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Take the edge off: A hybrid geographic food access measure

Xiang Chen

Department of Emergency Management, Arkansas Tech University, Russellville, AR, 72801, USA

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ABSTRACT

Measures of geographic food access overlook an important source of statistical biases, termed the edge effect. The edge effect refers to the fallacy that events contributing to the spatial pattern of an analysis unit may be outside of that unit; thus merely summarizing events within the unit may lead to distortion of the estimation. Food procurement activities can happen beyond existing administrative boundaries. Delineating food access using unit-based metrics may misrepresent the true space within which food stores are accessible. To overcome this problem, this paper proposes a gravity-based accessibility measure to improve unit-based statistical approaches in food access research. In addition, this method accounts for the spatial interaction between food supply (e.g., food items in stock) and demand (e.g., population) as well as how this interaction is mediated by the spatiotemporal separation (e.g., travel time, modality). The method is applied to the case of Franklin County, OH and has revealed the food access inequity for African Americans by modes of transport, including walking, biking, and driving. The analysis of the correlation between mode-specific food access and socioeconomic status (SES) variables reveals that using a single modality in food access research may not fully capture the travel behavior and its relationship with local food environments. With modifications, the proposed method can help evaluate food access for a target population group, such as Supplemental Nutrition Assistance Program (SNAP) users or selected ethnic minorities who may face acute difficulties in procuring economically affordable and culturally appropriate foods.

America has stepped into an era in which high-calorie, nutrient-poor foods prevail. Procuring and eating unhealthy foods on a regular basis will induce obesity-related health consequences, such as excessive weight gain, Type-II diabetes, and cardiovascular conditions (Caspi, Sorensen, Subramanian, & Kawachi, 2012; Reidpath, Burns, Garrard, Mahoney, & Townsend, 2002). To minimize the risk of obesity and strengthen national food security, particular attention is paid to the issue of food access, exploring how the accessibility of food is hindered by an array of geographic, economic, and informational barriers (McEntee & Agyeman, 2010). A growing body of literature has shown that access to healthy and affordable foods (e.g., fresh fruits and vegetables) is mediated by residential segregation, such as neighborhoods of different races and incomes (Larson, Story, & Nelson, 2009; Walker, Keane, & Burke, 2010). Demarcating areas where healthy food access is economically deprived and geographically limited helps to formulate effective health policy (Cummins & Macintyre, 2002).

Measures of geographic food access typically take two spatial approaches: proximity and density (Charreire et al., 2010). Specifically, proximity to the nearest food retailer can be quantified by various distance measures such as the Euclidean distance (Kipke et al., 2007), the Manhattan distance (Zenk et al., 2005), and the network distance (Algert, Agrawal, & Lewis, 2006; Pearce, Blakely, Witten, & Bartie, 2007). Density, on the other hand, is invariably interpreted as the summation of stores delimited by administrative units, such as census tracts and block groups (Charreire et al., 2010). For example, the U.S. Department of Agriculture (USDA) Economic Research Service (ERS) measures poor food access as census tracts that satisfy both the "low-income" and "low-access" criteria (USDA, 2017a). The criteria are based on tract poverty rate, median family income, and percentage of population living at a significant distance from the nearest supermarket (Ver Ploeg et al., 2012). The Centers for Disease Control and Prevention (CDC) has developed the Modified Retail Food Environment Index (mRFEI; CDC, 2011) that gauges healthy food provision based on the percentage of healthy food retailers within census tracts and a buffered area. The USDA and CDC measures, however, cannot capture food access at a smaller scale (e.g., block groups) or incorporate variables of transportation (e.g., modality). In order to reference micro-scale food

E-mail address: chenxiangpeter@gmail.com.

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access disparity, a limited set of studies have employed advanced geospatial methods by recourse to the geographic information systems (GIS), using spatial clustering (Baker, Schootman, Barnidge, & Kelly, 2006), cost surface (Burns & Inglis, 2007) or kernel density estimation (Moore, Roux, Nettleton, & Jacobs, 2008).

The administrative-unit-based metrics are heavily influenced by how the units are geographically delineated. These measures overlook an important source of statistical biases, termed the "edge effect" (Dreassi & Biggeri, 1998; Lawson, Biggeri, & Dreassi, 1999; Van Meter et al., 2010; Vidal Rodeiro & Lawson, 2005). In environmental health research, the edge effect refers to the statistical bias that events contributing to the spatial pattern of an analysis unit may be outside of that unit; thus merely summarizing events within the unit may lead to distortion of the estimation (Dreassi & Biggeri, 1998). Similarly, food procurement activities can happen beyond existing administrative boundaries. Delineating food access using unit-based metrics may generate under-estimation that misrepresent the true space within which food stores are accessible (Chen & Kwan, 2015; Sadler, Gilliland, & Arku, 2011).

To overcome this problem, this paper proposes a gravity-based accessibility measure to improve the statistical approaches in food access research. Not only does this measure address the potential method flaws at the edge of the statistical units, but it also accounts for the spatial interaction between food supply (e.g., food items in stock) and demand (e.g., population) as well as how this interaction is mediated by the spatiotemporal separation (e.g., travel time, modality) affecting geographic food access. With modifications, the proposed method can help evaluate food access for a target population group, such as Supplemental Nutrition Assistance Program (SNAP) users or selected ethnic minorities who may face acute difficulties in procuring economically affordable and culturally appropriate foods (O'Connell, Buchwald, & Duncan, 2011; Odoms-Young, Zenk, & Mason, 2009). In a broad context, this method can help evaluate the effectiveness of policy initiatives aiming at tailoring selected socio-spatial factors on food access, eventually shedding insights into access equity measures in environmental health research.

1. Edge effect and food access

The edge effect is a problem originated from spatial statistics (Griffith, 1983). It is presented as a fundamental statistical bias that when analyses are performed within a finite geographic region, effects induced beyond the regional boundary are excluded. This problem is of elevated importance in epistemological research as the spread of epidemics is less subject to pre-existing boundaries (e.g., country borders, coastal lines) than the spatial scope of human movement (Bharti, Xia, Bjornstad, & Grenfell, 2008). The edge effect is a related problem of the modifiable areal unit problem (MAUP), referring to the statistical bias caused by the change of spatial scope and the smallest observable unit (Fotheringham & Wong, 1991). The MAUP and edge effect severely obfuscate research on food access when administrative units are involved in the enumeration of food stores. The effect has been evidenced by the inconsistency in observations when the unit for analysis is modified. For example, a simulation study on food retailers found that considerable differences exist in accessibility measures derived with different sizes of the analysis unit, while the effect is most pronounced near the boundary (Van Meter et al., 2010). Another study comparing supermarket access measures using respective census tract and block group units identified different levels of associations with socioeconomic status (SES; Barnes et al., 2016). From an individual perspective, research on food activities has identified that the consumer-perceived neighborhood is generally smaller than the officially defined units; and the potential activity space for individuals to procure food has the greatest spatial extent (Crawford, Pitts, McGuirt, Keyserling, & Ammerman, 2014). Thus, using administrative units is insufficient to draw a solid food landscape in which food trips may cross multiple geographic units.

Another facet adding to the fallacy of the edge effect refers to the food retail location strategies. Planning for food retailers considers the business potential of a site in areas where the demand for food is high and access is visible. One decision-making variable is the ease of access that allows consumers to make the purchase without crossing excessive physical barriers, such as turning restrictions and road blockage (Timor & Sipahi, 2005). This criterion is essentially critical for fast-food outlets, as a significant amount of purchases are made by passing traffic or transient customers (Hurvitz, Moudon, Rehm, Streichert, & Drewnowski, 2009; Macintyre, McKay, Cummins, & Burns, 2005). To pursue economic benefit as well as accommodate consumers' need, locations along arterial roads with a relative access advantage become ideal solutions. As some of the arterial roads also serve as the boundaries for unit delineation, it is likely that a food store situated along the road but in the adjacent unit will not be included in the enumeration of business establishments. Also, the edge effect obfuscates data on the SNAP store redemptions, since a certified SNAP retailer can straddle two zip code zones (Shannon, 2014).

Although the edge effect has been mentioned or evaluated in numerous food access studies (Fraser & Edwards, 2010; Ledoux & Vojnovic, 2013; Sadler et al., 2011; Shannon, 2014; Van Meter et al., 2010), it is of relative difficulty to address it using traditional food access measures. This gap is likely the result that discussion on food environment assessments cannot be separated from SES variables, such as household income and poverty rate that intrinsically mediate access. These variables, when generated, are strictly solicited and consolidated based on administrative units. To reduce the edge effect, existing measures often apply compromise solutions by using a lower aggregation level such as block groups (Sharkey & Horel, 2008) or expanding the size of units in arbitrary manners (as seen in Fig. 1b and c). Based on past studies (Charreire et al., 2010; Chen & Clark, 2013; Larsen & Gilliland, 2008), the paper hereby proposes five types of methods upon which geographic food access is measured, as shown in Fig. 1.

These five methods view the separation of space in food procurement from different perspectives. (1) The container method (Fig. 1a) is the most widely employed method. This method derives statistics of food stores aggregated by specific geographic units, including census tracts (Moore & Diez Roux, 2006), zip code zones (Chung & Myers, 1999), counties (Morton & Blanchard, 2007; USDA, 2017b). To reduce the edge effect, two extensions of the container method include the container buffer method (Fig. 1b) and the container neighbor method (Fig. 1c). (2) The container buffer method creates a buffer distance around the administrative unit and uses the expanded region for areal statistics. The buffer distance, often loosely defined, includes half mile to one mile around census tracts (Block, Scribner, & DeSalvo, 2004; CDC, 2011), two to three miles around zip code zones (Alwitt & Donley, 1997), and approximately one and a half miles around the Local Government Areas (LGA, a subdivision used in Australia; O'Dwyer & Coveney, 2006). (3) The container neighbor method considers the statistical unit to be the administrative unit itself plus all surrounding units, identifying areas with a relative concentration of establishments (Hemphill, Raine, Spence, & Smoyer-Tomic, 2008). (4) The circular buffer method (Fig. 1d) creates a circular buffer around a food retailer as a dichotomous representation of the friction of distance. The buffer distance, often indicating walkability, takes the form of a quarter mile to two miles in urban regions (Charreire et al., 2010). (5) Lastly, as an extension of the buffer method, the network buffer method (Fig. 1e) considers travel to food retailers to