Visualizing nutritional terrain: a geospatial analysis of pedestrian produce accessibility in Lansing, Michigan, USA

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This article considers how geospatial analyses can influence cartographic outputs in studies of the spatial structure of food environments. We make two contributions. First, we present a new approach to conceiving and visualizing urban food environments as ‘nutritional terrains’, in which the opportunities and costs of locating (healthful) food vary continuously across space. While other researchers have conceptualized and represented food environments as continuous phenomena, we use detailed data to produce maps of food accessibility that have high resolution both spatially and in terms of food availability. Second, we show that decisions made about measuring and modelling food accessibility can create artifactual patterns independently of actual variation in food-environment characteristics. Although the type of method-driven patterning we identify will not surprise cartographers, we argue that non-geographers using geographic information technologies to visualize food environments must give greater attention to the unintended consequences of choices made in geospatial analyses.

**Keywords:** food environments; accessibility; visualization

**Introduction**

Built environments may constrain dietary choices, and contribute to diet-related public health problems, including overweight and obesity, diabetes and cardiovascular disease (French \textit{et al.} 2001, Papas \textit{et al.} 2007, Ford and Dzewaltowski 2008). Fundamentally, many of the public health problems observed in the developed world arise from over-consumption of calorie-dense, nutrient-poor foods, such as processed foods, and concomitant under-consumption of nutrient-dense, calorie-poor foods, such as fresh produce (Halkjær \textit{et al.} 2009, Liese \textit{et al.} 2009). Adequate consumption of fresh fruits and vegetables contributes to better health outcomes (Zenk \textit{et al.} 2005a,b, Adebawo \textit{et al.} 2006, Morland and Filomena 2007), yet millions of people who can afford to purchase these foods continue to under-consume them.

In the United States, researchers are devoting more attention to the role of environmental context in food consumption patterns (Shaw 2006, Beaulac \textit{et al.} 2009).
The accessibility of healthy food choices varies considerably depending on an individual’s geographic situation. A number of recent studies have quantified and mapped links between demographics, food accessibility and diet (White 2007, Black and Macinko 2008, McKinnon et al. 2009, Larson et al. 2009). From this literature, two main points are particularly relevant to our argument in this article. First, within a given urban area there may be substantial geographic variation in access to healthy food choices. In general, economically disadvantaged and minority-dominated neighbourhoods in the US have lower than average access to large retailers, including supermarkets, and thus generally experience higher prices for narrower selections of food items (Inagami et al. 2006). Second, these physical and economic constraints affect dietary choices, such that diet-related health problems tend to be higher in economically disadvantaged and minority-dominated neighbourhoods (Laraia et al. 2004, Andreyeva et al. 2008).

Studies of food accessibility represent an important advance in public health, yet many of these studies are cartographically simplistic, and, as a result, may have misleading results. In this article, we argue that public health-minded researchers must give greater attention to geospatial analysis as a possible source of artifactual patterns of food geography, because different, reasonable assumptions made in modelling food accessibility can create starkly different cartographic outputs. We support this argument with a case study of the food environment in Lansing, Michigan, USA.

Our research is significant because we explicitly build upon basic cartographic concepts both to provide a new approach to conceptualizing and visualizing food accessibility, and to identify an overlooked methodological issue that must be addressed in future studies. First, we assert that food environments are continuous geographic phenomena, and thus must be understood and visualized using surface or isarithmic approaches (Slocum et al. 2009). We conceptualize Lansing’s food environment as a ‘nutritional terrain’, where the opportunities and costs of finding (healthful) food vary continuously. While some geographic information system (GIS) analyses of food environments use surface or isarithmic approaches to visualization, many others represent food environments using point maps of retail locations, or choropleth maps that categorize pre-defined areas (such as census tracts) by the number and/or type of retailers located within an area. By comparing different methods of creating surface and isarithmic representations of a single food environment, and also by comparing these representations to derived choropleth maps, we show that decisions about geospatial modelling of accessibility must be a more prominent concern in health geographic research.

Additionally, we present a novel means of characterizing food retailers by using the availability of individual types of food as our fundamental elements of spatial analysis, as opposed to the more common practice of simply mapping retail locations. While our maps do represent the locations of food retailers, we did not assign labels such as ‘supermarket’, ‘convenience store’ and ‘grocer’. Instead, we inventoried the fresh produce offerings of each store, and mapped the availability of each type of produce in our study area. Thus, the ‘nutritional terrain’ we describe is not just continuous but also has very high resolution in terms of food availability. While our results mostly confirm the types of spatial inequalities in food accessibility observed by other researchers, our focus is on the geospatial methods that underpin many examples of food-environment research. We caution that cartographic depictions of food environments depend greatly upon measurement approach.
Although geographic information scientists (GIScientists) are familiar with how decisions made in modelling affect visualization (Monmonier 1996), the ways analytical methods can produce spurious patterns may be unfamiliar to many users of GISs in health geography who lack cartographic training.

**Background**

In general, accessibility is an important characteristic of urban geography. Accessibility is commonly cited as a goal in urban planning, building design and social justice. However, as pointed out by Peter Gould (1969), accessibility is one of those common terms that everyone uses until faced with the problem of defining and measuring it. Fundamentally, accessibility is determined by three components: the spatial distribution of potential destinations, the ease of reaching each destination, and the character of each destination (Handy and Niemeier 1997). In the context of food environments, nutritional accessibility metrics must account for the spatial arrangement of food retailers, the costs of travelling to any retailer and the foods available at each retailer.

Research on ‘food deserts’ – areas with low accessibility to (healthful) foods – has focused on the spatial distribution of retail food locations (Shaw 2006). One notable finding is that both quality and quantity of retail food locations vary significantly between neighbourhoods (Cummins and Macintyre 2006). Minority-dominated and socioeconomically disadvantaged neighbourhoods generally have fewer sources of fresh produce than non-Hispanic white neighbourhoods (Chung and Meyers 1999, Morland et al. 2002, Zenk et al. 2005b, Algert et al. 2006, Baker et al. 2006, Block and Kouba 2006, Powell et al. 2007a,b,c). Although these findings are important, the majority of food-environment studies to date have some methodological limitations (Howard and Fulfrost 2007). For our purposes in this article, the most significant problems include:

- **Coarse spatial analysis.** The majority of food-environment research has been conducted at coarse aggregate levels, such as census tracts, ZIP codes or counties (Morton and Blanchard 2007, Powell et al. 2007a,b,c). The use of aggregate areas can lead to misleading results, because accessibility is a continuous phenomenon (Handy and Niemeier 1997). For instance, some portions of aggregate political units may have good access to produce while other portions do not. Given the likelihood of significant intra-unit variation in food accessibility, it is unwise to analyse access at such coarse spatial scales even if other relevant data, such as those derived from the US census, are available only as aggregates.

- **Simplified definitions of access.** Most Americans purchase food at retail locations and travel via road networks. With each journey to a retail location, an individual consumer overcomes a cost of separation. This cost is frequently viewed as a function of time or distance. Unfortunately, many studies fail to accurately model separation costs. For example, some studies use Euclidean distance, or Manhattan-block distance (e.g. Zenk et al. 2005a,b) to model accessibility. These measures do not mimic the lived experience of consumers, who must travel along pre-defined, often indirect routes.

- **Simplified definitions of retail food sources.** Many studies have utilized proximity to the nearest retailer as a measure of access (Laraia et al. 2004,
Zenk et al. 2005a,b). This is problematic because store inventories differ, even between externally similar stores; not all ‘supermarkets’ are equal, and some small stores may have large inventories based on various factors. More detailed characterization of food retailers, based on food availability, is needed.

- Imprecise location data. Few studies of food access have accurately modelled the actual locations of retail locations (Sharkey and Horel 2008). Previous investigations rely heavily on geocoded addresses (Laraia et al. 2004) that others have demonstrated to be significantly inaccurate. These errors propagate when included in network accessibility analyses.

Perhaps the most important of these limitations is insufficient attention to the types of foods offered within retailers. Morland et al. (2006), for example, examined how the presence of a few, broad retail types influences obesity. Unfortunately the meanings of the categories ‘supermarkets’, ‘grocers’ and ‘convenience stores’ can be ambiguous. By focusing on the availability and accessibility of individual food items, GIS analyses can quantify and visualize the ‘nutritional terrain’ in an urban area: a continuous, fine-scale geographical characterization of food availability and accessibility. Each individual produce item within a food environment possesses a unique pattern of availability and thus accessibility, which depends upon the spatial arrangement of retailers offering the item, as well as the geospatial model employed to measure accessibility. By improving the cartographic depictions of inequalities within urban food environments our broad goal is to enable health officials to identify areas that have poor access to specific types of food, including produce, rather than simply poor access to a specific type of retailer.

Data collection and analysis

Overview

Our study area is the Lansing, Michigan, USA, metropolitan area (42°44′N, 84°33′W), which has a population of about 450,000 (Figure 1). We analysed the distribution of 94 food retailers who offered fresh produce during the period of data collection, February–April 2008. We assessed accessibility to these locations by independently analysing the three fundamental components of geographic access: the spatial distribution of food retailers, the cost of reaching each retailer from an address and the produce offerings of each retailer (Handy and Niemeier 1997). The methods used to analyse each aspect of access are described in the following subsections.

Spatial distribution of potential destinations

We compiled a list of all food retail locations (excluding restaurants) in the Lansing area using commercial data purchased from ESRI (Redlands, California) supplemented with Internet searches, phone book listings and on-the-ground searches of local streets. Next, we determined whether each location in this list (n = 246) was operational and offered any fresh produce, through telephone calls and in-person visits. We defined ‘fresh produce’ as any plant food offered for sale in an uncooked, unfrozen and undried form. We chose to sample food availability
based on produce availability because consumption of fruits and vegetables is emphasized in public health campaigns (Lasley and Litchfield 2007, Sharkey and Horel 2009). We identified 94 retail locations that offered fresh produce then visited each outlet in person. We used hand-held GPS receivers to determine the location of each retailer’s entrance. Some outlets had more than one entry; in these cases we recorded the coordinates of the entry point closest to the outlet’s produce section.

Cost of reaching each destination
Successful travel to a destination incurs costs of separation (Handy and Niemeier 1997). These costs are often quantified using geographic distance, travel time or required energy. When travel costs are overwhelming, they hinder a consumer’s ability to visit a destination. For example, a supermarket may be ‘too far away’ or ‘take too long to get to’ for a given consumer, who instead shops at a limited-selection convenience store. These costs are critical to dietary choice; therefore when analysing a food environment it is imperative that these separation costs be accurately modelled. We chose to employ network analysis to estimate the costs-of-separation that the consumers in urban environments are forced to overcome.

We measured network distances and pedestrian travel times outward from every produce retailer, which enabled the calculation of expected service areas for each location. Using GIS-based network analysis, we generated multiple network buffers

Figure 1. Study area: The Lansing, Michigan metropolitan area contains over 90 produce retailers including supermarkets, grocery stores, and convenience stores. Many of the supermarkets are located towards the periphery of the urban core.
to enclose all network locations varying distances (e.g. 0.1 miles, 0.2 miles) within each retailer in the study area. We created a unique set of network buffers for every produce item available in the study area, which facilitated the estimation of accessibility to both individual produce items and cumulative numbers of produce items.

We focused on pedestrians. Due to enhanced mobility, individuals with access to automobiles have lower separation costs relative than those who are limited to other modes of transport, especially walking. We defined separation costs in terms of estimated walking time along established street networks. The walking cost (in minutes) was formulated by dividing the length of the optimal network route (in miles) by an average walking speed of 3 miles per hour. Using the ArcGIS Network Analyst tool, and detailed road network data provided by the Michigan Center of Geographic Information, we employed network buffering to estimate realistic distance costs that separate consumers from retail locations.

**Character of destinations**

We visited each retail location and recorded every type of fresh produce offered in each location. We recorded each item priced separately in every store, with these exceptions: multiple sizes of single items, such as large and small zucchini squash, which were recorded as a single item; minimally prepared items, such as sliced melons, unless a given item was offered only in a minimally prepared form and packaged spices, because of the difficulty determining whether these were dried or otherwise preserved. These data collection efforts produced a matrix that summarized the presence–absence of each produce item \( (n = 447) \) in all 94-sample sites. As a means of characterizing individual food retailers, inventorying fresh produce availability allows more precise modelling of food accessibility than more simplified approaches that only differentiate retailers based on external characteristics, such as square footage, chain membership or sales volume.

Food accessibility can be defined and formalized in countless ways, but the intricacies of the definition are critical to the eventual results. In this article, we apply three different accessibility metrics to estimate pedestrian access to retail produce. We used GIS to calculate accessibility scores for every point within our study in three different ways. These methods are each detailed in the following sections.

**Container method**

The most straightforward approach to measuring geographic accessibility involves simply counting the number of opportunities (i.e. food retailers) accessible within some pre-defined cost constraint (e.g. distance). Such an approach is sometimes called a container measure because resulting accessibility scores are basically a count of the number of opportunities within a specific geographic range. For example, a container measure of hospital accessibility might simply count the number of hospitals within 25 miles of an address.

Since the atomic units of analysis in our study are individual produce items, we were able to generate service areas not only to retail locations but also more specifically to individual items (e.g. bananas, green beans, organic spinach). We modelled 10-min (0.5 miles) service areas for pedestrian access for every produce item available within the study area (Figure 2).
Figure 2. Individual item accessibility signatures: This set of small multiples shows how unique produce items have different accessibility signatures.
Using GIS overlay analyses, we calculated container measures that indicated how many unique produce items were available within a 10-min walk of every address in the study area. Our container-measure accessibility equation is:

\[ A_i = \sum_{j \in R} P_{ij} \]

\( A_i \) = Total produce accessibility of location \( i \)

\[ P_{ij} = \begin{cases} 
0, & \text{produce item } j \text{ is not accessible at location } i \text{ within distance } f \\
1, & \text{produce item } j \text{ is accessible at location } i \text{ within distance } f
\end{cases} \]

\( f = 10 \) min of pedestrian walk

\( R = \) Region containing all locations and produce types to be considered.

**Weighted method**

The container measure is simple and easy to understand, but treats all accessible opportunities uniformly. An item that is barely accessible (e.g. near the limit of the cost threshold) is considered just as accessible as an item that is literally next-door. Our second accessibility metric awards higher accessibility scores to those produce items that are closer than those that are further away. This weighted approach generates a higher-resolution model of accessibility for each item by identifying service areas that are graded spatially based on proximity.

We calculated weighted services areas for all 447 produce items and delineated multiple accessibility zones according to network distances. For example, areas within a 2-min walk to a retailer offering a particular produce item receive a higher accessibility score than areas >2 min away. Our equation for determining weighted accessibility is:

\[ A_i = \sum_{j \in R} P_{ij} W_a \]

\( A_i \) = Total produce accessibility of location \( i \)

\[ P_{ij} = \begin{cases} 
0, & \text{produce item } j \text{ is not accessible at location } i \text{ within distance } f \\
1, & \text{produce item } j \text{ is accessible at location } i \text{ within distance } f
\end{cases} \]

\( f = 10 \) minutes of pedestrian walk

\( W_a = \) Inverse distance weight from set \( a \)

\( a = \{0.1, 0.2, 0.3, 0.4, 0.5, 1\} \) min of walking

\( R = \) Region containing all locations and produce type to be considered.

**Cumulative distance method**

The container method and weighted method of accessibility modelling capture distance only in terms of pre-specified thresholds, and do not distinguish among opportunities outside of those ranges. For our third metric, we included a measure where accessibility at a given location is defined as the sum of the network separations from all available produce items to that location. In other words, the score reflects the total network distance a consumer would have to travel in order to
purchase every individual produce item (one item per journey) available in the study area. In general, the larger the result, the less accessible produce items are to that location. Furthermore, a centrally located origin is more likely to have a lower accumulated sum and therefore be more accessible than peripheral locations.

$$A_i = \sum_{j \in R} P_{ij} D_{it}$$

- $A_i =$ Total produce accessibility of location $i$
- $P_{ij} =$ \begin{cases} 0, & \text{produce item } j \text{ is not accessible at location } i \\ 1, & \text{produce item } j \text{ is accessible at location } i \end{cases}$
- $D_{it} =$ Distances from set $t$ for which accessibility at $i$ is measured
- $t = \{0.5, 1, 1.5, 2, 2.5, 3, \ldots, 12, 12.5, 13, 13.5, 14\}$
- $R =$ Region containing all locations and produce types to be considered.

**Results**
The three accessibility metrics each produced a different depiction of nutritional terrain for the study area. The resulting accessibility maps exhibit different thematic signatures; ‘food deserts’ – areas with low food accessibility – appear differently depending on the measurement approach.

**Container approach**
The output from the container method presents a patchy nutritional landscape in which accessibility to fresh produce is poor for most of the study area (Figure 3). In particular, few addresses in the densely populated centre of the study area have any produce items within a 10-min walkshed; more addresses in the suburban periphery of the study area have better access to fresh produce. In other words, locations with the greatest pedestrian access within are in relatively sparsely populated, automobile-oriented areas.

One of the benefits of the container measure is that the results directly translate to an intuitive description of fresh produce accessibility. For example, the most produce-abundant 10-min walkshed has access to 272 produce items. Unlike the other two accessibility metrics applied in this study, the output from the container measure provides a simple count of the number of produce items within a 10-min walk. Consequently, the container approach can facilitate certain types of map tasks better than the others. For example, a map-reader could easily identify zones that have pedestrian access to less than 10 different produce items. However, a drawback of this approach is that zones outside of the 10-min constraint appear uniformly disadvantaged; retailers that are 11 walking minutes from an address are lumped in with others that are much more distant.

**Weighted approach**
The depiction of nutritional terrain using the weighted method (Figure 4) is different than the output based on the container metric, because the weighted method uses multiple distance measures to characterize retailers. Furthermore, since the weighted
method includes buffers of up to 20 walking minutes (one mile), its output contains fewer zones of no access. Thus, the nutritional terrain produced through the weighted method is less patchy than that produced through the container method. Most of the study area appears to have at least some pedestrian access to fresh produce.

However, the quantitative output from the weighted method is less intuitive than the container approach. It does not correspond to a simple count, but instead offers a more abstract scoring of accessibility. This is the result of a measurement approach that places an emphasis on proximity to a retailer. Due to the scoring gradient in this weighted approach, map-readers cannot simply translate accessibility scores into a clear set of nutritional consequences (e.g. zones that have pedestrian access to less than 10 different produce items).

**Cumulative distance approach**

The cumulative distance metric produces a very different depiction of nutritional terrain (Figure 5). Using this method to model accessibility, the central parts of the city appear to have the best accessibility to fresh produce, because these areas are located relatively near to all suburban locations, whereas different suburban locations may be located on opposite sides of the city. However, this map reveals that some suburban areas have much greater produce accessibility than others. For
example, the eastern suburban periphery of the study area has better access to fresh produce than Lansing’s western suburbs – a phenomenon that is much less obvious using the other two methods of modelling access (Figures 3 and 4). The output from the cumulative distance approach suggests a much more concentrated, and less patchy nutritional landscape.

Discussion

The relative newness of food-environment studies means that relevant methodologies are still in stages of development; the methods used in many food-environment studies have been mixed in terms of quality and conceptual appropriateness (Booth et al. 2005, Papas et al. 2007, Beaulac et al. 2009). There have been few critical assessments of geographic methods used in food-environment research (Sharkey and Horel 2008), although inappropriate spatial analyses have led to questionable conclusions about food environments (Spielman 2006). Spatial analysis is rooted in geographic information science (GIScience), the body of theory necessary to develop and implement GISs. Many researchers use computer-based GISs as research tools for spatial analyses; GIScientists test the theoretical, conceptual and spatial appropriateness of different uses of geographic data. For instance, GIScientists have shown that decisions about the acquisition of geographic data and its insertion into GISs can strongly affect public health research findings (Elliott and Wartenberg

Figure 4. Results from the weighted method produce a less patchy, and more graded depiction of pedestrian produce access.
2004, Zandbergen 2007, Boone et al. 2008). Similar assessment of geographic methods in the specific context of food-environment research is necessary to validate data sources and analytical approaches widely used to develop public-health policy in the US (Sharkey and Horel 2008).

GISs can be used effectively to identify disparities in nutritional terrain across an urban landscape. However, the quality of output visualizations and analyses depend upon both data quality as well as decisions made in data analysis. Many researchers recognize that map quality depends upon data quality – the ‘garbage-in–garbage-out’ reality of GIS analyses is widely known – but the dependence of map output upon analytical decisions that occur several steps prior to map production is less widely recognized amongst GIS users who are not trained in GIScience. While many map-readers tend to see maps as ‘true’, all maps include ‘white lies’ that cartographers use to simplify geographic reality (Monmonier 1996). Furthermore, previous food-environment investigations often rely on so-called one-map solutions (Monmonier 1991) that ‘foster highly selective, authored views perhaps reflecting consciously manipulative or ill-conceived design decisions’, which in turn can misrepresent or skew the geographic complexities of urban food environments.

Our results show that visual depictions of food environments are as vulnerable cartographic distortion as maps depicting other geographic phenomena. Despite
similar production methods using identical inputs, cartographic outputs can be considerably different and these differences can influence geovisual narratives. For example, if someone wanted to show that the western periphery of Lansing has particularly poor access to produce, a map using our data and the cumulative distance metric in Figure 5 would be more effective than a map using either the container method or the weighted method (Figures 3 and 4).

The topics of sensitivity analysis and uncertainty are not new to GIScientists, but few food-environment studies have considered how these phenomena may affect their analyses. Furthermore, and perhaps more troubling, most previous investigations use only one approach to model nutritional accessibility, and rely on its output to correlate food-environment characteristics with other geographic variables. Yet our results indicate that applying different accessibility metrics to a single dataset can produce very different, but equally valid cartographic outputs; these differences would influence all subsequent statistical operations, such as analyses designed to test possible correlations between food accessibility and diet-related health indicators. The implications of decisions made in the beginning stages of a nutritional accessibility study propagate throughout its entire methodology.

There is a need to improve the methods through which urban food environments are visually depicted. While it is clear that differences in food accessibility within urban areas contribute to positive or negative health outcomes, our results show that it is unclear how at-risk areas should best be identified through accessibility modelling. We have used three different approaches to model food accessibility, and have shown that each of these approaches produces a significantly different map of Lansing’s nutritional terrain. Although each of our approaches is rooted in previous accessibility research (Handy and Niemeier 1997), we have found uses of only the container method in food-environment studies, and no assessment of whether this is the best method of describing or analysing food accessibility. Public officials and decision-makers rely upon maps of food accessibility in developing and implementing public-health policies, yet the cartographic implications of the geospatial analyses used to produce such maps have received very little consideration.

Geographic accessibility is a critical component to many types of food-environment research, yet most studies have employed simplistic approaches to accessibility measurement. Accessibility is determined by the spatial distribution of destinations, the costs of reaching these destinations, and the character of these destinations. Modelling accessibility requires many decisions about how to simplify geographic reality, meaning that food accessibility studies inevitably include a number of simplifying assumptions that influence cartographic outputs. Research is needed to evaluate which metrics – of all three components of accessibility – provide the most meaningful description of the environmental context of diet-related public health problems. Furthermore, as suggested by Monmonier (1991), future food-environment investigations should consider adopting a multiple-output approach, based on multiple access models and cartographic design decisions, that present a more diverse, if also more ambiguous depiction of nutritional accessibility. The dangers associated with the ‘one-map’ solutions that currently dominate food-environment investigations are particularly potent when cartographic outputs are so sensitive to input parameters, which is exactly what our results demonstrate.

We have shown that given a set of precise inputs, GISs can effectively produce high-resolution depictions of nutritional terrain. Indeed, more food-environment research should be based upon direct observations of food-environment
characteristics (Papas et al. 2007, Ford and Dzewaltowski 2008), such as the inventories of fresh produce availability we used in this research. However, our main point is that the appearance of nutritional disparities depends upon the intricacies of the accessibility modelling approach. This suggests that there is inherent uncertainty within any quantitative approach to nutritional accessibility modelling. To date this particular issue has been neglected by most studies, and future investigations should start to consider its impact on their own results.

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