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Assessment of the Retail Food Environment Using Integrated GIS and Modified Measures in Wuhan, China

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Abstract

The retail food environment (RFE) has a significant impact on people's dietary behavior and diet-related outcomes. Although RFE research has received a lot of attention, there are very few studies that shed light on the foodscape and assessment methodologies in the China context. Based on open data obtained from Dianping.com and AutoNavi map, we classified all food outlets into six types. Geographic Information Systems (GIS) techniques were employed to create two network buffer areas (1-km and 3-km) and calculate the absolute measures and relative measures (*i.e.*, *mRFEI* and *Rmix*). We modified the calculation of relative measures by adding items and assigning weights. The mean *mRFEI* using the 1-km and 3-km buffer sizes across the communities were 10.45 and 20.12, respectively, while the mean *mRmix* of the two buffer sizes were 20.97 and 58.04, indicating that residents in Wuhan have better access to fresh and nutritious food within 3-km network buffers. Residents in urban areas are more likely to be exposed to an unhealthy food environment than those in rural areas. Residents in Xinzhou and Qiaokou districts are more likely to be subjected to unfavorable neighborhood RFE. The open data-driven methods for assessing RFE in Wuhan, China may guide community-level food policy interventions and promote active living by shifting built environments to increase residents' access to healthy food.

Keywords

Retail Food Environment (RFE), Diet Quality, Geographic Information Systems (GIS), Density, Big Data

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1. Introduction

The retail food environment (RFE) refers to the physical food environment, which is an important notion for characterizing food systems and understanding neighborhood food access [1]. From a spatial perspective, RFE can be described as geographic access to different types of food outlets within a community or neighborhood [2] [3]. Numerous studies have demonstrated that RFE shapes our daily dietary behaviors and influences inhabitants' health outcomes. For example, people who reside in an area with a high availability of ultra-processed food and an absence of fruit and vegetables are more likely to become overweight [4]. Neighborhoods characterized by a growing number or a high proportion of fast-food outlets may contribute to type 2 diabetes mellitus (T2DM) [5] and hypertension [6] in residents. Access to full-service restaurants was found to be significantly associated with a lower prevalence of diabetes [7]. Researchers and policymakers recognize that assessing the food environment features is fundamental work for a more in-depth understanding of the residents' food choices and diet-related outcomes as well as further development of effective food policy interventions.

Considerable studies have been conducted on RFE, and the researchers come from a variety of fields, mainly including public health, health geography, and urban planning. They concentrated on the RFE neighborhood disparities [8] [9], the associations between RFE and diet-related outcomes [4] [5] [6] [10], food environment assessment methods [11] [12] and secondary data validity [9] [13] [14] [15] [16] [17]. These practical studies primarily from developed countries such as Canada [6] [11] [13], the United States [5] [17] [18], the United Kingdom [19] [20], and Spain [21], whereas developing countries contributed relatively limited experience and knowledge of RFE. There are significant disparities in dietary behaviors and food environments between countries with diverse cultural backgrounds, particularly in food culture.

China is a country with a diverse and unique food culture, because of its complicated cooking processes and multifarious cruises and dishes [22]. The food landscape of China is distinct from that of other countries like the United States, Italy, France, India, etc. The distinction is particularly obvious in the following three aspects: First, in terms of access to fresh and nutritious food, unlike Canadians, who typically buy meat, fruits, and vegetables at grocery stores or chain supermarkets, a sizable proportion of Chinese residents are accustomed to and capable of purchasing these items at a more comprehensive or specialized market (*i.e.*, Cai Shi Chang), where many small merchants gather to sell meats and veggies. Although food freshness is difficult to maintain in these markets due to a lack of advanced and standardized management. Second, Chinese people have many choices when dining out because there are thousands of full-service restaurants or street food (*i.e.*, Xiao Chi) with different cuisines and dishes in urban areas. Generally, Chinese food can be roughly divided into eight regional cuisines [23], including Guangdong/Cantonese (Yuè cài), Sichuan (Chuān cài), Jiangsu (Sū cài), Zhejiang (Zhè cài), Fujian (Mǐn cài), Hunan (Xiāng cài), Anhui

(Huī cài), Shandong (Lǔ cài) cuisine. Because of differences in cooking methods and ingredients, the energy and nutrient content of each dish varies significantly. A close study [24] on the energy and nutrient content of dishes in the eight cuisines revealed that Sichuan cuisine has the highest fat content due to the heavy use of salt and oil, as well as the cooking tradition of using animal fat and viscera, whereas Fujian cuisine makes good use of cooking to achieve a fresh and refreshing taste, so Fujian cuisine is relatively light and the fat content is much lower than other cuisines, with nearly 60% of dishes categorized as the low-fat. People in Zhejiang province prefer pickled foods and enjoy the aromatic fragrance of soy sauce, so the sodium content of Zhejiang cuisine is relatively high, which is thought to contribute to hypertension. Furthermore, due to population mobility and differences in eating habits, restaurants in a Chinese city tend to diversify, exposing residents to a more complex food environment. As a result, when assessing the health of China's food environment, we should not just simply designate full-service restaurants as "moderately healthy food outlets" (*i.e.* both healthy and unhealthy food outlets). Third, there are many specialty food stores (e.g., bubble tea shops, dessert shops, snack shops, tonic shops, etc.) in Chinese cities, which are also important sources of food for residents' daily diets. However, the nutrient content of the food served by these outlets varies greatly; for example, bubble tea and dessert shops serve high-calorie food, which is more likely to contribute to obesity and diabetes. Previous studies did not account for specialized food stores in their food environment assessment models, which undoubtedly influenced the accuracy of the assessment results. In a nutshell, given the diversity and complexity of China's food environment, it is required to develop a more precise food classification standard as well as effective assessment methodologies for RFE in the Chinese context.

Over 500 food environment assessment methods have been developed and applied to relevant empirical research during the last few decades. However, there is little consistency (no "gold standard") in terms of method validity [1]. Aside from subjective measures, there are two mainstream objective measures for assessing RFE. The first mainstream is known as "in-outlet examinations", and it assesses the consumers' nutrition environment [25], which includes factors such as food availability, quality, affordability, and variety. The second one is a GIS- derived (geographic information system) method that measures the geographic access to various types of retail food sources including restaurants and food stores [2] [9] [20]. Fieldwork data (*i.e.*, ground-truthing data, land use, and parcel data, licensing data from governments (official data), commercial company data, and open data (such as OSM data) are typically utilized in these measures. This approach has the advantage of taking geographical equality and residents' purchasing behavior into consideration, and it has been widely used by many health geographers and urban planners who wish to promote healthy food equity for vulnerable groups.

The purpose of this study is to build a framework for assessing RFE in the Chinese context. This research proposes to reclassify Chinese retail food outlets

using open food outlet data gathered from Dianping.com and AutoNavi map. Then, we strive to improve existing assessment methods by incorporating weights related to the health level of various types of food outlets and restaurant cuisines into our modified models. Using Wuhan as an example, we will investigate residents' exposure to unhealthy food and geographical equality of access to healthy food. Our study contributes to establishing a classification criterion suited for retail food outlets, which may provide experiences for assessing RFE in other Chinese cities. In addition, we presented a modified relative density metric (*i.e.*, *mRmix*) for RFE assessment. The methods and findings of this study will help to more accurately assess RFE, design community-level food policies and initiatives, and support healthy eating in urban neighborhoods.

2. Study Area and Data

2.1. Study Area

Wuhan is the capital of Hubei province and an important pivot city for the region [26]. Wuhan is a national center city of China, with a population of roughly 13.74 million at the end of 2022. As shown in Figure 1, Wuhan is composed of

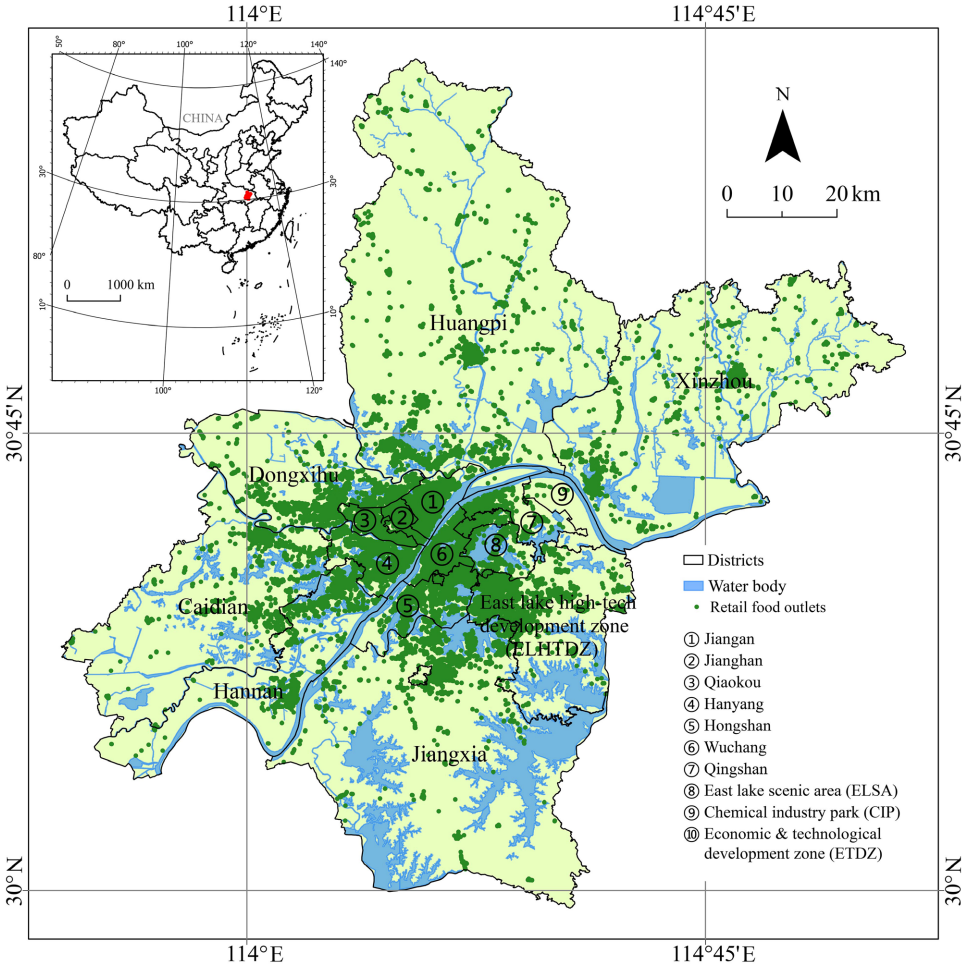

Figure 1. Study area; retail food outlets distributions in Wuhan, China.

17 administrative districts, including 7 central urban districts, 6 new urban districts, and 4 development zones. Wuhan has a multi-ethnic and multicultural society, which is reflected in its enthralling foodscape. Wuhan's cuisine is influenced by culinary traditions from all over the country, thousands of immigrants from different places and ethnic groups have resulted in a diverse foodscape and rich tapestry of food cultures. Therefore, it offers an excellent case study to explore China's food environment.

2.2. Food Outlet Data and Classification

Data about food outlets were collected from Dianping (https://www.dianping.com) and AutoNavi map (https://mobile.amap.com/), and the data was accessed on September 1st, 2022. Dianping.com mainly provides full-service restaurants, fast-food outlets, and street food (*Xiao Chi*) outlets data. Dianping.com is a crowd-sourced local business review and social networking site, which gives detailed information including ID, name, outlet types (including primary-secondary-and tertiary-class), address, and converted geographical coordinates. The primary class of all food outlets is categorized as "delicacy (*Mei Shi*)", the secondary-class characterizes the cuisines and flavors of each food outlet, and the tertiary-class describes the detailed information of each outlet such as dishes, and food menus. To address the issue of data incompleteness, we obtained the point-of-interest (POI) data from the AutoNavi map using Python web crawling as supplemental data. The POI data mainly provides food outlets including supermarkets and convenience stores. Finally, the food outlet data for RFE assessment was generated by merging these two data sources.

To determine whether the food served by each food outlet is healthy or unhealthy, we categorize Chinese retail food outlets into the following categories: chain supermarkets, convenience stores, fruit and vegetable markets, fast-food outlets, full-service restaurants, and specialty food stores by referring to the classification standard from the North American Industry Classification System (NAICS) [6]. In total, 6 retail food outlet types with 67 subclasses were identified. **Table 1** presents the six outlet types, and **Appendix A** lists the 67 subclasses. Supermarkets and convenience stores were identified using the AutoNavi POI data based on the tags containing text such as "supermarket (*Chao Shi*)", "convenience store (*Bian Li Dian*)", and "large general market (*Zong He Shi Chang*)". Fast-food outlets, restaurants, and specialty food stores were extracted from Dianping.com. Fast-food outlets were identified based on the secondary-class with tags including "fast food (*Kuai Can*)" and "street food (*Xiao Chi*)". Unlike full-service restaurants, which can provide residents with a wide variety of cooked items, specialty food stores sell only one type of food. Generally, specialty food stores include several outlet types such as bakeries, crayfish stores, dessert shops, dried fruit and nuts stores, pickled & braised food stores, snack stores, and tonic shops. Full-service restaurants, in particular, were reclassified into several classes based on the categories of regional cuisines in China. Considering the overall energy and nutrients vary significantly between Chinese cuisines

Table 1. Classifications of retail food outlets in Wuhan, China.

Category	Definition	Weights
Chain supermarkets	Stores that primarily sell a variety of fresh and prepared food products, have multiple locations and are owned by large retail companies	1
Convenience stores	Stores located at a place with convenient transportation that primarily sells convenience goods and food products that are already prepared and packaged	1
Fast-food outlets	Eating places that sell pre-prepared or quickly prepared food at a counter that is likely highly processed	1
Fruit & vegetable	Stores that primarily sell fresh fruits and vegetables	1
Full-service restaurants	Eating places where patrons typically order from a waiter, can be seated for dine-in and pay after eating	0 - 1
Specialty food stores	Eating places that typically sell pre-prepared or quickly prepared food at a counter, are not fast food outlets	0 - 1

[24], we also assigned weights (ranging from 0 to 1) to our calculation of RFE measures. The detailed classifications and weights assignments are listed in a table in **Appendix A**.

3. Methods

3.1. Geographic Access to Food Outlets

The RFE measures were calculated using Service Area Analyst in ArcGIS Pro (version 3.0.1, ESRI) to create road network buffers around the centroid of all 3493 neighborhood communities (*Shequ*) in Wuhan, China. *Shequ* is a China-specific concept that refers to the smallest standard geographic unit [27]. Considering residents' modes of transportation (e.g., by foot and by vehicles), two network buffer sizes (*i.e.*, 1-km and 3-km) were computed from the centroid of each *Shequ* (an example is shown in **Figure 2**). The 1-km buffers were used to hypothesize that residents take an approximate 10- and 15-minute walk from the centroid to access food outlets [28]. The 3-km buffers capture how people access food in relatively remote areas where people are more likely to drive to food outlets [9].

3.2. Modified Food Environment Measures

All food outlets were spatially joined to the two buffers, and the number of different types of food outlets in each buffer area was counted. By referring to the widely used assessment methods, two intensity measures (*i.e.*, absolute density and relative density) were employed to evaluate the RFE (the equations are shown in **Table 2**). The absolute measure calculates the number of each food outlet type that fell within a buffer and divides the total area of the buffer. The relative measure includes two metrics: the modified retail food environment index (*mRFEI*) and the fast-food restaurant mix (*Rmix*). The *mRFEI* calculates the

Table 2. Modified measures for China-specific retail food environment.

Measures	Definitions and equations
Absolute density	$\text{Density}_{\text{type}} = \dfrac{\text{Count}_{\text{type}}}{\text{km}^2}$
Relative densities	1) The modified retail food environment index (*mRFEI*): $mRFEI = \dfrac{\text{chain supermarkets \& grocery stores} + \text{fruit and vegetable markets}}{\text{chain supermarkets} \mid \text{grocery stores} + \text{fruit and vegetable markets} + \text{fast-food outlets} + \text{convenience stores} + \text{specialty stores}} \times 100\%$ 2) The weighted fast-food and restaurant mix (*mRmix*): $mRmix = \dfrac{\text{fast-food outlets} + \sum_i \left(W_i * \text{full-service restaurants}_i\right) + \sum_j \left(W_j * \text{specialty stores}_j\right)}{\text{fast-food outlets} + \text{full-service restaurants} + \text{specialty stores}} \times 100\%$ where, i, j refers to the type of full-service restaurants and specialty stores, respectively; W_i and W_j is the weight of restaurant type i and specialty stores type j, respectively.

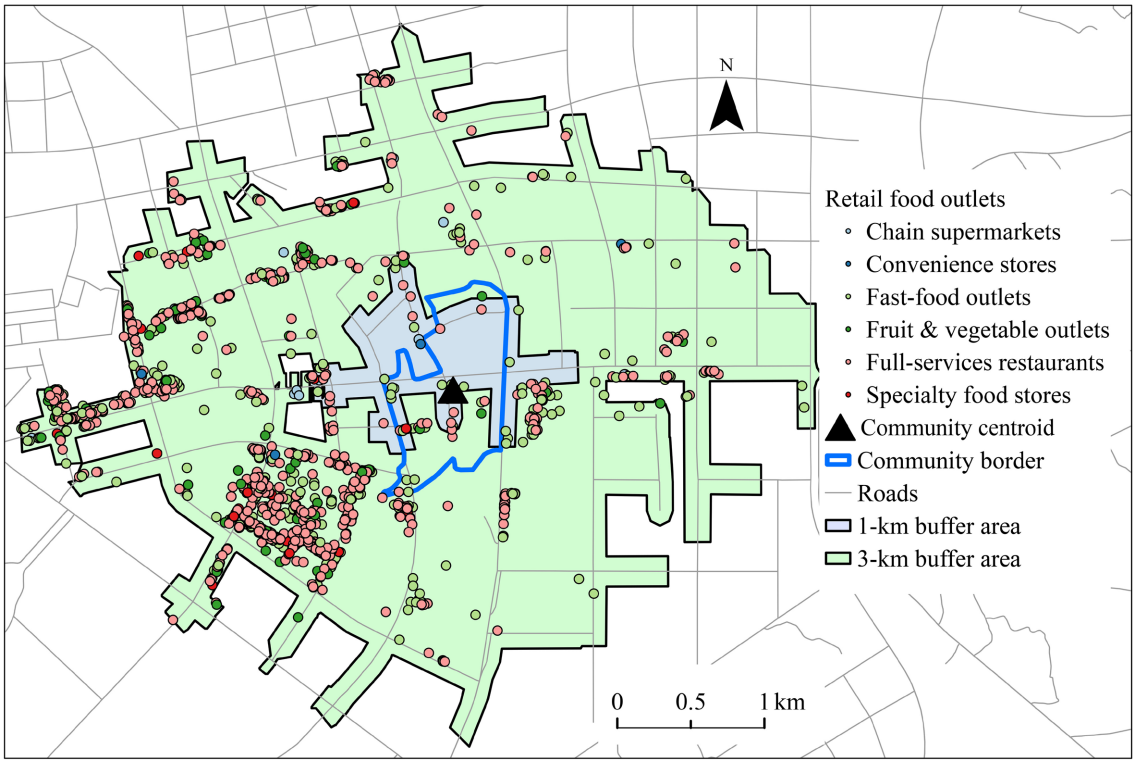

Figure 2. Example of the 1-km and 3-km buffer areas around the centroid of a community.

proportion of outlets that provide a wide range of fresh and nutritious foods within each buffer. We include specialty stores in the denominator in our modified version. The original *Rmix* calculates the proportion of fast-food restaurants relative to fast-food and full-service restaurants within each buffer. However, because regional cuisines and dishes differ significantly in terms of energy and nutrients (*i.e.*, the degree of nutrition), we modified the calculation of *Rmix* by categorizing full-service restaurants and assigning weights to their subtypes. As a result, a weighted measure (*mRmix*) is also presented in Table 2.

4. Results

4.1. Classification Results and Statistics of Absolute and Relative Densities

The catering business in China is now making record-breaking amounts of money because to the rising economic level. By the end of 2019, there were over 9 million retail food outlets in China, with full-service restaurants having the most (7118,058) and fast-food outlets having the second-highest number (1,827,908), per data from iiMedia Research (https://data.iimedia.cn). In China, the *mRmix* value is 19.450.

As for RFO at Wuhan level, all food outlets were classified using the methods described in Section 2.2. Figure 3 depicts the proportions of different types of food retail outlets in Wuhan. According to statistics, Wuhan has 2869 chain supermarkets (2%), 3277 convenience stores (2%), 64,866 fast-food outlets (38%), 12,232 fruit and vegetable markets (7%), 73,234 full-service restaurants (43%), and 14,850 specialty food stores (8%). Among the specialty food stores, 34% are bakeries, 13% are crayfish stores, 10% are dessert shops, 6% are dried fruit and nuts stores, 17% are pickled & braised food stores, 13% are snack shops, and 7% are tonic shops.

As shown in Table 3, 12 absolute density measures and two relative density measures (*mRFEI* and *mRmix*) were derived inside 1-km and 3-km network buffers surrounding 3493 community centroids. According to statistics, full-service restaurants and fast-food outlets have the largest absolute density. Each community's buffer zone contains an average of approximately 100 full-service restaurants and fast-food outlets. The high density of fast food outlets reflects China's fast-paced consumption pattern as well as the people's long-term unhealthy lifestyle. Fruit & vegetable density is 20.982 per 1-kilometer buffer and 18.002 per 3-kilometer buffer. Inhabitants of Wuhan have easy access to fresh fruits and vegetables. While chain supermarkets have the lowest absolute density of the five major categories (4.352 of 1-km buffer and 3.695 of 3-km buffer). This could be attributed to chain supermarkets' high operating costs and extensive service offerings. In terms of subcategories under the specialty food outlets, bakery has the

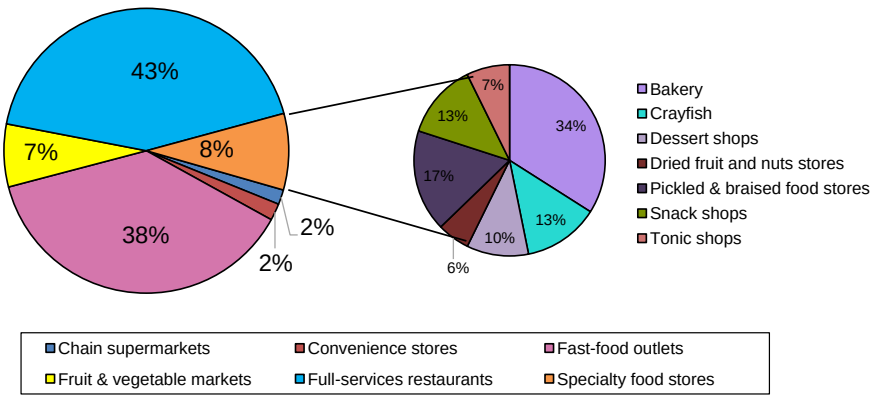

Figure 3. Classification results of retail food outlets in Wuhan, China.

Table 3. Absolute and relative densities of food outlets in Wuhan, China.

Measures	Outlet type	Buffer size	
		1-km	3-km
Absolute densities	Chain supermarket	4.352	3.695
	Convenience store	6.734	5.504
	Fast-food outlet	115.924	98.305
	Fruit & vegetable market	20.982	18.002
	Full-service restaurant	125.740	109.043
	Specialty food store		
	Bakery	9.671	8.503
	Crayfish store	3.949	3.419
	Dessert shop	3.664	3.307
	Dried fruit and nuts store	1.923	1.599
	Pickled & braised food store	4.416	3.765
	Snack shop	3.615	3.002
	Tonic shop	1.724	1.536
Relative densities	*mREFI*	10.449	20.194
	mRmix	20.967	58.045

highest density, while tonic shops have the lowest. Bakeries are popular among residents due to their ease and freshness. In recent years, an increasing number of bakeries have sprouted up in Wuhan. It is worth mentioning that the absolute densities of one kilometer are slightly higher than those of three kilometers. That implies that there is a higher density of food outlets within walking distance than driving distance, and Wuhan residents can easily reach there on foot. All of these indicators show that Wuhan has a convenient and diverse food environment.

The mean *mRFEI* utilizing the 1-km buffer size across Wuhan is 10.449, indicating that approximately 10% of food outlets deliver fresh and healthy food on average. The mean *mRmix* in Wuhan using the 1-km buffer size is 20.967, implying that fast-food restaurants account for one-fifth of all food enterprises on average. This demonstrates that walking exposes people in Wuhan to fewer fresh and healthful items as well as unhealthy fast foods. However, things changed when the buffer size is increased to 3 kilometers. The mean *mRFEI* utilizing the 3-km buffer size climbs to 20.194 over Wuhan, while the mean *mRmix* rises substantially to 58.045. That is when consumers have increased access to fresh and nutritious foods by driving, they are also exposed to far more unhealthy fast foods (almost 60% are fast-food outlets). Meanwhile, it can be found by comparison that Wuhan's *mRmix_1km* (20.967) and *mRmix_3km* (58.054) are higher than the *mRmix* of China (19.450). As a central city in China, Wuhan has a thriving economy, a quick pace of life, and a high demand for fast food. As a result, more fast food restaurants are located in Wuhan, which makes the *mRmix*

of Wuhan higher than the average level in China. And this also indicates an unhealthy food environment in Wuhan.

4.2. Kernel Density of Absolute and Relative Densities

In this section, we used Kernel Density Estimation (KDE) to build curves of two relative densities to show the food environmental health level in Wuhan. A total of 3493 communities were involved. As shown in Figure 4, the peaks of *mRFEI*_1km and *mRmix*_1km are close to 0, while the main peaks of *mRFEI*_3km and *mRmix*_3km both migrate to the right. The primary peak migration of *mRmix*_3km is the largest (near 80), indicating that the likelihood of consumers encountering fast-food outlets within driving distance is considerably increased. This might be due to the fact that fast food outlets are more concentrated in Wuhan communities' border regions than in their local communities' centers, making it difficult for the 1-km buffer zone to completely cover their concentration area. As a result, the 3-km buffer zone has a higher density of fast-food outlets. In terms of the peak height of the main peak, the peak height of the nuclear density curves of *mRFEI*_1km and *mRmix*_1km is higher than that of *mRFEI*_3km and *mRmix*_3km, indicating that as buffer size increased, the difference in community relative density distribution of fresh and nutritious food outlets and fast food outlets expanded. Each KDE curve is a non-standard bell curve. The *mRmix* KDE curve shows a coexistence of a main peak and a secondary peak, indicating that the relative density distribution of fresh and nutritious food outlets is polarized. The *mRFEI* curve shows a primary peak and many sub-peaks that coexist, showing that the relative density distribution of fresh and nutritious food outlets exhibits multi-polar differentiation properties. In contrast to the *mRmix* value,

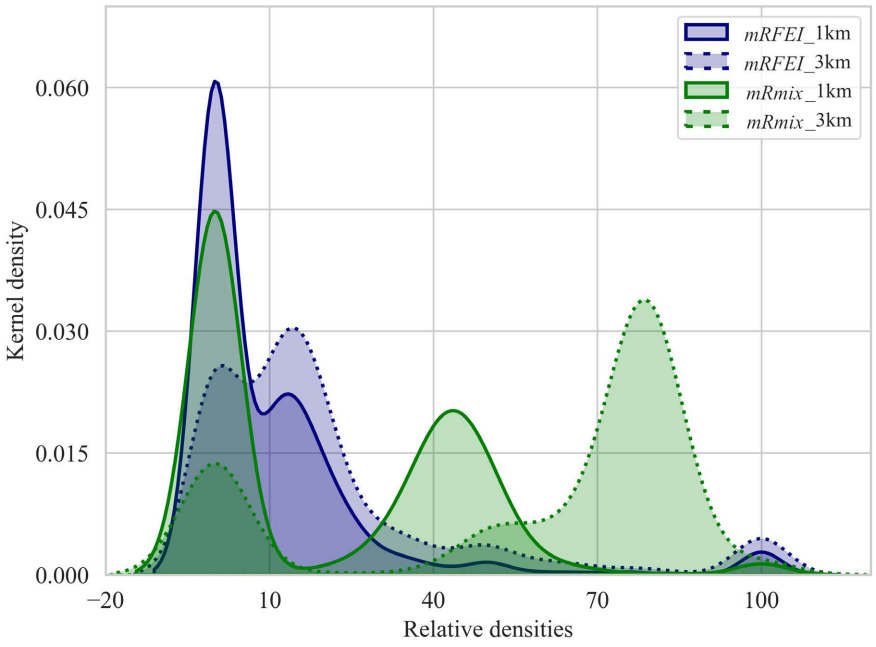

Figure 4. Kernel density estimates of the two relative densities using 1-km and 3-km buffer size.

which is mostly concentrated in two intervals, the *mRFEI* value of various communities is concentrated in many intervals, indicating that the relative density distribution of fresh and nutritious food outlets is more complex. This is due to the fact that fast-food outlets frequently consider economic benefits when deciding where to place themselves and are often located in economically developed and densely populated areas. Therefore, *mRmix* values of different locations are polarized according to the degree of economic development. As for the locations of fresh and nutritious food outlets, they are affected by both economic benefits and government planning, which results in relatively complicated *mRFEI* values throughout communities (In China, commercial service facilities such as Fruit & vegetable markets are included in the government's unified plan). In summary, compared with the *mRFEI* curve, which is concentrated near 0, the *mRmix* curve is more concentrated in the high-value area, and therefore the food environment in Wuhan presents an unhealthy trend.

4.3. Spatial Differences of Food Environment at Multiple-Scale Areas

The spatial distribution of *mRFEI* and *mRmix* in Wuhan at the community level reveals that two high-value areas of relative density are primarily distributed in the city's central region (including Jiangan, Jianghan, Qiaokou, Hanyang, Wuchang, Qingshan, and Hongshan district) and along the main transportation corridor (see **Figure 5**). These areas have developed transportation, a thriving economy, a dense population, and a high demand for catering, and thus a concentration of food outlets gather here. The contradiction between people's desire for a healthy lifestyle and short mealtimes has resulted in relatively high *mRFEI* and *mRmix* in this region (about 20 for *mRFEI* and 70 for *mRmix*). It is important to note that relative densities using 3-km are typically substantially greater than those using 1-km, meaning that consumers may access more fast-food restaurants and outlets for fresh and nutritious food by driving than by walking. More than half of the communities' mRmix_3km in Wuhan reaches 70 or higher, and the prevalence of high-calorie, high-fat, and high-sodium catering has had a major negative impact on Wuhan's efforts to create a healthy food environment. In addition, communities with high mRFEI_3km are scattered in the periphery of Wuhan (different from the other three figures). This is mostly owing to the proximity of these areas to the production of fresh and nutritious foods such as fruits and vegetables; therefore, there are more sales sites to minimize transportation expenses.

As shown in **Figure 6**, the average relative density of each district is estimated based on Wuhan's administrative divisions. For the same buffer size, each region's *mRmix* values are bigger than its *mRFEI* values. The greatest mRFEI_1km scores are obtained by Jiangan, Hanyang, and Wuchang, while the lowest scores are obtained by Hannan, Huangpi, and CIP. The highest mRFEI_3km scores are found in Qiaokou, Hanyang, and Wuchang, while the lowest scores are found in Jiangxia, Huangpi, and CIP. When it comes to *mRmix*, Xinzhou, ELHTDZ, and

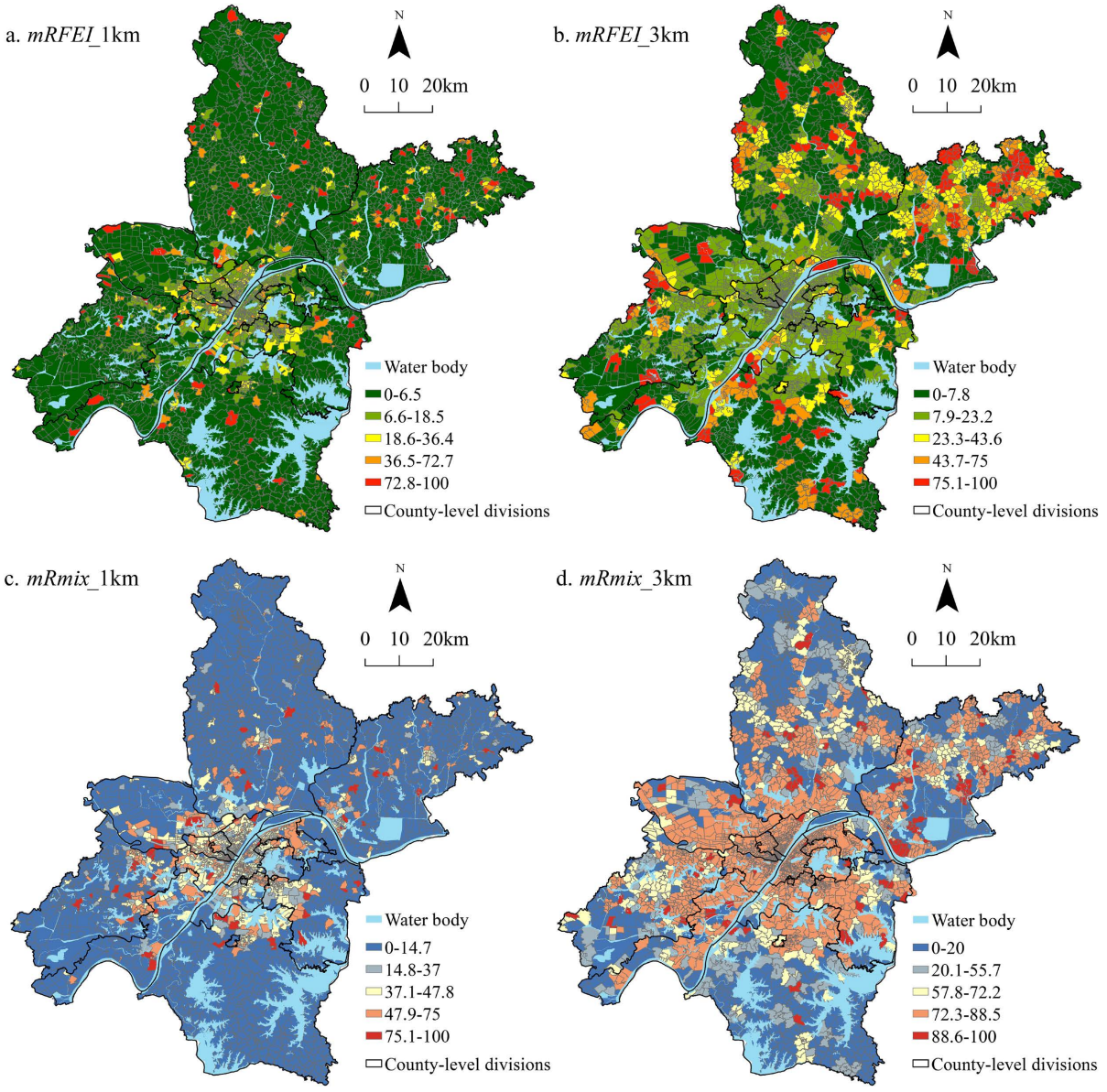

Figure 5. Spatial distribution of the two relative densities using 1-km and 3-km buffer size.

Jiangxia have the highest mRmix_1km ratings, while ELSA, Qiaokou, and ETDZ have the lowest. Qiaokou, Wuchang, and Jianghan have the highest mRFEI_3km values, while Hannan, CIP, and Jiangxia have the lowest. mRmix_3km in Qiaokou, Wuchang, Jiangan, Qingshan, Hanyang, Hongshan, ETDZ, and ELSA remains high (above 70 in each district, significantly higher than the national average of 58.045). CIP has a significantly lower *mREFI* than other districts, and citizens there have restricted access to fresh and healthy food, which should be rectified by the government. Furthermore, Jiangxia's mRmix_1km is relatively high in many communities, although the mRmix_3km is relatively low. Similarly, across regions, Qiaokou has a comparatively low mRmix_1km and a relatively high mRmix_3km. Different modes of mobility can be seen to have a substantial impact on fast food accessibility.

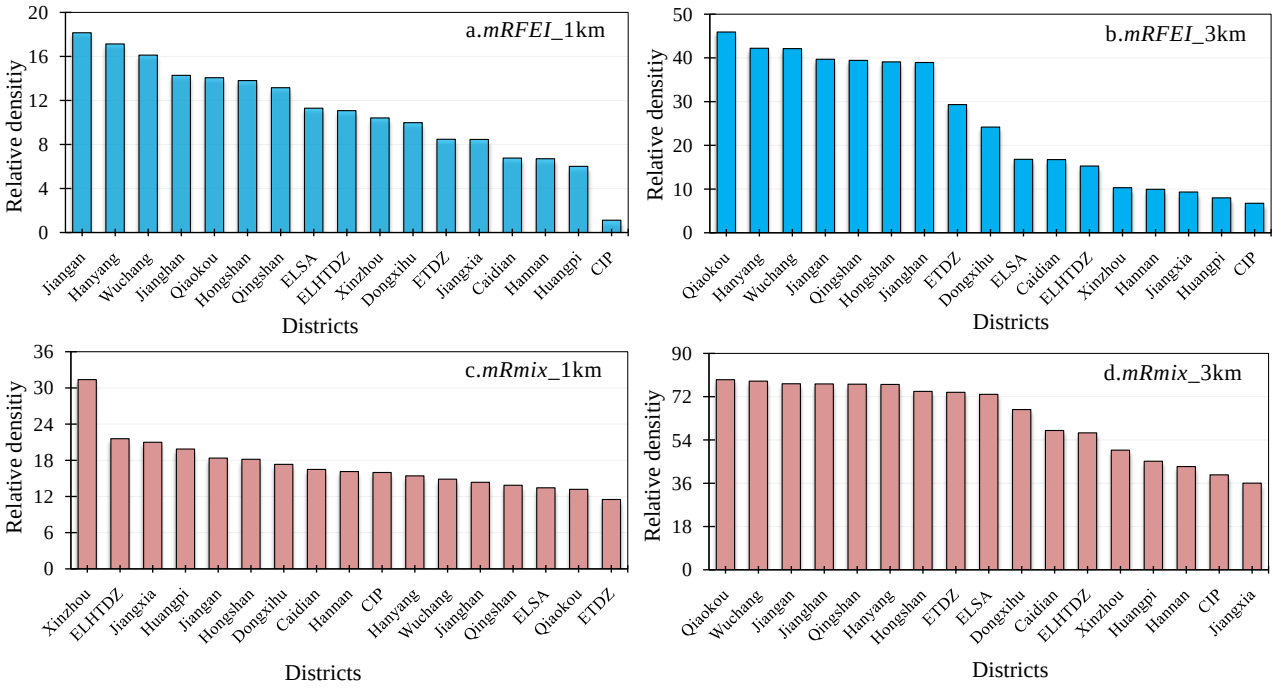

Figure 6. The mean value of the two relative densities of retail food environment index scores using the 1-km and 3-km buffer size around each community area.

A further examination of Figure 5 and Figure 6 reveals that the northern part of the Huangpi district and the southwestern part of the Caidian district are "food deserts" (with low *mREFI* and high *mRmix*), an area where residents lack access to healthy foods. People in these areas have limited access to fresh and nutritious food, but they have easy access to fast food. This is associated with complex geographic and socioeconomic factors, as well as with poor diet, and can cause health disorders such as obesity and diabetes.

5. Conclusions and Discussions

In this article, we used open data and modified assessment methods to build a framework for assessing RFE in the Chinese context, taking Wuhan as an example. We conclude that: 1) We have effectively created more accurate food classification standards and effective assessment techniques for China's RFE. 2) Full-service restaurants and Fast-food outlets have the highest density of any absolute density, with an average of nearly 100 full-service restaurants and fast-food outlets in each community's buffer area. This high density of fast food restaurants reflects China's fast-paced consumption pattern and people's long-term sub-healthy lifestyle. 3) In contrast to the *mRFEI* KDE curve, which is concentrated near zero, the *mRmix* KDE curve is more concentrated in the high-value area, indicating that the food environment in Wuhan is unhealthy. 4) The Wuhan city's central areas (including Jiang'an, Jianghan, Qiaokou, Hanyang, Wuchang, Qingshan, and Hongshan districts) and the main transportation corridor have two high-value zones of relative densities (*mREFI* and *mRmix*). 5) Food deserts do exist in the

northern part of the Huangpi district and the southwestern part of the Caidian district. People in this neighborhood have limited access to fresh and nutritious food, yet fast food is readily available. The findings of this study can be utilized to develop community-level food policies and initiatives, as well as to promote healthy eating in urban environments.

The findings from our study may provide valuable policy implications for public health policymakers to improve Wuhan residents' access to fresh and nitrous food. Meanwhile, this study has two strengths. First, we built a framework for assessing neighborhood food environments in the Chinese context utilizing open data and GIS techniques. Unlike some developed countries, such as Canada, the United States has a variety of data sources, both official and unofficial (commercial), for food environment assessment research. To the best of our knowledge, there are "gold standard" data sources (*i.e.*, data obtained from the governments) for food environment assessment research in China. For this reason, this study explored the methodology of RFE assessments using open data and improved the original models. Second, we highlighted the importance of reclassifying food outlet types because the initial classifications are not suitable for a more diverse Chinese foodscape.

However, this study also has three limitations, which are as follows. The first is that the validity of open data for RFE assessment needs further verified. Although Dianping.com is the most popular website/app for crowd-sourced reviews about businesses, the completeness of this data source had not been investigated in the existing study. This could be due to a lack of "gold standard" data to compare during the verification process. Second, relying solely on geographic data is limiting [29] [30], comprehensively assessing a neighborhood requires examining individual and social restrictions, such as physical disability, family income, and lack of access to a vehicle or transit [1]. Third, in this study, we did not consider the digital food environment. With the prevalence of e-commerce, an increasing number of Chinese people can get a variety of food via food delivery platforms such as Meituan, Pingduoduo, and Ele.me. Distance is no longer a major barrier to food access. As a result, the edges of buffers (*i.e.*, the accessible regions) are becoming inexplicit, and the assessment methods for the food environment need further explored. In recent years, many scholars have argued that the digital food environment should receive more attention in future research [31] [32] [33] [34] [35] focusing on topics such as the data acquisition and validation, digital food environment assessment methods, and health interventions by digital means.

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Authors' Contributions

Yitian Liu: Conceptualization; Data curation; Formal analysis; Writing-original

draft. **Guangping Chen:** Conceptualization; Data analysis; Funding acquisition; Methodology; Project administration; Supervision; Writing-review & editing.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Appendix A

Detailed classifications of food outlets and weights assignments for RFE assessment using Dianping.com and POI data

Category			Definition	Weights
Primary class	Secondary class	Tertiary class		
Chain supermarkets	Supermarket		Stores that primarily sell a variety of fresh and prepared food products, have multiple locations and are owned by large retail companies	1
	Mall			1
Convenience stores	Convenience store		Stores located at a place with convenient transportation that primarily sells convenience goods and food products that are already prepared and packaged	1
Fast-food outlets	Snack fast food		Eating places that sell pre-prepared or quickly prepared food at a counter that is likely highly processed	1
Fruit & vegetable	Fresh fruit		Stores that primarily sell fresh fruits and vegetables	1
	Integrated market			1
Full-service restaurants	Noodle shop		Eating places where patrons typically order from a waiter, can be seated for dine-in and pay after eating	0.2
	Ben Bang Jiangsu and Zhejiang cuisine			0.2
	Guangdong cuisine			0.4
	Home cooking			0.5
	Fish and seafood			0.2
	Hot pot			1
	Barbecue kebabs			1
	Marinated duck neck			1
	Roast meat			1
	Sichuan cuisine			0.8
	Hunan cuisine			0.6
	Hubei cuisine			0.5
	Northeastern Chinese cuisine			0.5
	Xinjiang cuisine			0.5
	Private house cuisine			0.5
	special cuisine			0.5
	Creative dishes			0.5
	Korean cuisine			0.5
	Other cuisines	Vegetarian diet		0.1
		Other Chinese food		0.5
		others		0.5
	More regional dishes	Hokkien cuisine		0.8

Continued

		Guizhou cuisine		0.6
		Anhui cuisine		0.6
		Jiangxi cuisine		0.6
		Shandong cuisine		0.4
		Inner Mongolian dishes		0.6
		Shanxi cuisine		0.5
		Northwest Chinese folk cuisine		0.5
		Yunnan cuisine		0.5
	Beijing cuisine	Roast duck		0.8
		Beijing cuisine		0.5
		others		0.5
	Southeast Asian food	Vietnamese cuisine		0.4
		Indian food		0.4
		Singaporean food		0.2
		Thai food		0.4
		Nanyang Chinese food		0.4
	Japanese cuisine	Sushi		0.4
		Teppanyaki		0.8
		Japanese barbecue/roasts		1
		Japanese noodles		0.4
		Japanese hot pot		0.6
		Japanese cuisine		0.4
		Japanese buffet		0.5
	Western food	Light salad		0.1
		Steak		0.4
		Pizza		0.8
	Buffet			0.5
	Middle eastern dishes			0.5
Others	Bakery		Eating places that typically sell pre-prepared or quickly prepared food at a counter, are not fast food outlets	0.6
	Dessert shops			1
	Snack shops			0.8
	Pickled & braised food store			1
	Dried fruit and nuts store			0.2
	Tonic shops			0.1
	Crayfish			0.8