Journal of Children and Poverty

ISSN: 1079-6126 (Print) 1469-9389 (Online) Journal homepage: http://www.tandfonline.com/loi/cjcp20

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To cite this article: Richard C. Sadler & Don J. Lafreniere (2017) You are where you live: Methodological challenges to measuring children's exposure to hazards, Journal of Children and Poverty, 23:2, 189-198, DOI: 10.1080/10796126.2017.1336705

To link to this article: http://dx.doi.org/10.1080/10796126.2017.1336705

Published online: 05 Jun 2017.

JOURNAL OF CHILDREN AND POVERTY, 2017
VOL. 23, NO. 2, 189–198
https://doi.org/10.1080/10796126.2017.1336705

POLICY BRIEF

You are where you live: Methodological challenges to measuring children's exposure to hazards

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ABSTRACT
Many of the challenges that affect children living in poverty are directly related to the neighborhoods in which they live. Places that inhibit healthy living and those that expose children to environmental pollution tend to more heavily affect children in poverty. This environmental injustice is a natural concern of the fields of urban planning, geography, and children's health. Yet many decisions that affect opportunities for healthy living are made without a full understanding of how neighborhood context influences such opportunities. In this brief, we paint inequalities in child health outcomes as a spatial problem, review some of the geospatial tools used by urban planners and geographers, discuss common reasons for misclassification or misrepresentation of spatially explicit problems, and propose more suitable methods for measuring opportunities and exposures germane to the field of child poverty. Throughout, we emphasize the need for evidence-driven, spatially grounded responses to child poverty issues with a spatial dimension.

KEYWORDS
GIS (geographic information science); geography; environmental exposure; Flint Water Crisis; child health

Introduction

Child poverty is undoubtedly one of the major challenges in public health today, particularly given the disproportionate burden of environmental injustice perpetrated on the most disadvantaged populations. One topic of more recent concern is how environmental problems can be masked through using either an inappropriate level of census geography or the incorrect application of geographic analysis, leading researchers and government officials to commit a type II error (wrongly concluding that no problem exists).

The recent example of the Flint Water Crisis has shown that state-level government officials can be blind to spatial inequalities in environmental exposure due to a lack of geographic expertise (Hanna-Attisha et al. 2016; Sadler 2016). In that case, officials had not explicitly geocoded the locations of children with elevated blood lead levels (EBLLs), despite concerns that the city's recently overhauled municipal water system was leaching lead. Because their level of aggregation was the much larger and more unwieldy ZIP code, their results suggested no significant change and therefore no cause for alarm. It was not until a research team (including this paper's co-author Sadler)

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more closely examined the spatial pattern of EBLLs that definitive evidence of a significant increase in the incidence of EBLLs following the water source change could be shown.

But the example of the Flint Water Crisis is far from the only case in which framing a problem using an inappropriate unit of geographic analysis can lead to misleading results. It is important to understand why such errors are made and what we can do to overcome them. In this policy brief, we will explore methodological problems common to geographers and discuss their importance to the study of child poverty and related public health issues. Throughout, we emphasize the essential role that geographers play in the study of the built environment within the context of neighborhood-level exposures.

Child poverty as a spatial concern

Children living in poverty experience a range of challenges in their daily lives. These include being less likely to: establish conceptual and linguistic functioning at an early age (Flores 2004), access high-quality childcare facilities (Prentice 2007), remain in one school system (Porter and Edwards 2014), graduate from high school (Donlan, Prescott, and Zaff 2016), live in communities with a range of job opportunities (Richardson, Glantz, and Adelman 2014), live in neighborhoods free of criminal activity (Patterson 1991), live near healthy food sources (Eisenhauer 2001; Sadler, Gilliland, and Arku 2013), have high-quality parks near their homes (Burdette and Whitaker 2004), live in neighborhoods with good housing conditions and public infrastructure (Sadler and Lafreniere 2017), or live in neighborhoods with low exposure to environmental pollution (Pastor, Sadd, and Morello-Frosch 2004).

The magnitude of the specific health consequences of these exposures cannot be overstated. While they are outside the purview of this article, these characteristics deserve attention because nearly a quarter of children in the United States are born into poverty and all of these characteristics restrict upward socioeconomic mobility (Coller and Kuo 2016).

Additionally, all of these characteristics are important to geographic inquiry into the relationship between children's poverty and their environments because they have an inherently spatial dimension. Researchers may need to model not only the nearest source of junk food or pollution, for instance, but also the quality (e.g. by measuring total pollution output) and quantity (e.g. by measuring density or clustering) – or both attributes simultaneously – of features of interest and their impact on neighboring children. The tools of a geographer are therefore essential to understanding how these characteristics interact, allowing for the exact pinpointing of routes of exposure, as well as for modeling the effects of living in proximity to (or distant from) health-affording or -degrading features in the built environment.

The tools of a geographer

The foundation of geographical thought is the old adage 'location, location, location'. Just as 'you are what you eat', geographers believe 'you are where you live'. Thus, the locations in which children live, attend school, and play – or, conversely, the locations of community features that can affect children's health and poverty level – are of particular interest to geographers. The procedure of pinpointing the exact locations of features of interest in children's built environments is known as 'geocoding'. Geocoded locations can be spatially connected to other features nearby (such as the nearest school or the number of fast food restaurants within a one-mile walk), and spatial analytics and statistics can be used to infer the importance of these proximities to children's physical, mental, emotional, and economic health.

The growth of geographic information systems (GIS) over the past several decades has afforded researchers – particularly geographers – with new tools with which to perform this geographic analysis. GIS allows a user to create, manipulate, store, overlay, and analyze any data that can be geocoded. It also allows the user to digitize new information from existing data (for instance, inputting a paper map with point source pollution locations and converting them via the software). Being able to rapidly input information based on geographic location and connect it to co-occurring features of interest has opened new doors for analysis and has greatly increased our understanding of the spatial correlates of poverty and other social issues.

An ongoing problem with GIS analysis is that the way in which information is connected or aggregated can introduce errors into the estimates of exposure, resulting in either the under-reporting or over-reporting of environmental impacts on children. Thus, as GIS has grown as an analysis tool, researchers have needed to remain vigilant, so as to not introduce spatial errors in their data. Additionally, as GIS has been adopted more frequently by non-geographers, rules and best practices put in place to limit spatial errors are not always known or followed.

Common spatial errors

The shortcomings in geographic analysis fall into several categories, three of which will be discussed here: the modifiable areal unit problem (MAUP), the ecological fallacy, and geocoding error.

Modifiable areal unit problem

According to the MAUP, the results of statistics aggregated by space will vary depending on the size (or scale) and shape (or zoning) of the units used to aggregate data (Openshaw 1984). Essentially, two researchers could use the same data to arrive at very different conclusions regarding the incidence of disease or the density of junk food outlets in a community.

A zoning or shape effect of the MAUP was the main culprit that delayed the recognition of EBLLs in children during the Flint Water Crisis. This is because five of the seven 'zones' (ZIP codes, in this case) used in analysis for the city of Flint included homes with a Flint mailing address that were not actually using the city of Flint's water supply (Hanna-Attisha et al. 2016). In fact, one-third of the addresses within these seven ZIP codes were not located in the city itself and thus were not receiving Flint water at all (Sadler 2016). The sustained lower incidence of EBLLs among children outside the city dragged the overall incidence down, masking the increase in EBLLs among the city's children after the change in water source. (For more on the genesis and outcomes of the Flint Water Crisis, see Brush et al. 2015; Dixon 2016; Sadler and Highsmith 2016.)

Scale or size effects of the MAUP are common in research that uses buffer zones or administrative units to derive density estimates of exposure. For children, buffer zone distances may be walkable zones around a child's home or school of between 400 and 1600 meters, and measured either along a street network or as Euclidean distance (as explored in Sadler and Gilliland 2015; Sadler et al. 2016). Administrative units may include the census tract or neighborhood in which the home or school is located or a school attendance zone. Each of these is susceptible to the MAUP because any observed spatial association may change depending on which scale of administrative or areal unit is employed.

The MAUP would be less of a concern when the areal units being employed (e.g. school districts or counties) comprise, or are equal to, an agency's service area. In these cases, while the boundaries of the areal units may not match geographically, the larger area being served by a child poverty agency would still constitute a representative population. For example, a county-level agency that delivers an afterschool children's reading program could aggregate the smaller school districts within the county to conduct an exploratory analysis of the distribution and accessibility of their programs across their service area.

Ecological fallacy

The ecological fallacy can also influence the creation or interpretation of results. Because populations within any administrative unit can be heterogeneous, equating aggregated population-level characteristics with individuals within a unit of analysis can lead to erroneous conclusions. Thus, epidemiological studies often aim for individual-level analyses as the gold standard. At the very least, researchers must be careful not to commit the error of equating group-level characteristics to an individual. In the case of the Flint Water Crisis, we would commit an ecological fallacy if we saw a cluster of EBLLs in one portion of the city and made the erroneous assumption that all children were poisoned, even when controlling for neighborhood-level effects. In reality, uptake of lead is contingent on many factors, including home/school water chemistry, water consumption behaviors, dietary factors, and biological proclivity. We must therefore remain careful not to suggest that 100% of Flint's children were affected.

Schwartz (1994) has cautioned, however, against a wholesale rejection of aggregate-level variables (such as those at larger administrative units), because some environmental characteristics *can* affect an entire population. She and others have argued that 'intimate and ultimate causes each deserve attention, and neither negate the validity of the other' (Schwartz 1994, 822; drawing from Bahnson 1974; Coe 1978). In other words, while a disease-causing agent may be proximately understood to be of non-geographical origin, the long-term risk factors for such disease may manifest a geographic pattern that can be understood with the use of GIS and spatial analysis.

Geocoding errors

The process of geocoding data is not immune to geographic error. Many geographic studies make use of off-the-shelf geocoders embedded within commercial GIS software, such as the world geocoding service provided by Esri, the maker of the GIS software package ArcGIS. Others use public data sets, such as the US Census Bureau's TIGER road centerline, ZIP code, or various census geography files to create custom geocoders that match the level of geography in their health-related data sets.

Issues abound, however, when using geocoders not custom built for the population of interest or the specific geographic scale of analysis. Healy and Gilliland (2012) discuss how census tract centroid and postal code-based geocoders have a particularly high error rate for rural areas. Meanwhile, scholars such as Rosu and Chen (2016) have attempted to improve postal code-based geocoders but still find significant positional errors in both urban and rural areas. The gold standard is geocoding to specific civic addresses, but this approach must also be used with caution, because accuracy may be limited to the road frontage or parcel centroid of a civic address (a problem for apartment buildings and large residential lots or farms). In worst-case scenarios, civic addresses are outright misplaced (Cayo and Talbot 2003).

In studying issues tied to child poverty, researchers must consider not only how to measure the familial and individual circumstances that affect the child, but also the larger scale built environmental and societal forces that inherently and disproportionately affect such populations.

Objective measures of exposure

Even when accounting for the aforementioned issues, studies of the built environment can be inaccurate: researchers continue to seek new methods for improving estimates of exposure. Importantly for geographers working in children's health, exposure proxies ignore the well-known fact that human activity spaces are much more complex than single locations (Setton et al. 2011), a concept also known as 'spatial polygamy' (Kestens et al. 2012; Matthews et al. 2011).

Many studies using an ecological approach to exposure have 'treated the environment-individual relationship as a unidirectional one' and residents as 'predictable organisms responsive to their environment' (Shannon 2014 4). In response, more balanced methodological approaches have sought to contextualize the exchange between individuals and their environments (Algazy et al. 2010; Neff et al. 2009). Such estimation is important because children – of any population subgroup – are heavily affected by spaces near their homes and schools.

Rather than relying on exposure proxies, geographers and exposure scientists have begun using individual-level tracking techniques – such as GPS tracking – to more objectively define the activity spaces being used by children (Loebach and Gilliland 2016a, 2016b; Rainham et al. 2008; Shearer et al. 2015). This move to GPS tracking responds to the criticisms of using buffers to connect children to their environment, as they fail to account for the scale or zoning effect of the MAUP (Boruff, Nathan, and Nijënstein 2012; Chaix et al. 2009; Rainham et al. 2010; Spielman and Yoo 2009).

Several researchers have remarked on the importance of using more than GPS tracking to determine essential elements in environmental exposure because of the unpredictability and mobility level of an individual (Chaix et al. 2013; Nuckols, Ward, and Jarup 2004; Sadler and Gilliland 2015). Similarly, although the use of activity spaces overcomes the limitations of zeroing in on exposure at one location, activity tracking with GPS is not always feasible. Researchers have thus advocated for higher quality individual-level neighborhood assessments, including the use of activity diaries and the modeling of activity-space ellipses – oblong circles circumscribing the standard deviation of the mean of *x* and *y* coordinates for a set number of observations, which may be used as a proxy for a daily activity space (Kestens and Daniel 2010; Lovasi, Grady, and Rundle 2012; Vallée et al. 2010; Williams et al. 2014; Zenk et al. 2011).

Researchers have also been able to link social environmental characteristics to populations through the use of deprivation indices (Pampalon et al. 2009; Sadler, Gilliland, and Arku 2013). These indices make use of publicly accessible census data available at smaller geographic units, such as the dissemination area or the census block group (about the size of an urban neighborhood). Indicators of social and material deprivation are combined, often as unweighted sums of standard scores for such characteristics as rates of adult unemployment, lone parenthood, low educational attainment, and low income. Such indices allow researchers to zero in on neighborhoods in which the many facets of child poverty are more extreme and where other public health risk factors may thus be more prevalent.

The importance of context and good spatial measures

One of the best ways to avoid committing these errors is to gain a firm understanding of how the feature of interest manifests itself in the environment. Rather than constructing an exposure proxy because it is convenient or easy during an observational study, the researcher should develop metrics that best approximate exposure. For example, modeling distance decay plumes around point source pollution – taking into account wind direction and the dilution rates of the source of interest – would yield a demonstrably better estimate of actual exposure than using circular buffers or aggregate estimates by census unit.

Of additional concern is that children do not use and view their environments in the same way as their adult counterparts – and children of differing ages use their environments differently (Papas et al. 2007) – yet children overall have little involvement in the planning process (Holloway and Valentine 2005; Knowles-Yánez 2005). To best study the impacts of environmental variables on children's health and outcomes, researchers must work to frame inquires at the spatial scale of the child and attempt to view the interconnections between children and their environment through the eyes of a child.

Qualitative GIS approaches have emerged in recent years to incorporate adult understanding of spatial concepts such as community and neighborhood (Cope and Elwood 2009; Kwan and Ding 2008; Lafreniere and Gilliland 2015). These approaches are ripe for use in studying children's geographies and health. For example, opportunities exist to integrate children's qualitative assessment of their environments, such as how they use unofficial play spaces, avoid areas of risk, and inefficiently commute to school (Hume, Salmon, and Ball 2005; Loebach and Gilliland 2016b). Children themselves can be active participants in the research, rather than simply subjects for observation. Projects have shown that children can learn GIS to record and analyze their qualitative use of space and their environments and to integrate quantitative environmental data into the geospatial research model (G.R.A.C.E. 2016; Raymond 2017).

The issue of using good spatial measures takes on particular importance if we assume that, in an ideal world, policy-making is derived directly from available research for the betterment of society (suggested as a goal in Torgerson 1986). While evidence often fails to translate into effective policy for several reasons, including ineptitude, non-scientific values, and pure political gain (Brownson et al. 2010; Roe 1990; Teret

2001), we must nonetheless ensure that research findings are as close to incontrovertible as possible. Equally troubling is that errors in analysis can also cause us to commit errors of the third type, causing us to ask and solve erroneous research questions and thus advocate for the entirely wrong policy (Dunn 1994).

Using these tools to address child poverty

Using geographic tools, we can enhance our understanding of what types of built forms are more or less conducive to addressing the built-in inequalities faced by children, particularly those living in poverty. Urban planners routinely use such information to determine, for instance, where to site park improvement projects or transportation improvements to encourage active travel. But other decision-makers may be less familiar with these concerns.

We must therefore continue to advocate not only for policies that will help families emerge from or avoid poverty, but also for geographic tools and expertise that facilitate the inquiry necessary to formulate effective policies around better urban planning and environmental protection. Without such collaboration, grants, fund appropriations, and public policy will continue to be informed by inaccurate areal units, despite recognition on the part of local planners, public health officials, and others that the issues are better framed at another spatial level.

Best practices

- To think like a geographer, consider features in your agency's service area that may vary in type or magnitude across the landscape.
- Any provider can visualize basic spatial information through free mapping programs (e.g. Google Maps, Open Street Map, ArcGIS Online, BatchGeo).
- Try to work with disaggregated, individual-level data whenever possible; this allows you to make the decision about how it may ultimately be aggregated.
- Keep your areal unit as geographically condensed and spatially contiguous as possible.
- For spatial data that may have specific spatial patterns (e.g. census data, school attendance information, patient data, social services, Head Start programming, afterschool programming), seek out someone with expertise in GIS to examine if disparities may exist that cannot be seen without higher-level mapping or spatial analysis.
- Think beyond individual-level characteristics (e.g. socioeconomic status) to consider localized built environmental influences (e.g. pollution around factories, exposure to junk food, crime).

Disclosure statement

No potential conflict of interest was reported by the author.

Notes on contributors

Rick Sadler is an urban medical geographer whose research focuses on the intersection of urban planning and public health. His work is rooted in community partnerships and aimed at strengthening the understanding between the built environment and health behaviors/outcomes, with the goal of building healthier cities for children and adults.

Don Lafreniere is an urban historical geographer whose research interests center on creating GIS methodologies for reconstructing historical environments and spatializing populations. His recent work includes teaching youth how to use geospatial methods to uncover the relationships between the built environment and life course health and well-being.

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