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Spatial Disparity of Neighborhood Food Environment by Socioeconomic Status: Application of Urban Network Analysis

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Abstract: There is a large amount of academic research to date on food environments that has been widely conducted in Western countries. This is due to the high population density of Asian megacities, the advancement of public transportation systems, and the relatively low dependence on private vehicles, which has led to a lack of attention, relatively, to the surrounding food environments. Thus, this study aimed to analyze food environments at the neighborhood level by considering demographics, households, land use, and physical environmental factors in Seoul, South Korea. We employed urban network analysis methods to assess food access and availability in various neighborhoods. The primary findings indicate that Seoul's food environment is significantly related to the elderly population, aging infrastructure, and proximity to public transportation. In particular, a higher concentration of elderly residents negatively affects food availability and access, irrespective of income level, potentially exacerbating social inequality based on income. Our findings identify various factors that contribute to spatial disparities in local food environments and provide policy implications to mitigate inequalities in neighborhood food environments.

Keywords: neighborhood built environment; food environment; food accessibility; food availability

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1. Introduction

The local urban food environment is a significant contributing factor to human health. It encompasses neighborhood communities, individual homes, and grocery and convenience stores, and is considered one of the driving factors in the formation of healthy eating habits to combat obesity and various adult diseases [1], There has been considerable research on the impact of the food environment on residents' health [2–6].

According to a recent report released by Statistics Korea, the nation's food price growth rate is more than three times the OECD average [7]. As of July 2020, food rose 2.8 percent year on year relative to the living price index, and the fresh food index (fresh fish, fresh vegetables, fresh fruits, etc.) was reported to have soared 8.4 percent year on year. Rising food prices can not only negatively affect households but also cause national problems for some low-income people, including increased welfare costs [8,9].

In this regard, low-income older adults have difficulty purchasing food nearby, which has become a social issue in Japan, which has a similar urban structure to South Korea. Unlike in Western countries, the food access issue in Japan mostly affects older low-income adults who are relatively less mobile. This problem develops as the neighborhood-level fresh food stores in the city center where these older adults live gradually close down [10]. Compared to younger people, the behavioral constraints on older adults are noticeable and lead to a decrease in their mobility [11]. This decline in mobility has an adverse effect on grocery purchases and could further lead to older people becoming socially excluded [12–15].

The concept of a food desert has been actively studied in the West since it first emerged in the 1990s as a term for dwellings within public housing districts in Scotland [16]. Scholars' opinions on food deserts have been quite varied [17]. Cummins and Macintyre (2002) defined food deserts as "poor urban areas that cannot afford to buy fresh food", while other researchers interpreted them as "urban areas with fewer than 10 food stores or no more than 20 workers" [8]. On the other hand, in most studies, food deserts target poor residents who have limited mobility or access to retail outlets selling fresh food and develop when there is no grocery store within a reasonable radius for them [18–21].

In Western countries, some studies have concluded that economic level and race are factors that affect the food environment. Numerous previous studies have reported that grocery store use differs according to the economic level of the neighborhood. In terms of food safety, low-income groups more frequently use convenience stores or fast-food restaurants that serve unhealthy food [22,23]. This can be interpreted as fewer supermarkets providing fresh food in low-income residential areas than in high-income neighborhoods, so low-income residents are forced to consume unhealthy foods instead [5,24]. This result is particularly pronounced in black neighborhoods, whereas whites have wider choices and easier access to grocery stores [25,26]. It is argued that this is also related to the health of the residents: the intake of fresh fruits and vegetables among blacks increases as they live closer to a supermarket, which helps to lower the obesity rate—an underlying cause of various diseases [27,28].

However, in evaluating a neighborhood food environment, it is difficult to apply Western standards to Asian countries due to physical and social differences, and there is a need for research that better reflects the characteristics of Asian regions with large populations and high spatial density [29,30]. Nakamura et al. [31] analyzed the correlation between food intake and accessibility among older adults (aged 65 and older) in 12 prefectures in Japan and found that there were insufficient grocery stores available in their neighborhoods, and this had negative health effects. Tani et al. [32], studied a neighborhood food environment and the mobility of older residents nearby from 2010 to 2013 and emphasized the need for a neighborhood grocery store that was accessible (within walkable distance) for less mobile older adults.

Food environment studies conducted in South Korea have shown that this phenomenon is common among poor and older residents [3,33]. Lee and Kim [33] conducted in-depth interviews with residents by selecting poor areas of Seoul and also investigated the residents' food consumption behaviors and food environments. Those researchers found that the food desertification phenomenon in South Korea is caused by the prevalence of poor and older adults and the lack of fresh food stores, because those residents cannot move far due to their limited mobility, and some of them need food delivery services from supermarkets even short distances away. Similarly, Yang and Kim [3] conducted in-depth interviews with the elderly in five neighborhoods of Mapo district in Seoul on their food purchasing behaviors and food purchasing environments. Most of the participants responded that they went to the supermarket more often than to other food sources. Others frequently mentioned important factors were a grocery delivery service and easy access within 10 min on foot. In addition, contrary to foreign studies, it was found that when subway stations are nearby, elderly low-income people in South Korea mainly use traditional markets regardless of the distance. The researchers suggested that additional domestic research is needed to better reflect differences in perception as a factor that did not appear in foreign countries.

In South Korea, which is rapidly transitioning into a super-aged society, the importance of a local food environment that accommodates the elderly is steadily rising alongside their increasing demographic share. However, comprehensive research addressing the issues related to this is still lacking. In this vein, this study aims to expand existing research by theoretically evaluating the food environment in Seoul, South Korea at the neighborhood level based on food availability and food accessibility by considering demographics, households, land use, and physical environmental factors. For this, we derived relevant variables from various public datasets from 2018 and utilized them in our analysis. Our findings can help planners and scholars recognize the significance of walkable food environments, prompting the development of tailored strategies to enhance food environments across various age demographics and mitigate food desertification.

2. Material and Methods

2.1. Study Area

This study focused on the capital city of South Korea, Seoul, which is the largest and most populous in the country (Figure 1). The area of Seoul is about 605 square kilometers with a population of 9.7 million. The Seoul region has a diverse population and a rapidly changing food environment. The spatial unit for our analysis was the census block group (*gypgaegu* in Korean), which is the smallest unit that can utilize population and housing census data, making it an appropriate unit to analyze changes in the food environment. Seoul had 19,153 census block groups in 2018, but some of the blocks were entirely composed of river and green areas, so only 16,473 census blocks were utilized here.

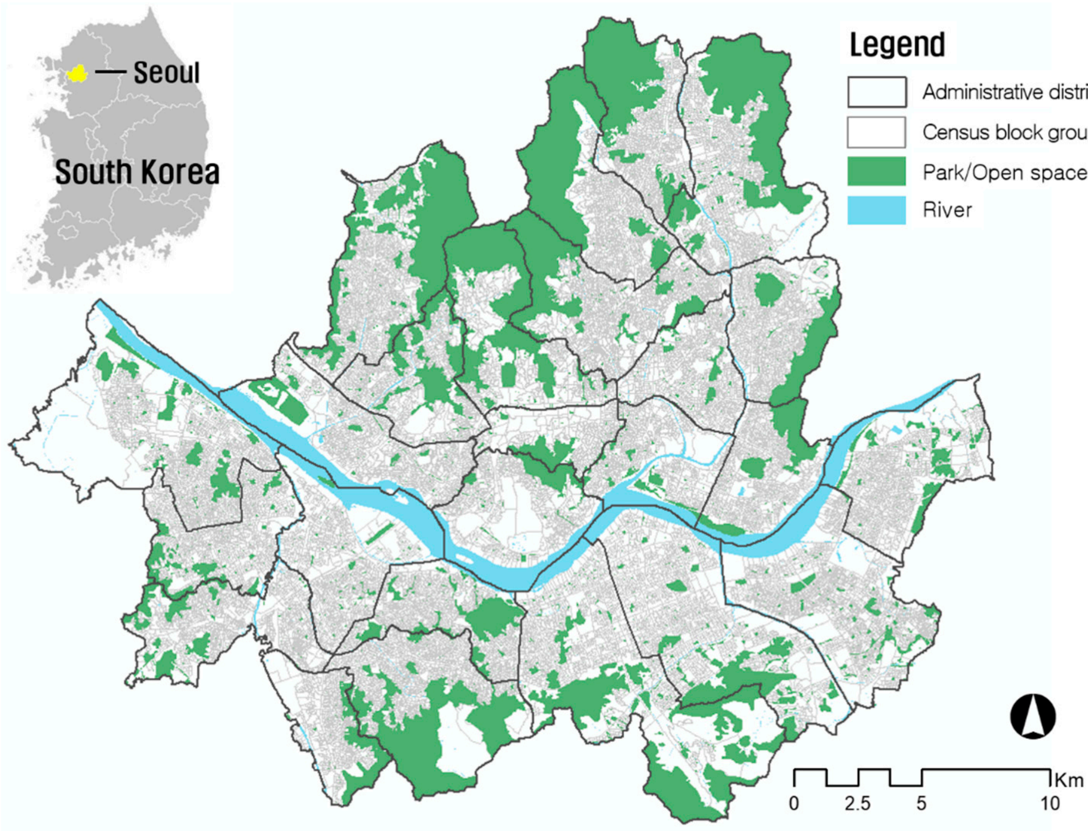

Figure 1. Study area of Seoul. Source: map by the authors.

2.2. Data Source and Variable Selection

The data used in this study can be categorized into three main types. First, data on grocery stores in Seoul in 2018 were obtained from the Small Enterprise and Market Service (SEMAS), a public data portal that provides data on commercial establishments. In this study, three types of grocery stores were used: supermarkets, traditional markets, and discount stores that sell fresh foods that are much used in daily life. In addition, convenience stores that are open 24 h a day and mainly provide convenient foods were added as a food environment variable and used in the analysis. Second, the neighborhood environment variables used as independent variables were analyzed using 2018 data provided by the Statistical Geographic Information System [34] and the Seoul Open Data Plaza [35]. Finally, the average apartment transaction price, used as a proxy for income, was based on 2018 data from the Ministry of Land, Infrastructure, and Transport.

Table 1 shows the variables and their descriptions. In this study, food availability and accessibility were used as dependent variables that applied to grocery stores in the residents' neighborhood environments. The identification of food environment has varied in previous studies, and definitions are considered differently depending on the country and region where the research was conducted. In South Korea, food environments are rapidly changing and such considerations in academia are still inadequate, so the criteria for defining these areas are based on food availability and accessibility [3,36]. This analysis used the Reach and Gravity indexes constructed in district units, as well as urban network analysis (UNA) tools for the dependent variables. In both the Reach and Gravity indexes, the higher the number, the better the availability and accessibility of grocery stores at the neighborhood level [37].

Table 1. Definition of variables.

Variables		**Definition**
Dependent variables	Food availability	Value of Reach
	Food accessibility	Value of Gravity
Demographic	Middle age (%)	40~59 years old population percentage
	Age of 70 or above (%)	Age 70 or above population percentage
	Population density	Total population/area (1000 people/km^2)
	Employment density	Total No. of workers/area (1000 people/km^2)
Residential	Multi-family houses (%)	No. of multi-family houses/total census output area houses
	Apartment (%)	No. of apartments/total census output area houses
	Other (%)	No. of other houses/total census output area houses
	Building age of 20 or above (%)	No. of buildings aged 20 or above/total census output area houses
	Building age of 10 or less (%)	No. of buildings aged 10 or less/total census output area houses
	The market price of an apartment	The market price of an apartment per 1 m^2 (*dong*)
Land use	Density of commercial area	Total floor area of commercial facility/total census output area
	Density of office area	Total floor area of office facility/total census output area
	Density of residential area	Total floor area of residential facility/total census output area
	Density of other areas	Total floor area of other facility/total census output area
	Density of green area	Total floor area of green/total census output area
	Land-use mix	Land-use mix of census output area
Accessibility	Density of intersection	No. of intersections/census output area (km^2)
	Bus stop	Bus stop within 400 m (Y/N)
	Subway station	Subway station within 400 m (Y/N)
	Senior welfare center	Senior welfare center within 400 m (Y/N)
	△ of convenience stores	Change in the number of convenience stores (2018–2015) (Y/N)

The independent variables were the demographic, residential, land-use, and accessibility factors of each census block group unit. Demographic variables included the population percentage of middle-aged people, people aged 70 or older, the population density, and the employment density. Each percentage was calculated by dividing the total number of layers across the corresponding census block unit.

The variables at the residential level were selected based on prior research and were classified into multi-family and coalition housing, apartments, and other housing types (businesses, non-residential, etc.). The building aging rate was established by utilizing housing data for each year, specifically the percentage of buildings more than 20 years old and those less than 10 years old. The average apartment price per square meter in each administrative *dong* (neighborhood, which is a larger census unit than the *gypgaegu*) was selected as the variable for the household income level and used as a proxy for income level. Based on the assumption that the average apartment price would be related to the purchase of fresh food for basic living, the final analysis model had areas with high and low incomes compared to the median apartment value of the entire administrative district of Seoul.

Finally, the variables of land use and accessibility were calculated for the total areas of commercial, business, residential, and green space, and the land-use mix. The land-use mix was calculated using the concept of entropy indicators, wherein the indicator is between 0 and 1, and the closer the value is to 1, the more uniform the mix of applications is. The density of intersections, the presence of bus stops and subway stations, and the presence of senior welfare centers were considered accessibility factors. For convenience stores, the difference in their Reach values in 2015 and 2018 reflected changes in their availability (the Reach index) over those three years. Convenience stores were added in consideration of the recent increase in the number of single-person households and the increasing demand for home meal replacement (HMR), led by convenience foods [38].

2.3. Methodology

This study analyzed the effect of the neighborhood food environment through the availability and accessibility of food in Seoul. The dependent variables used in this study were availability and accessibility (representing the neighborhood food environment), and their relationship with the neighborhood environment characteristics was assessed using the reach and gravity index indicators via UNA (see Equations (1) and (2)):

$$Reach^r[i] = \sum_{j \in G-\{i\}; d[i,\ j] \leq r} W[j] \quad (1)$$

$$Gravity^r[i] = \sum_{j \in G-\{i\}; d[i,j] \leq r} \frac{W[j]}{e^{\beta d[i,j]}} \quad (2)$$

where G is the number of destinations that are found within radius r from i, d $[i, j]$ is the shortest route (m) between origin i and destination j, β is the exponent that controls the effect of distance decay on the shortest route between i and j, and $W[j]$ is the weight of a destination j

A UNA analysis was performed by setting a network radius of 400 m from the center point of the urbanized area within each census unit—400 m is an appropriate walking distance for many older adults, set in consideration of their average walking speed based on six-minute walking tests used to evaluate their health [38,39]. Reach is an indicator of availability, representing the total number of grocery stores in the area calculated through the network radius. As already confirmed in previous studies, higher Reach value areas are associated with more available grocery stores [40].

Gravity, which indicates the accessibility to grocery stores, is directly proportional to the number of stores at the destination: as the distances to the grocery stores increase, the Gravity value is inversely proportional. In other words, if the number of reachable destinations is the same but the total distance to them is different, the Gravity value is different by the distance decay coefficient. Handy and Niemeier [41] obtained the distance decay coefficient by assigning a walking distance (meters) reference value of 0.00217.

Finally, for the average apartment transaction price, administrative *dong*-based data were used because of difficulties in obtaining data on the income level of each household. These data were used as a proxy for the household's economic level and played a role in identifying the food environments. Therefore, each neighborhood was classified as an area with an upper- or lower-income level based on the median of the data (Figure 2).

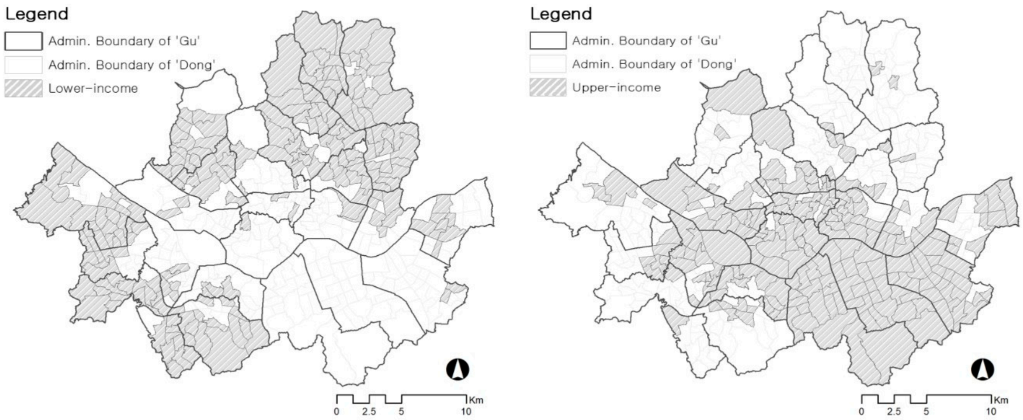

Figure 2. Lower-income (**left**) and upper-income (**right**) areas in Seoul. Source: maps by the authors.

3. Results

3.1. Descriptive Analysis Results

Table 2 shows the descriptive statistics of the variables used in this study (Table A1). It presents the basic statistics and multicollinearity between variables for each dependent variable and the factors of demographics, residence types, land uses, and accessibility. The dependent variable, grocery store availability, was found to be an average of 3.62 per census unit, which means that access to three to four grocery stores was possible within a 400 m network radius in each census unit. The highest availability of grocery stores was 26 and the lowest was 0. Likewise, the accessibility to grocery stores was an average of 2.10, and the gap between the maximum value (14.16) and the minimum value (0) was large.

Table 2. Descriptive statistics of variables.

	Variables	Obs.	Mean	S.D.	Min.	Max	VIF
Dependent variables	Food availability	16,473	3.62	2.97	0	26	-
	Food accessibility	16,473	2.10	1.72	0	14.16	-
Demographic	Middle age (%)	16,473	23.89	1.86	0	47.81	1.12
	Age of 70 or above (%)	16,473	12.53	3.03	0	45.87	1.22
	Population density	16,473	43.91	26.87	0.03	307.65	1.49
	Employment density	16,473	11.25	45.72	0	2504.43	1.13
Residential	Multi-family houses (%)	16,473	32.83	35.03	0	100	4.42
	Apartment (%)	16,473	46.58	46.73	0	100	5.89
	Other (%)	16,473	4.29	12.77	0	100	1.66
	Building age of 20 or above (%)	16,473	50.47	38.67	0	100	1.45
	Building age of 10 or less (%)	16,473	19.7	28.5	0	100	1.41
Land use	Density of commercial area	16,473	0	0.01	0	0.59	1.46
	Density of office area	16,473	0	0.02	0	0.98	1.27
	Density of residential area	16,473	0.02	0.01	0	0.35	1.18
	Density of other areas	16,473	0	0.02	0	1.42	1.21
	Density of green area	16,473	0.01	0.07	0	3.99	1.03
	Land-use mix	16,473	0.29	0.3	0	1	1.98
Accessibility	Density of intersection	16,473	23.18	66.68	0	2066.26	1.02
	Bus stop	16,473	0.99	0.11	0	1	1.06
	Subway station	16,473	0.33	0.47	0	1	1.04
	Senior welfare center	16,473	0.11	0.31	0	1	1.01
	△ of convenience store (Reach)	16,473	0.62	0.49	0	1	1.05

In all of the census blocks, the average presence of middle-aged people between 40 and 59 years old was 23.9%, and the highest percentage was 47.8%. The average proportion of the population aged 70 or older by census district was 12.5%, and the highest percentage was 45.9%. Among the variables related to the residential characteristics at the aggregate district level, the percentage of apartments was the highest at 46.6%, and that of the other housing types was 4.3%, the lowest overall, while 50.5% of the buildings were more than 20 years old and 19.7% were less than 10 years old. In the case of land-use characteristics, the average land-use mixing degrees calculated using the total floor area and green area of commercial facilities, business facilities, residential facilities, and other facilities was 0.29. Finally, regarding accessibility, the average density of intersections per census block was 0.84. The average number of bus stops within 400 m was 0.99, indicating that most district residents could reach bus stops. On the other hand, the average number of subway stations was only 0.33. The average number of welfare centers where older adults could receive welfare services within the set radius was 0.11. Finally, the positive change in convenience store availability was found to be 0.62 on average for each aggregate section, indicating that the number of convenience stores was steadily increasing.

3.2. Analysis Results

Tables 3 and 4 show the analysis results of the regression model for the total area of Seoul and both lower- and high-income levels by the median apartment market price per square meter. As expected, the neighborhood food environments were significantly associated with income level. The demographic variables of middle age, age 70 or older, and both the population and the employment densities were statistically significantly associated with food availability and accessibility. The middle-aged population percentage showed a strong positive association with the availability and accessibility of grocery stores in Seoul overall, as well as in low-income areas. The proportion of the population aged 70 or older had a negative relationship in all the regions, regardless of income level.

Table 3. Analysis results of negative binomial regression for food availability.

Variables		Seoul			Lower-Income			Upper-Income		
		Coef.		z	Coef.		z	Coef.		z
Demographic	Middle age	0.006	*	1.79	0.010	**	2.37	−0.002		−0.32
	Age of 70 or above	−0.017	***	−7.71	−0.017	***	−5.50	−0.014	***	−4.35
	Population density	0.005	***	18.40	0.005	***	13.10	0.005	***	12.57
	Employment density	0.001	***	3.85	0.001	**	2.53	0.001	***	2.98
Residential	Multi-family houses	−0.004	***	−10.63	−0.005	***	−10.54	−0.002	***	−4.77
	Apartment	−0.008	***	−27.25	−0.009	***	−20.50	−0.008	***	−18.14
	Other	0.001		1.41	0.000		−0.23	0.001		1.74
	Bldg. age of 20 or above	−0.054	**	−2.78	−0.089	***	−3.30	−0.012		−0.44
	Bldg. age of 10 or less	0.000		−0.95	0.000		0.68	−0.001	**	−2.16
Land use	Commercial	1.555	***	3.10	1.396	*	1.83	2.027	***	2.94
	Office	−0.228		−0.73	−0.322		−0.57	−0.032		−0.08
	Residential	−1.908	***	−3.30	−3.564	***	−3.34	−0.927		−1.33
	Other	−1.460	***	−4.34	−1.615	***	−3.11	−1.311	***	−2.97
	Green	−0.520	***	−4.00	−0.214		−1.59	−1.386	***	−5.04
	Land-use mix	0.143	***	5.27	0.173	***	4.76	0.089	**	2.20
Accessibility	Density of intersection	0.000		1.19	0.000	**	−2.02	0.000		−0.52
	Bus stop	1.339	***	14.83	1.431	***	11.13	1.257	***	9.92
	Subway station	0.079	***	6.14	0.064	***	3.57	0.105	***	5.65
	Senior welfare center	0.062	***	3.33	0.128	***	5.20	−0.027		−0.95
	△ of convenience store	0.344	***	27.03	0.324	***	18.86	0.365	***	19.41
Constant		0.010		0.08	−0.051		−0.28	0.000		0.61
Number of observations		16,473			8270			8203		
LR chi-squared		3310.66 ***			1678.41 ***			1657.16 ***		
Pseudo R^2		0.0427			0.0425			0.0437		
AIC		74,247.74			37,848.39			36,308.33		
BIC		74,417.35			38,002.84			36,462.61		

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 4. Analysis results of linear regression for food accessibility.

Variables		Seoul			Lower Income			Upper Income		
		Coef.		t	Coef.		t	Coef.		t
Demographic	Middle age	0.018	***	2.59	0.030	***	3.19	−0.002		−0.16
	Age of 70 or above	−0.035	***	−7.68	−0.037	***	−5.57	−0.026	***	−4.21
	Population density	0.009	***	16.44	0.010	***	11.64	0.009	***	11.66
	Employment density	0.001	***	3.11	0.001	*	1.74	0.001	***	2.79
Residential	Multi-family houses	−0.009	***	−12.59	−0.012	***	−11.40	−0.007	***	−6.77
	Apartment	−0.017	***	−26.42	−0.018	***	−19.27	−0.016	***	−18.35
	Other	0.001		0.49	−0.001		−0.42	0.001		0.67
	Bldg. age of 20 or above	−0.052		−1.36	−0.112	**	−1.98	0.009		0.18
	Bldg. age of 10 or less	0.000		0.94	0.001		1.59	0.000		−0.48
Land use	Commercial	3.146	***	3.08	2.902	*	1.82	4.398	***	3.20
	Office	−0.795		−1.26	−1.178		−0.93	−0.426		−0.59
	Residential	−4.052	***	−3.46	−7.802	***	−3.45	−2.143		−1.58
	Other	−2.516	***	−4.24	−3.013	**	−2.89	−2.218	***	−3.10
	Green	−0.757	***	−4.04	−0.505	*	−1.93	−1.058	***	−3.93
	Land-use mix	0.247	***	4.31	0.342	***	4.21	0.111		1.38
Accessibility	Density of intersection	0.000		0.85	0.001	*	1.80	0.000		−0.99
	Bus stop	1.111	***	10.12	1.489	***	8.75	0.833	***	5.85
	Subway station	0.153	***	5.70	0.122	***	3.09	0.207	***	5.70
	Senior welfare center	0.093	**	2.36	0.259	***	4.63	−0.101	*	−1.80
	△ of convenience store	0.663	***	25.80	0.665	***	17.95	0.654	***	18.47
Constant		1.223 ***		5.25	0.852 ***		2.61	1.667 ***		4.95
Number of observations		16,473			8270			8203		
F		159.06 ***			80.51 ***			79.94 ***		
R^2		0.1620			0.1633			0.1634		

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

The results of the analysis for the residential factors confirmed that the percentage of multi-family houses and apartments had a negative relationship with both the availability and accessibility of grocery stores (the higher the multi-housing percentage, the lower the availability and accessibility of stores). Residents of old buildings in low-income areas lack mobility and economic power, and their walking mobility would also be expected to decrease—all of which makes for poor food environments.

Looking at the results of the land-use characteristics, the total floor area of commercial facilities had a strong positive relationship with both the availability and accessibility of grocery stores. Both commercial floor area and land-use mix showed strong positive correlations with grocery store availability and accessibility. In contrast, residential, other, and green space square footage were negatively correlated with grocery store availability and accessibility. The only exception to these statistically significant correlations of residential areas was observed in high-income neighborhoods, where the correlation was not statistically significant. This suggests that the surrounding food environment is superior in a place where there is an appropriate mix of uses rather than a high concentration of a single use.

We found that the density of intersections is positively correlated with grocery store availability and accessibility only in low-income neighborhoods. The number of bus stops and subway stations was found to be strongly positively related to both access and availability. We also found that the presence of a nearby welfare center varied by income level, with a positive relationship in lower-income neighborhoods and a negative relationship in higher-income neighborhoods. Changes in the number of convenience stores were positively related to both food availability and accessibility.

4. Discussion

This study analyzed factors affecting neighborhood food environments in Seoul by using data related to demographics, residential types, land uses, and transportation accessibility at the census block level and further based on grocery store data. We hope that the discussion on the availability and accessibility of grocery stores, along with the policy implications and recommendations based on the analysis of this study, will serve as a reference for rethinking and improving the food environment in Seoul.

First, the findings emphasize the crucial importance of the relationship between the food environment and demographics. The analysis shows that the food environment in low-income neighborhoods, as well as in Seoul as a whole, differs between the proportion of the population aged 70 and older. Food availability and accessibility are favorable in neighborhoods where middle-aged people are expected to be economically active, while it is negative in neighborhoods with high concentrations of older people. This means that the higher the proportion of low-income seniors (which is a class that can be harmed by food insecurity in their neighborhoods), the lower the availability and accessibility to grocery stores. This suggests that the cost and time incurred by low-income seniors with low economic power and mobility will increase as they travel long distances to purchase groceries. These results align with previous studies that reported an association between older adults and food insecurity [3,15,33,42,43]. Given that prior research has shown that economic status affects food choices and intake, which in turn influences diet quality among the elderly [3,44–46], these findings could exacerbate social inequalities for the elderly. Previous research has shown that poor food environments are closely associated with high concentrations of low-income seniors and hilly areas, with low-income seniors having to travel longer distances to purchase food, which directly affects food desertification in nearby areas [47]. Additionally, the gradual decline in traditional markets, which previous studies have identified as a preferred shopping venue for the elderly, is believed to contribute to food insecurity among this demographic [9,10]. Therefore, the need for grocery stores within walking distance is important for these vulnerable populations, and services such as home-delivered food should be expanded for seniors with relatively limited mobility.

Next, our findings indicate that among residential environment variables, a higher proportion of multi-generational houses and apartments is associated with a poorer food environment. Additionally, the age of the building is significantly related to the nearby food environment. Specifically, the availability and accessibility of grocery stores decrease as buildings age. This phenomenon is observed only in low-income residential areas, suggesting that residents living in low-income multi-family housing might face a deteriorating food environment. This aligns with previous studies that have shown grocery stores gradually disappearing over time in areas with a high proportion of old buildings [10]. Meanwhile, we found that food availability in high-income areas decreases as the proportion of new buildings increases, which can be inferred as a measure of development. Considering that upper-income areas are actively developing areas close to urban centers in Seoul, the difference in food environments between lower-income and upper-income groups is likely to gradually increase. In Seoul, poor neighborhoods tend to be isolated and clustered [15], so it is necessary to provide customized food welfare services that reflect the degree of poverty by segmentation.

According to the analysis of land use, aside from office facilities, land use generally has a strong relationship with the neighborhood food environment. Notably, higher residential floor area is associated with poorer food availability and accessibility in lower-income neighborhoods, but not in high-income neighborhoods Lower-income residents are anticipated to possess lower levels of personal mobility, such as personal vehicles, in contrast to residents in higher-income neighborhoods, underscoring the need for a reevaluation of the food environment tailored to their circumstances. Our analysis shows that the land-use mix in lower-income neighborhoods has attributes that promote food availability and accessibility, which is consistent with previous research that suggests that an appropriate land-use mix promotes a healthy food environment [48,49]. Therefore, land-use plans should incorporate a suitable mix of uses to enhance the food environments in low-income neighborhoods.

Public transportation is an essential part of life in lower-income neighborhoods, where people are less likely to own a car. We found that proximity to bus and subway stations was associated with better food availability and accessibility. Since public transportation is a public good, providing daily services and infrastructure to vulnerable populations [50], it can be seen as an appropriate means to alleviate food insecurity among those aged over 65 in Seoul, who have access to discounted transportation passes. However, traveling long distances and carrying heavy luggage on public transportation for regular grocery shopping may not be a feasible solution. This suggests that the location and expansion of transit stops for vulnerable populations and the proper distribution of routes will be even more important. Convenience stores were also found to have a positive impact on the food environment for all income levels, indicating that convenience stores complement rather than replace traditional grocery stores. This contrasts with food environment studies conducted in the West [17,22,28], likely because convenience stores in Japan and South Korea sell some fresh produce and offer a wider variety of foods, such as nutritious bento boxes. Considering the current trend of more convenience stores opening in neighborhoods, our results emphasize that providing more diverse and nutritious food is important for improving the food environment.

5. Conclusions

This study contributes to the existing literature by addressing the gap in understanding of the impact of specific factors related to the neighborhood food environment in South Korea and their effects on food access and food availability. Our findings are expected to serve as a basis for improving the food environment in neighborhoods and contribute to the efficient distribution of grocery stores to socially marginalized groups. However, despite these contributions, this study has several limitations, including the following.

First, this study had limitations in identifying the economic level of individual households. Data limitations made it difficult to identify individual and household economic levels, such as the presence or absence of a car. In addition, the average apartment transaction price used as a proxy for income was too broad and did not reflect differences in economic levels within income groups.

Next, there were difficulties in confirming the actual purchasing behavior of grocery store users. While the rate of online grocery shopping among the elderly is not expected to be high, the recent growth in the online market, with its quick and convenient same-day delivery options, has led to an increase in households ordering fresh food online. This study, however, does not account for this trend, highlighting a significant limitation.

Lastly, this study did not account for topographical differences in its analysis. In the case of Seoul, the city boundary includes mountainous areas, and these topographical factors may affect the food environment. Future studies that consider various regional geographical factors are expected to be more effective in identifying food environments.

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Data Availability Statement: The data presented in this study are openly available. The datasets can be accessed through the SGIS at https://sgis.kostat.go.kr (accessed on 13 October 2020) [33] and the Seoul Open Data Plaza at https://data.seoul.go.kr (accessed on 13 October 2020) [34].

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Table A1 presents the results of descriptive statistics separately for low-income and high-income groups based on the income level proxy, the market price of an apartment per square meter. We conducted *t*-tests to assess differences in means between the groups. The results show that most variables, including the dependent variables of this study—food availability and food accessibility—were statistically significant ($p < 0.05$), indicating a mean difference between the two income groups.

Table A1. Descriptive statistics of variables by income groups and *t*-tests of mean differences between two groups.

Variables	Lower-Income Groups					Upper-Income Groups					*t*-Test of Mean Difference	
	Obs.	Mean	S.D.	Min.	Max.	Obs.	Mean	S.D.	Min.	Max.	t	*p*
Food availability	8270	3.84	3.03	0	26	8273	3.40	2.89	0	23	9.537	0.001 ***
Food accessibility	8270	2.23	1.76	0	14.46	8273	1.97	1.68	0	13.30	9.736	0.001 ***
Middle age (%)	8270	23.95	1.97	0	47.81	8273	23.83	1.72	0	38.56	4.336	0.001 ***
Age of 70 or above (%)	8270	12.53	3.01	0	45.86	8273	12.83	3.02	0	44.67	−12.93	0.001 ***
Population density	8270	44.47	26.64	0.05	307.65	8273	43.35	27.08	0.03	277.17	2.671	0.008 ***
Employment density	8270	9.54	34.15	0	1509.96	8273	12.98	54.91	0	2504.43	−4.846	0.001 ***
Multi-family houses (%)	8270	35.55	35.22	0	100	8273	30.08	34.6	0	100	10.067	0.001 ***
Apartment (%)	8270	43.36	46.34	0	100	8273	49.82	46.9	0	100	−8.886	0.001 ***
Other (%)	8270	4.21	12.8	0	100	8273	4.37	12.74	0	100	−0.848	0.397
Building age of 20 or above (%)	8270	50.44	37.38	0	100	8273	50.5	39.9	0	100	−0.092	0.926
Building age of 10 or less (%)	8270	20.31	27.69	0	100	8273	19.1	29.28	0	100	2.724	0.006 ***
Density of commercial area	8270	0	0.01	0	0.5	8273	0	0.01	0	0.59	−2.75	0.006 ***
Density of office area	8270	0	0.02	0	0.6	8273	0	0.03	0	0.98	−4.576	0.001 ***
Density of residential area	8270	0.02	0.01	0	0.22	8273	0.02	0.01	0	0.35	−12.515	0.001 ***
Density of other areas	8270	0	0.02	0	0.7	8273	0	0.03	0	1.42	−0.547	0.585
Density of green area	8270	0.01	0.07	0	3.99	8273	0	0.06	0	3.47	0.829	0.407
Land-use mix	8270	0.3	0.3	0	1	8273	0.28	0.3	0	1	3.737	0.001 ***
Density of intersection	8270	23.14	65.13	0	1792.53	8273	23.22	68.2	0	2066.22	−0.082	0.935
Bus stop	8270	0.99	0.11	0	1	8273	0.98	0.12	0	1	2.106	0.035 **
Subway station	8270	0.3	0.46	0	1	8273	0.35	0.48	0	1	−7.493	0.001 ***
Senior welfare center	8270	0.11	0.32	0	1	8273	0.1	0.31	0	1	2.137	0.033 **
△ of convenience store	8270	0.62	0.48	0	1	8273	0.61	0.49	0	1	1.068	0.286

*** $p < 0.01$; ** $p < 0.05$.

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