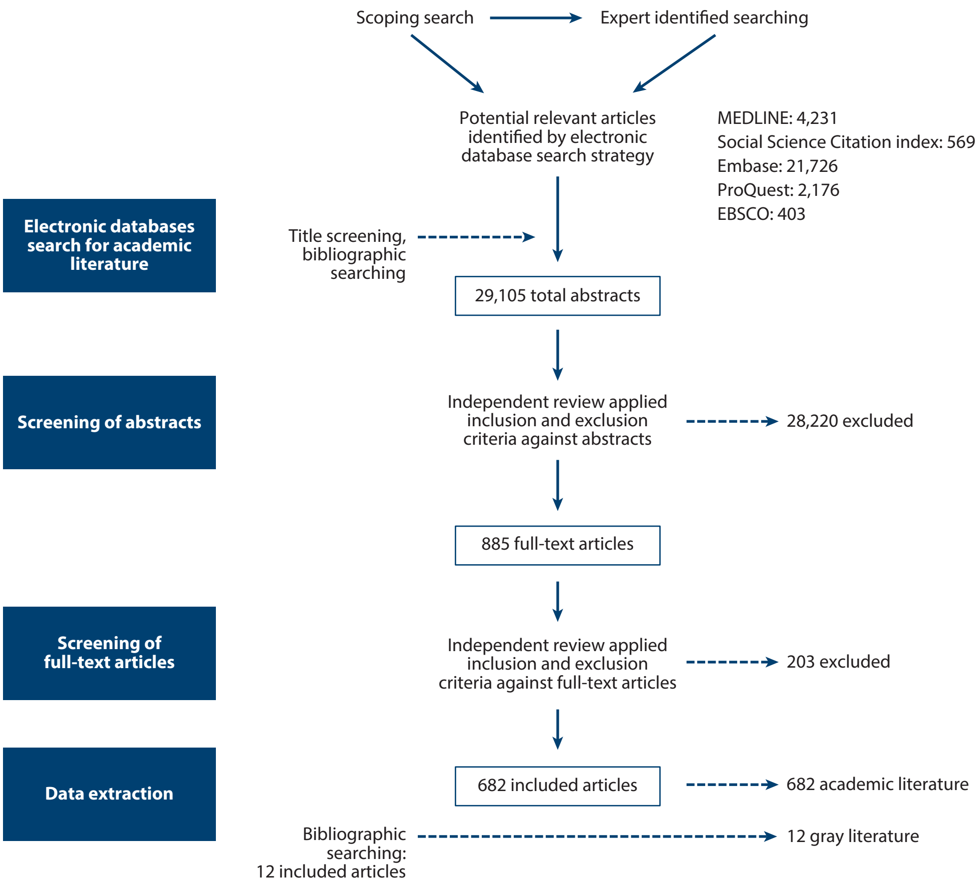

Figure 2

Flow diagram of search and inclusion strategy.

synthesis. These characteristics included the metrics used, data collection methodology, and the major conclusions of the study, in addition to general characteristics such as the year of publication and study location.

RESULTS

We retrieved a total of 682 peer-reviewed publications relevant to urban health metrics using the search methods and exclusion criteria described in the Methods section above. **Figure 3** shows the distribution of the publications by "urban" and "health" categories, as well as by the time period of publication. We present here a few key trends based on the figure as well as more in-depth cross-tabulations.

First, the number of relevant publications sharply increased over the four time periods. In 2006–2010, there are four times as many publications as in 2001–2005. In 2011–2015, until the time of writing this review, there were nearly 2.5 times as many publications as in 2006–2010.

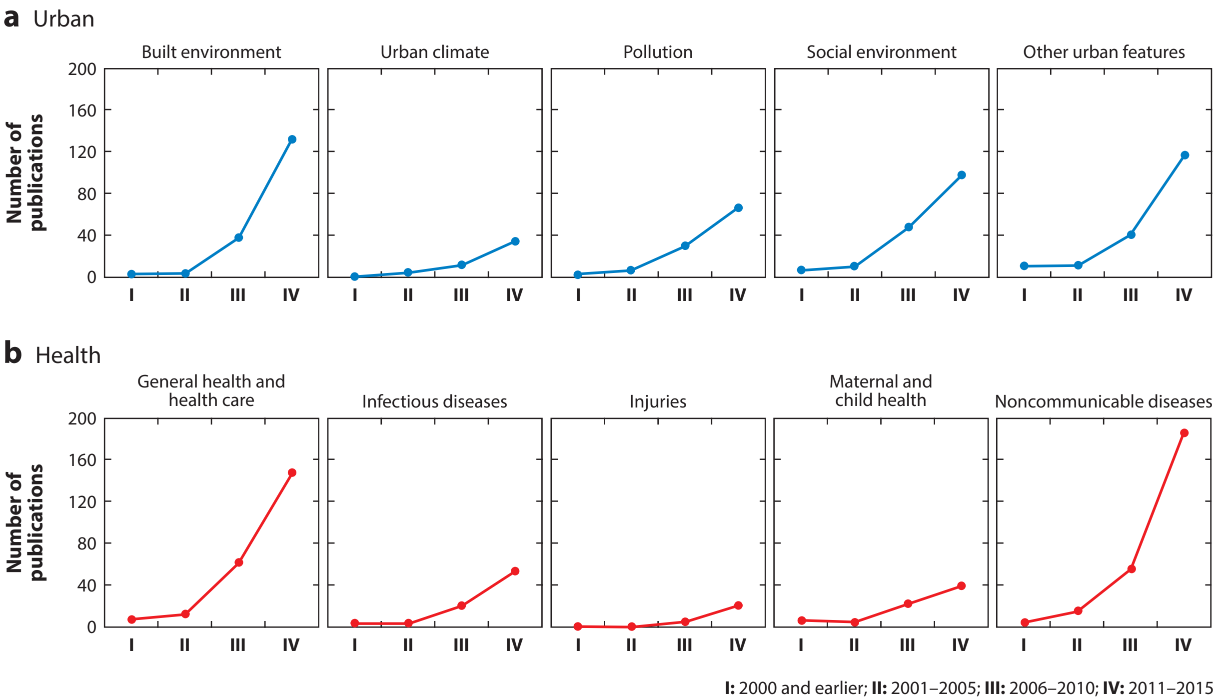

Figure 3

Number of relevant publications by categories of (*a*) urban and (*b*) health research and year of publication.

Second, the number of publications for each of the urban research categories in 2011–2015 has increased, compared with the number of publications in the previous five years. The greatest increase in relevant publications was in the built environment category: from 38 to 132 papers over the two time periods. This increase in volume of research was partially explained by greater attention to linking the impacts of urban living, such as food environments, neighborhood environments, and green spaces, on health. But there was also more research on traditional topics such as slums and transport.

Although research linking urban air pollution to health dominated the volume of publications under the pollution category, there was new interest in noise pollution. For 2011–2015, we extracted 13 publications on noise pollution and health compared with just one publication in 2006–2010. Similarly, greater research focus was noted on urban heat islands and the impact of rising temperatures in 2011–2015 as compared with the previous five years. Ten relevant publications were extracted for 2011–2015 compared with just one in the previous five years. Forty-one publications on urban policy were extracted for 2011–2015 compared with nine in 2006–2010.

Third, the primary health area of focus was NCDs. For 2011–2015, 186 publications focused on NCDs, and their risk factors were extracted compared with 57 in the previous 5 years. This increase was strongly driven by interest in analyzing urban impacts on cardiovascular health, physical activity, and obesity. However, research on mental health witnessed the maximum increase over the 2 time periods: from 7 papers to 39 papers.

We now analyze the use of specific metrics in these studies by the urban categories of research. Although an exhaustive analysis of metrics is beyond the scope of this review, we elaborate on developments in some key established areas or newly developing fields.

Built Environment

Of the 177 research articles on the built environment, 128 articles researched the relationship or impact on general health or NCDs. Food environments and the concept of food deserts, defined as areas (mostly low-income) where nutritious foods are difficult to access, are of particular interest in North America. Spatial data on street networks, transit and walking networks, and densities of food outlets are used in most studies (27, 43, 64, 65). Research linking urban food environments to health is nascent, and therefore most appropriate metrics for determining access are still being debated.

Forty-one of the 177 built environment studies investigated the impacts on physical activity or obesity as the key health risk. Numerous composite measures, such as the Walk Score, the Neighborhood Environment Walkability Scale (NEWS), and a neighborhood walkability scale, have been developed to specifically measure neighborhood walkability (24, 72). The Walk Score is a proprietary measure of walking distance from a given address to a diverse set of amenities such as restaurants, grocery stores, shopping, coffee, banks, parks, schools, books, and entertainment. Points are assigned to each type of amenity, and higher weights are given for destinations with more walking trips. NEWS, a subjective measure of walkability, comprises items across eight domains: residential density, land use mix (diversity), street connectivity, land use mix (access to services), infrastructure, aesthetics, traffic safety, and safety from crime.

Indices have also been developed and validated for defining an urban form. An urban sprawl index is a composite measure commonly identified by four characteristics: low residential density; rigidly separated homes, shops, and workplaces; roads with large blocks and poor access; and a lack of well-defined activity centers (45). Public spaces such as green or open spaces are linked to various health outcomes in research, including violence (62), general health and well-being (55, 109), obesity (86), and cardiovascular health (77). Although traditional metrics of access to parks using proximity indicators can be used, one can apply a variety of indices to capture multiple dimensions. For example, an index measuring variability in neighborhood greenness (77) in Perth, Australia, was used to capture two potential promoters of physical activity: an aesthetically pleasing natural environment and access to urban destinations.

Geographic information systems (GIS) are used to develop objective measures for neighborhood characteristics, for example, by creating street network buffers. Although the most commonly used GIS software is ArcGIS, open-source solutions such as Quantum GIS alleviate cost limitations but can be more challenging from an operational perspective (5). New freely accessible tools and databases are likely to enhance the quality and quantity of research on the built environment. For example, free, publicly available data from Google were found to be nearly as effective in predicting walking outcomes as were walkability measures derived without such publicly and nationally available measures (15, 69). A systematic review of 13 published studies using Google Earth and Google Street View, two free geospatial services, concluded that they appear as promising alternatives to field-audit for assessment of objective dimensions of the built environment. However, the study noted that agreement with field-audit results was lower for subjectively assessed items such as aesthetics and street atmosphere.

The key health variables of interest were general health of the population, obesity, physical activity, and child health. Obesity was most commonly measured using the body mass index (BMI), defined as the body mass divided by the square of the body height and universally expressed in kg/m^2. An individual with a BMI value of 30 kg/m^2 or greater is considered to be obese. Greater variation was noted in the measurement of physical activity. A validated and commonly used instrument to measure physical activity is the International Physical Activity Questionnaire (IPAQ), which was developed for cross-national monitoring of physical activity and inactivity. High physical activity is defined as at least 3 days of vigorous activity, accumulating at least 1,500 metabolic equivalent of task (MET) minutes per week, or 7+ days of any combination of walking or moderate or vigorous activity, achieving at least 3,000 MET minutes per week (35).

Pollution

The WHO estimates that 7 million premature deaths resulted from indoor and outdoor air pollution in 2012 (119). The bulk of research (88 of 107 publications extracted) linking pollution to health has been conducted on outdoor air pollution. Mortality is the most studied health end point associated with air pollution (32). One reason is the widespread availability of mortality data for large populations, and another reason is its simple interpretation (18). Although earlier research focused on linking air pollution to respiratory health (47, 60), the focus has shifted more recently to its impacts on cardiovascular health (10, 73, 113). The scope of studying air pollution's impact on health has also expanded to areas such as maternal and child health (85, 92) and mental health (22).

Standard metrics and methods are used to estimate the extent of air pollution. In particular, measures of the concentration of particulate matter (PM) of different sizes such as $PM_{2.5}$ and PM_{10} (particles with diameters less than or equal to 2.5 μm and 10 μm) were most commonly used to determine health effects (7, 8, 18, 44, 53, 75, 92, 113). Other common pollutants include nitric oxides and sulfur dioxide (89, 90). The US Environmental Protection Agency (EPA) has developed standard tools, such as the Benefits Mapping and Analysis Program (BenMAP), to estimate the impacts of air pollution on health (107). However, Strickland et al. (89) suggest that the pollutant metric selected for use in a health benefits assessment should be based on the research or policy question of interest. Other studies point to the need to delve deeper into the chemical composition of pollution and to use different models for determining health impacts (48).

Although indoor air pollution caused an estimated 4.3 million deaths in 2012 compared with 3.7 million deaths attributed to outdoor air pollution, all but three of the studies in our review focused on outdoor air pollution. This may be because much of the research is focused in North America, where the issue of interest is outdoor air pollution.

With respect to noise pollution, half of the studies focused on determining the impact of road traffic noise on health (23, 26, 51). However, results varied and were sometimes inconclusive on the actual impact of traffic noise pollution (26). Even though the links between urban noise pollution and issues of population health appear to be more recent, the metrics for noise pollution are well established. The L_{EQ} represents the average noise level received over a period of time that typically spans minutes to hours, whereas the L_{MAX} represents the very highest exposure received over a period of seconds or even milliseconds (50, 61). A-weighted decibels (dBA) are an expression of the relative loudness of sounds in air as perceived by the human ear. Dosimeters are used to measure a person's noise exposure integrated over a period of time. The availability of appropriate metrics and measurement tools combined with an increasing interest in the impact of noise pollution on health in urban areas are motivating factors for future research.

Social Environment

The social environment and its impact on urban health were major research areas, accounting for 164 of all publications extracted for this review. The major concern was to determine social inequalities in health in urban areas across race/ethnic, socioeconomic, gender, or migrant groups. The health issues considered are diverse, including child health, mental health, obesity, physical activity, HIV, and substance abuse (4, 9, 12, 34, 59, 66). At the same time, the emphasis on NCDs was stronger than in the case of the built environment, especially on mental health. Sociodemographic indicators were commonly collected through surveys to facilitate disaggregated analysis.

Racial or ethnic disparities in health were of particular interest in the United States, which accounted for 29 of 33 such studies. Segregation of communities in cities and its impact on health were measured using various metrics, including segregation indices, an isolation index, and a location quotient measure (81, 112). The isolation index, commonly used in the literature, is a measure of socioeconomic isolation. It is calculated as the average across all census tracts of the probability of within-tract encounters between residents below and above a low-income threshold in the case of an index for poverty. This index is, however, not independent of the mean and variance of income within areas. Segregation indices measure the distribution of groups of people from different races within neighborhoods. The indices examine five dimensions of residential segregation: evenness, exposure, concentration, centralization, and clustering.

Social capital in urban areas plays an important role in determining individual health risks and outcomes (49, 56). Network social capital refers to resources accessed through one's social connections and can be measured using a position generator instrument. This instrument measures individuals' social capital by assessing a person's ties to others working in specific types of occupations. In a study on rural–urban migrants in China, workplace social capital was assessed using a validated and psychometrically tested eight-item measure. This Workplace Social Capital Scale uses a five-point Likert-scale, with which the participants assess workplace social capital, defined as the shared values, attitudes, and norms of trust and reciprocity as well as practices of collective action in their workplace (31).

Key health indicators included various aspects of mental health such as depression and perceived stress as well as risks associated with sexually transmitted infections and alcohol and substance abuse. Numerous instruments can support the measurement of stress and depression. For instance, the Composite International Diagnostic Interview diagnoses lifetime major depressive disorder (33). The Perceived Stress Scale, developed in 1983, measures the degree to which respondents appraise situations in their lives as stressful. Participants are asked to indicate, using a five-point scale, the extent to which they "felt or thought a certain way" over the past month (93).

Urban Climate

The primary interest, historically, in studying urban climate and health has been the relationship of ozone exposure to mortality (70, 88). Numerous studies using measures of ozone concentration at 1 day, 8 hours, or hourly levels have correlated its impact on mortality with mixed results. Some studies claimed strong evidence that ozone exposure had an effect on mortality, with a larger effect specifically on cardiovascular and respiratory mortality (8). Other studies concluded that there were small increases in mortality associated with ozone exposure (14). However, no relevant publications came up in our search on ozone exposure and health in urban areas for 2011–2015.

Instead, a few studies have addressed the impact of heat, which is particularly relevant in urban areas given the urban heat island effect. In three studies, high heat was shown to have robust effects on mortality (37, 41, 76). Low SES, age, and high-density residential zoning exacerbated the impact of high heat on mortality (41). The key metrics involved are air temperature, wind speed, and socioeconomic and demographic indicators. One validated and commonly used measure is the heat index, which is the result of several biometeorological studies that investigated the combined effect of air temperature and relative humidity on the human perception of thermal comfort (38).

The heat index (HI) can be calculated using ambient temperature (°F) and relative humidity (%) for ambient temperature greater than or equal to 80°F and relative humidity greater than or equal to 40% (52).

Other Urban Factors

In this category, we included studies that researched the impacts of general urban characteristics on health (3, 46, 108). However, three subcategories are specifically of interest to this review. First is the subcategory of defining urban metrics for measuring and informing health decisions in cities. An index developed by Rothenberg et al. (84), for instance, is described as "a flexible tool, whose method rather than content is standardized, may be of use for local evaluation, for decision making, and for area comparison" (p. 823). The authors adopted a method used by the Human Development Index, standardized indicators for small area units on a [0, 1] interval, and combined them using their geometric mean to form an urban health index (UHI).

The second subcategory is urban policy and its impact on health. A paper on health in all policies in Richmond (in the United States) reveals that the strategy has an explicit focus on equity and guides city services, from budgeting to built and social environment programs (17). The authors highlight how a participatory process utilizing health equity metrics was instrumental in achieving the formulation of this strategy.

Five studies for cities using the Urban Health Equity Assessment and Response Tool (Urban HEART) (118) considered a similar approach to using health equity metrics, by incorporating the social determinants of health (SDH), to inform decision making on health in cities (4, 78). Utilizing an SDH framework, Urban HEART guides local and national stakeholders through a process to identify, prioritize, and track health inequities and their social determinants using the best available evidence and offers a range of response strategies aiming to reduce identified inequities (118). The tool has been used, to date, by more than 100 cities in 53 countries worldwide. Indicators in the tool are organized under health outcomes and four SDH domains: physical environment and infrastructure, social and human development, economics, and governance.

An independent evaluation of the process of using Urban HEART was completed in 15 cities from 7 LMICs in 2013. The evaluation noted some key lessons, especially with respect to metrics in an LMIC context. First, availability of data, especially disaggregated data, is often lacking in cities of LMICs. Second, priority areas for action in LMICs can differ from those in HICs (e.g., water and sanitation), although in some other areas their interests may coincide (e.g., risk factors for NCDs). Third, there could be a lack of analytical capacity within LMIC cities to make the best use of the data that are collected (e.g., for estimating life expectancy) (1, 21, 63, 66, 67, 74, 79, 105).

Geographical Gaps

LMICs are expected to account for more than 90% of urban population growth in the coming decade. However, the research from LMICs made up only 37% of all papers in our review, which equated to the percentage of relevant papers focused solely on the United States. The next highest research output by country was from China, India, and Brazil with 47, 35, and 31 papers, respectively. We reiterate that our review included only papers written in English, and thus research outputs from these countries in their official or native languages (i.e., Chinese, Portuguese) were not included. Research with a global remit accounted for less than 5% of the total number of publications.

Research priorities do differ between LMICs and HICs, especially for health. Infectious diseases accounted for 7.6% of total publications for HICs, compared with 21.3% for LMICs. Maternal and child health issues were also proportionately more important in LMICs (7.8% in HICs compared with 15.4% in LMICs). With respect to urban categories, research in LMICs focused on general urban characteristics in 37.5% of the papers, compared with 19% for HICs. By contrast, HICs accounted for more than three-quarters of publications on pollution.

Clearly a gap in research exists for the developing country context with respect to using metrics to understand and inform policy on urban health. In their 2011 paper titled "No Data, No Problem, No Action: Addressing Urban Health Equity in the 21st Century," Friel et al. (29) conclude,

> Urban development that places health equity as a central policy goal will improve health, reduce social inequity, and support communities to cope with, and avert further, global environmental change. To do this requires fine-grained measurement, multilevel monitoring systems, action on the social and environmental determinants of health and inclusive systems of governance. (p. 859)

Furthermore, Coburn & Cohen (16) suggest "that indicator processes might be one important strategy to encourage new models of urban health governance in both the global north and south" (p. 5).

DISCUSSION

In our literature review, we found that interest in the development and research of metrics for understanding the links between urban living and health is sharply increasing. This upward trend has been facilitated by innovative new methodologies for data collection and analysis. Spatial data and mapping were the most commonly used data collection methods (2, 7, 11, 20, 24, 41, 53). Another major source of data has been large-scale household surveys (28, 42, 91). The latter have been particularly useful in LMIC contexts.

Numerous methods can be used to collect and analyze spatial data. Maps are considered an effective method of communicating messages to policy makers and have therefore been adopted globally. As a 2011 review on urban health metrics states (110), "They compel attention, and their implications are easily grasped by politicians, policymakers, and journalists. They also invite criticism and spark debate, helping to develop local knowledge" (p. 814).

GIS, another popular tool, assigns spatial coordinates to data that can be mapped, and it can map both spatial and nonspatial information (5, 11, 55). A number of GIS software utilities are available online, such as ArcGIS (54), and limited versions are sometimes made available for free. Open data policies of cities from countries such as the United States, the Netherlands, the United Kingdom, and Australia are powering a new civic movement that is changing the way citizens experience their cities and improving their understanding of health risks and health care. However, the lack of geocoded health data as well as the high level of technical expertise required to perform geospatial analysis are still significantly limiting the potential of this type of analysis, especially in LMICs.

Supplemental Figure 1 shows an illustration of different health-related layers overlaying a gray background map of the city of Amsterdam. The following data displayed on the map were made available by the Dutch government's open data policy: (*a*) noise levels from highways represented by dB classes from red to green along the highways, (*b*) predicted yearly average of fine-particle exposure at street level in colored lines along streets in $\mu g/m^3$, and (*c*) regions of the city colored from orange to green displaying citizens' satisfaction with their living environment. Such information can assist urban planners and designers in making appropriate changes to improve health and quality of life in cities.

Supplemental Material

Remote-sensing technology uses satellite-based information, enhances accuracy, and is particularly useful for small-area data collection. Although it is used mostly in high-income contexts, its utility in LMICs is also appreciated (22, 25, 54, 71, 84). A 2012 study from China uses nighttime imagery from the Defense Meteorological Satellite Program (DMSP) Operational Linescan System (OLS). The authors recognize that the DMSP/OLS "provides a new data source for large-scale urban research" (p. 1376). It is particularly advantageous because it can work at night and detects lights in urban areas, which distinguish the urban background from the dark background associated with rural areas (57).

The current status of urban health metrics has a number of strengths. Increased research on the social and built environments has the potential to impact decision making on key topics of public interest, such as air quality, public spaces, transport, and housing. Improved science and methods as well as greater availability and affordability of new data collection technologies are important enabling factors for enhancing the quality of research (110). The research has occasionally been linked to decision making (4), and new models and frameworks are being considered to improve the quality of metrics in the future (13, 19). A more recent review, for example, showed that 14 composite indicators relevant for urban health are available to support decision-making processes (83).

Gaps in Current Research

Some gaps have been noted in the current literature on urban health metrics, which are important to address going forward. First, the quantity and breadth of research using metrics for urban health are limited in LMIC contexts. This is likely the result of a lack of quality data at the city level as well as the limited capacities in some countries to analyze relevant data. The scope of research is also limited in LMICs. For example, despite that LMIC cities such as New Delhi and Beijing make international headlines for their poor air quality, the number of scientific publications linking air quality to health is limited to date.

Second, it is unclear from our review whether research is being sufficiently linked to decision making. Although the development of frameworks and testing of indicators are used to advance science, an important objective of eliciting the impacts of urban living on health should be to support evidence-based decision making. Evidence generated from greater civic engagement through the use of open data and city-specific mobile applications has the potential to influence urban policy for health.

To address these gaps in the development of urban health metrics, the global research and development community should consider the following actions:

1. Work with policy makers to link research to decision making by generating credible evidence, a few compelling messages, and demonstrative visual tools for communicating those messages (110). This process will be facilitated by bringing in a diverse group of stakeholders to support the messages, as well as by crafting locally efficient interventions to tackle the issues at hand (118).
2. Develop metrics to study the link between less-researched urban and health categories that are equally important to understand. The current volume of research is strongly driven by HIC interests, especially the United States. This has the advantage of setting the precedent for others to efficiently utilize existing science and technology. In addition, whereas some metrics are likely to be more locally relevant, it is important to have indicators that are generalizable and globally applicable as well. The science around air pollution is moving in this direction, for example, where standard metrics are used worldwide.
3. In addition to the development of new metrics, there needs to be a stronger global mechanism to increase the capacity of researchers worldwide to apply these new metrics. International organizations are well placed to support such an initiative and should work more closely

with researchers to improve dissemination. A higher volume of research and development of information systems also needs to be supported in LMIC contexts. Countries such as China have been building a strong research infrastructure, but other countries may require the support of the international community of donors and researchers to produce quality research.

Limitations

This review has three main limitations. First, the review was limited to articles in English only. This may have, for example, resulted in the selection of fewer studies from Latin America, which is a highly urbanized region of the world. Second, during the selection of articles, numerous articles related to developing metrics for important issues relevant to health were excluded because they did not explicitly state a link to health (one of the criteria for exclusion). Third, new developments in health metrics were not considered for this review unless they were explicitly focused on urban issues.

CONCLUSION

The urban population as a proportion of the global population is expected to rise rapidly from 54% in 2014 to 66% in 2050. More than 90% of this increase is in LMICs, where the capacity to deal with the rapid rise in demand for resources is limited (97, 101). Lack of resources combined with a skewed distribution of resources are concerns especially for population health and health equity (115, 122).

Metrics that elucidate the links between urban living and health are important to improve the health impact of urban policies. Although interest in the development of new and appropriate metrics is on the rise, there appears to be a bias toward developing more sophisticated metrics for issues of interest to cities in HICs. Nearly 2 in 3 publications reviewed for this study focused on HICs or regional contexts.

Moving forward, the wide gap in quality of urban health metrics between cities in HICs and many in LMICs, including the capacity for data collection and analysis, needs to be bridged. This increase in capacity for research and development will be an important investment for achieving global development goals, especially the SDGs.

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Supplemental Material

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