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Article

Mapping Nutritional Inequality: A Primary Socio-Spatial Analysis of Food Deserts in Santiago de Chile

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Abstract: This study investigates the socio-spatial distribution of food deserts in Santiago de Chile, aiming to understand how urban planning and socioeconomic factors influence access to nutritious food. Employing geospatial analysis techniques with data from OpenStreetMap and the 2017 Census, the research identifies areas within Santiago where access to healthy food is limited. The novelty of this study lies in its application of spatial autocorrelation methods, specifically Local Indicators of Spatial Association (LISA), to reveal clusters of nutritional inequality. The findings indicate significant concentrations of food deserts in both lower socioeconomic peripheral areas and, surprisingly, in some high-income central areas. These results suggest that both poverty and urban infrastructure, including car dependency, play critical roles in shaping access to healthy food. By highlighting over two million residents affected by food deserts, the study underscores the urgent need for integrated urban planning and public health strategies. This research contributes to the understanding of urban nutritional inequality and provides a replicable methodological framework for other cities. The implications extend beyond Santiago, offering insights into how urban design can be leveraged to improve public health outcomes through better access to nutritious food.

Keywords: food deserts; spatial epidemiology; urban planning; public health; nutrition

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1. Introduction

Urban environments significantly influence dietary behaviours and nutritional outcomes, with various factors at play that can either promote or hinder healthy eating habits [1]. Urbanization is linked with changes in food availability, access, and consumption patterns that often lead to increased consumption of processed foods and decreased intake of fresh produce [2]. This shift contributes to higher rates of obesity and non-communicable diseases (NCDs) in urban areas compared to rural areas [1–3]. Urban residents often face barriers such as higher food prices and limited access to healthy food options, which can lead to poorer dietary outcomes [4]. Also, the availability of diverse food outlets and the physical accessibility of food stores significantly affect dietary behaviours in urban settings. Studies have shown that proximity to food stores that offer healthy food options is associated with better dietary habits [5]. Conversely, areas with limited access to healthy foods, known as food deserts, often have residents with poorer dietary outcomes.

Economic constraints are a critical factor influencing dietary choices in urban environments. Lower-income urban dwellers often opt for cheaper, energy-dense, but nutrient-poor foods due to financial limitations [1,3]. Interventions such as providing subsidies for healthy foods or implementing food pricing policies could potentially improve access to nutritious foods [1]. Cultural beliefs and social norms also play significant roles in shaping dietary behaviours in urban settings. These factors can influence food preferences and consumption patterns, which are important to consider when designing nutrition interventions [6]. Effective urban nutrition policies and interventions need to address the multifaceted nature of food environments. This includes enhancing the availability and affordability of healthy foods, regulating food marketing, and improving the overall quality of urban food environments [4,6]. Educational campaigns and community-based programmes can also play a role in promoting healthy dietary behaviours [5].

Developing and applying frameworks that consider the unique aspects of urban food environments in Low- and Middle-Income Countries (LMICs) can help in understanding and addressing the challenges faced by urban populations. Such frameworks should integrate various levels of influence, including individual, household, community, and policy factors [4,6]. From the perspective of the global obesity epidemic, considering the city as a nutritional space is a necessary shift that integrates urban planning with public health. One of the spatial manifestations of this gap between planning and nutrition is found in food deserts, defined as areas where access to healthy food is scarce or, quite simply, non-existent.

Food deserts significantly impact urban populations by limiting access to nutritious and affordable food, which can lead to poor dietary choices and increased health risks. Asakawa et al. [7] highlight that elderly residents in urban and rural areas suffer from poor nutritional conditions due to inadequate access to food and weak social ties, which disrupt healthy eating behaviours. Similarly, Frayne and McCordick [8] discuss the long-term health vulnerabilities of children in Southern African cities due to limited access to nutritious food, emphasizing the dire developmental consequences of malnutrition from an early age. Likewise, Karpyn [5] explores the relationship between the food environment and dietary outcomes in urban food desert communities, finding that perceptions of neighbourhood food availability and household food challenges significantly correlate with dietary outcomes. Bedore [9] provides a critical analysis of food deserts within the urban political economy, arguing that food deserts are not only about the availability of food but also about the choices and class relations that shape access to food in urban settings. Food deserts can exacerbate class disparities and limit individual autonomy and dignity by narrowing food choices for the underprivileged. Food deserts have a visible impact on urban populations, highlighting the importance of addressing food access, social ties, and the broader socioeconomic and environmental factors that contribute to food insecurity in cities. So far, the spatial visibility of food deserts is scarce in Latin America.

The study of food deserts from a geospatial perspective involves analyzing the spatial distribution of areas with limited access to affordable and nutritious food. Mack et al. [10] introduce a spatial optimization approach to locate urban gardens near food deserts, using Phoenix, Arizona, as a case study. Their paper highlights the use of maximal covering location models to propose alternative urban garden sites to improve food access. The methodology involves integrating census tract data with spatial analysis to identify potential sites for urban gardens, demonstrating how geospatial tools can be employed to address urban food access issues effectively. Jiao et al. [11] present a method to measure food access for different vulnerable population groups at a smaller geographic scale with various transportation modes. This study is set in Austin, Texas, and uses methods based on Geographic Information Systems (GIS) to quantify different transportation food access for different vulnerable groups at the block group level. By incorporating detailed mobility networks and classifying food establishments as healthy or unhealthy, this approach provides a nuanced understanding of food accessibility across different modes of transportation and for various demographic groups.

Sigalo et al. [12] explore the use of social media data, specifically geotagged Twitter data, to predict food deserts in the United States. This innovative approach leverages natural language processing techniques to analyze food-related tweets and assess their association with food desert status. By mapping tweets to their respective census tracts and analyzing the sentiment and nutritional content of food mentions, this study offers a novel method to identify and understand food deserts through the lens of social media. Most of these papers refer to census tracts as spatial units of analysis. Joyner et al. [13] employ a critical geographic approach to examine food apartheid in Salt Lake City, focusing on linking historical redlining maps with current food access issues. This study underscores the importance of considering historical and socio-political contexts in geospatial analyses of food deserts. These methodological contributions to spatial analyses of food deserts emphasize the importance of using diverse data sources, including census data, social relations, and cultural conditions, to enrich the analysis. Advanced GIS techniques and spatial optimization models are crucial for identifying the locations of potential urban gardens and analyzing the accessibility of food sources.

The nutritional challenges posed in the literature focus on the need for comprehensive strategies to address malnutrition and obesity in the context of Chile. Rodríguez-Osiac [14] highlights the significant challenge of obesity and related chronic diseases in Chile, noting the widespread consumption of processed and ultra-processed foods as major contributing factors. Furthermore, Rodríguez-Osiac [15] discusses the implementation of the NOURISHING framework in Chile, which categorizes actions to promote healthier eating across three domains: food environment, food systems, and behaviour change communication. However, there are gaps in the implementation of continuous public health communication, education, and fiscal measures, such as incentives for healthy and sustainable food production and taxes on unhealthy foods, to strengthen the implementation of healthy environments. This indicates a policy gap where economic tools could be leveraged to influence food affordability and purchase incentives, thereby supporting healthier dietary choices at the community level.

Santiago is a highly segregated and unequal city [16–19], whose spatial distribution patterns have already caused health problems [20–22] due to an urban and territorial planning model weakened by the prevailing deregulation model [23,24], with permissive urban and housing policies that contribute little to social cohesion [25–28]. The health problems associated with this urban model were already stressed during the new coronavirus pandemic. This article presents an exploratory study of the socio-demographic characteristics of households residing in food deserts in Santiago, Chile. This research applies a spatial epidemiology framework, which is a multidisciplinary field that examines the geographic distribution of diseases and their determinants, including demographic, environmental, and genetic factors [29]. It involves the use of geographic information systems and statistical methods to analyze and map disease patterns [30]. Pattern analysis is a key tool in this field, allowing for the evaluation of the spatial distribution of health outcomes [31]. The field also encompasses the study of spatial patterns in epidemic models, with a focus on the role of the force of infection [32]. The book Spatial Analysis in Epidemiology provides a comprehensive overview of the concepts and methods in this field [33]. This article uses a methodology infused by the methodological stance in spatial epidemiology aimed at articulating nutrition and urban planning.

To this end, data collection was conducted to visualize the territorial location of food deserts in the city, offering a replicable methodological approach for other cities through the use of OpenStreetMap data. A second phase of analysis examines the condition of food deserts to characterize the population living in these areas. The information and method developed in this research provide opportunities to reconsider urban planning tools, promoting better integration between urban planning and public health.

2. Materials and Methods

Spatial epidemiology is a multidisciplinary field that examines the geographic distribution of diseases and their determinants, including demographic, environmental, and genetic factors [29]. It involves the use of geographic information systems and statistical methods to analyze and map disease patterns [30]. Pattern analysis is a key tool in this field, allowing for the evaluation of the spatial distribution of health outcomes [31]. The field also encompasses the study of spatial patterns in epidemic models, with a focus on the role of the force of infection [32]. The book Spatial Analysis in Epidemiology provides a comprehensive overview of the concepts and methods in this field [33]. This article uses a methodology infused by the methodological stance in spatial epidemiology aimed to articulate nutrition and urban planning.

This article methodologically builds on spatial epidemiology to generate a unique map for the city of Santiago, the capital of Chile, one of the nations with the highest obesity rates, which increased by 23% between 2016 and 2024 (World Population Review, 2024). This database is composed of information obtained from georeferenced data from OpenStreetMap for the city of Santiago, Chile. Santiago, the capital of Chile (Figure 1), is the nation's largest city with a population of around 9 million, making it one of Latin America's most populous urban areas. Covering approximately 641 square kilometres, its metropolitan expanse extends to 15a,403 square kilometres. Santiago is administratively divided into 34 communes, each with its own municipal government, and the region is overseen by a regional governor. Geographically, it is situated in the central valley between the Andes mountains and the Coastal Range, with the Mapocho and Maipo Rivers running through it. As Chile's economic hub, Santiago generates a substantial portion of the national GDP, featuring advanced infrastructure and extensive public transport networks. Despite its economic strengths, the city faces significant socioeconomic disparities, with affluent areas contrasted by regions of poverty and limited access to services. Santiago's economy is diverse, with robust finance, retail, manufacturing, and service sectors.

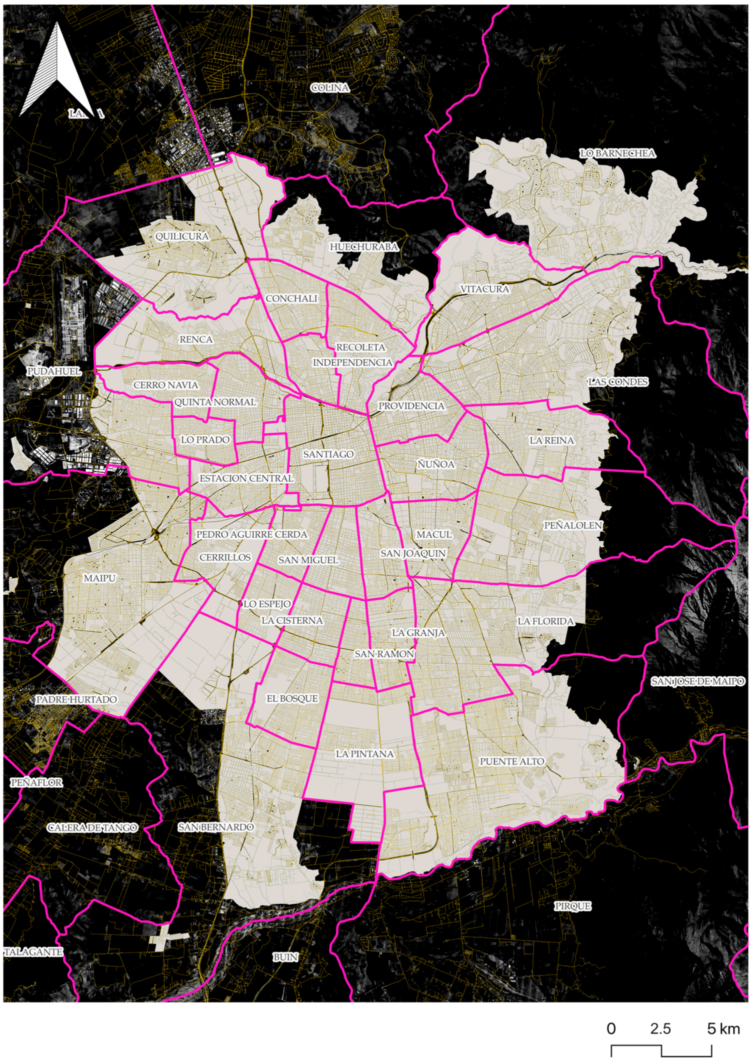

Figure 1. Map of Santiago de Chile.

A search was conducted using specific parameters considered as spaces for the distribution of healthy foods for the specific case of Chile. These were under the general category of 'shops,' which were then specified using the keywords listed in Table 1, with those results. The map of resultant shops georeferenced are presented in Figure 2 marked by blue dots, while the division of comunas of Santiago (districts) is marked by magenta lines. The shops selected in OpenStreetMap were those indexed in the database as actually offering healthy food in Santiago. We excluded others that may provide a mix of fast food and healthy food, as well as restaurants, since these often offer a variety of food types. Additionally, we focused on identifying shops that sell food for preparation at home.

Table 1. Type of shops considered in the analysis.

Type of Shop	Count (*n*)
Convenience store	1282
Bakery	508
Supermarket	206
Greengrocer	109
Variety store	38
Herbalist store	13
Tea	10
Deli shop	9
Cheese store	3
Dairy shop	2
Farm products	2
Grocery store	2
Nutrition supplements	1

With the georeferenced points, a census layer was applied to characterize the blocks demographically and their socio-economic composition in establishing distances to these points. Different isochrones were determined to identify households that, due to their distance from food sources, can be considered to be located within food deserts. This determination was made using QGis software 3.4, employing the "union by proximity" function, applying a criterion of a maximum of 5 census blocks as a reference for direct proximity, from which distance measurement began. Although this is not a fixed measure due to the variation in shapes and sizes of blocks, the average is that if a household is 1500 m away from a store selling healthy products, it is considered a food desert.

Therefore, the spatial determination of food deserts is based on distance rather than subtraction. In other words, the farther a block is from healthy food supply points, the greater the probability of being a food desert. Once the most critical food desert areas were defined, these areas were characterized using information from the 2017 Census. After calculating the levels of access to healthy food facilities, we employed spatial autocorrelation analysis, specifically using Local Indicators of Spatial Association (LISA), to identify and cluster zones characterized by food deserts. LISA analyses spatial autocorrelation to uncover local variations in geographic patterns. Moran's *I* is a fundamental statistic in spatial analysis, particularly useful for understanding socio-spatial patterns within urban environments. It quantifies the extent of spatial autocorrelation, which refers to the degree to which similar values of a particular attribute—such as access to healthy food—are spatially clustered, dispersed, or randomly distributed across a geographic region. The statistic is calculated by comparing the value of the attribute at each location with the values at neighbouring locations, considering the spatial arrangement of those locations.

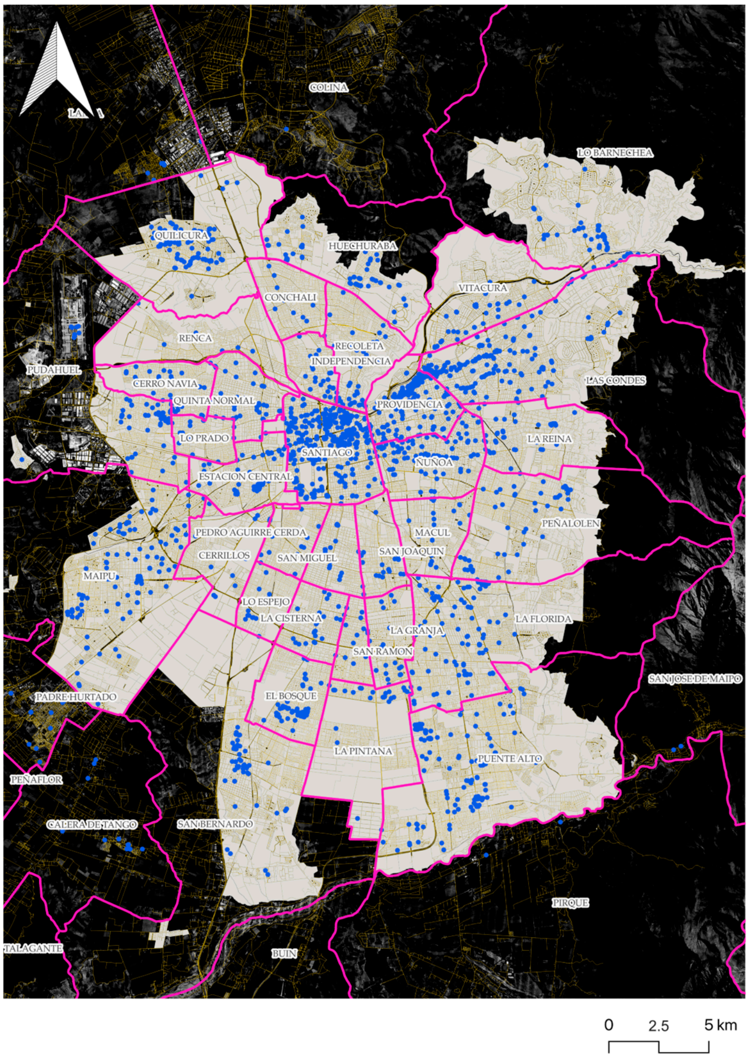

Figure 2. Shops indexed for the analysis.

The formula for Moran's I is as follows:

$$I = \frac{N \sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij}(x_i - x)(x_j - x)}{W \sum_{i=1}^{n} (x_i - x)^2}$$

where N is the number of spatial units (e.g., neighbourhoods or census tracts); x_i and x_j are the values of the attribute at locations i and j, respectively; x is the mean of the attribute values; w_{ij} is the spatial weight between locations i and j, which defines the neighbourhood structure; and W is the sum of all spatial weights. A positive Moran's I indicates spatial clustering, meaning that similar values (e.g., areas with low access to healthy food) tend to be located near each other. This would suggest that food deserts are not randomly distributed but rather form distinct clusters in certain parts of the city. A negative Moran's I, on the other hand, indicates spatial dispersion, where areas with dissimilar values are located near each other. This would imply that regions with good and poor access to healthy food are interspersed. A Moran's I value near zero suggests randomness, indicating no significant spatial pattern in the distribution of the attribute.

While Moran's I provides a global measure of spatial autocorrelation across the entire study area, it does not reveal where these patterns occur locally. To address this limitation, LISA are used. LISA extends the analysis by calculating a local Moran's I value for each individual location within the study area. This localized analysis allows researchers to identify specific neighbourhoods or census tracts that contribute most to the overall spatial autocorrelation.

In the context of our research, LISA is particularly valuable for understanding spatial inequality related to food access. By identifying clusters of areas with low access to healthy food (food deserts), we can pinpoint regions where disparities in access are most pronounced. Visualizing these spatial relationships through LISA offers valuable insights into the complex factors that shape food environments and the well-being of communities within cities. After calculating the LISA values and identifying the High-High cluster, which represents areas with the highest potential for being food deserts, a socioeconomic characterization of these city zones was conducted. This characterization utilized data from the 2017 Census [34], the ISMT [35–37], and the 15-Minute City Index of Santiago [38–40]. The Socio-Material Territorial Index (ISMT) is a synthetic indicator used to stratify socioeconomic levels. It summarizes socio-material conditions based on four census variables: household head's education (79% variance), household overcrowding (7% variance), shared housing (3% variance), and housing material quality (11% variance), derived from Chile's 2017 Census. The 15-Minute City Index measures the accessibility of essential urban functions within a 15 min reach in Santiago. Using principal component analysis, it evaluates 28 functions—like services, education, and green spaces—highlighting areas with varying accessibility levels to guide urban planning towards more equitable, walkable neighbourhoods [41–43].

3. Results

The spatial distribution of food deserts in Santiago, as depicted in Figure 3, shows the levels of proximity from houses to healthy food points as indicated in the legend. The concentration of food deserts in specific areas suggests that residents in these neighbourhoods may experience greater challenges in maintaining healthy diets due to the lack of convenient and affordable access to fresh produce and other nutritious options. This can contribute to health disparities, including higher rates of obesity, diabetes, and other diet-related diseases. Nevertheless, there are also food deserts in peri-central areas such as San Miguel, San Joaquin, Macul, Lo Prado, and the severe case of Renca. Also, surprisingly, the high-income areas in Las Condes, Vitacura, and Lo Barnechea also show food deserts. These districts may have a factor of excessive dependence on cars, which may compensate the inaccessible presence of abundant healthy food supply.

Figure 4 presents a map illustrating the results of a LISA analysis conducted on the distribution of food deserts in Santiago. The map utilizes a colour scheme to represent the LISA results. Areas in red are classified as "High-High" clusters, indicating a statistically significant concentration of food deserts. These are neighbourhoods where the lack of access to healthy food is not only prevalent but also spatially clustered together. In contrast, areas in blue are classified as "Low-Low" clusters, signifying areas with good access to healthy food options that are also clustered together. The implications of this map are significant for understanding the spatial dynamics of food access in Santiago. The presence of High-High clusters (red areas) in the northeastern and southwestern peripheries of the city suggests that these areas are not only experiencing food deserts but are also spatially connected, forming larger zones of limited access to healthy food. This concentration of food deserts in specific geographic areas can exacerbate health disparities and perpetuate socioeconomic inequalities. Conversely, the Low-Low clusters (blue areas) indicate neighbourhoods with good access to healthy food options, often located in more affluent parts of the city. The "High-Low" category (yellow) highlights neighbourhoods lacking food access but adjacent to areas with better resources, while "Low-High" areas (orange) have good food access despite being near food deserts. This spatial pattern highlights the uneven distribution of resources and opportunities across Santiago, with some communities enjoying greater access to healthy food than others.

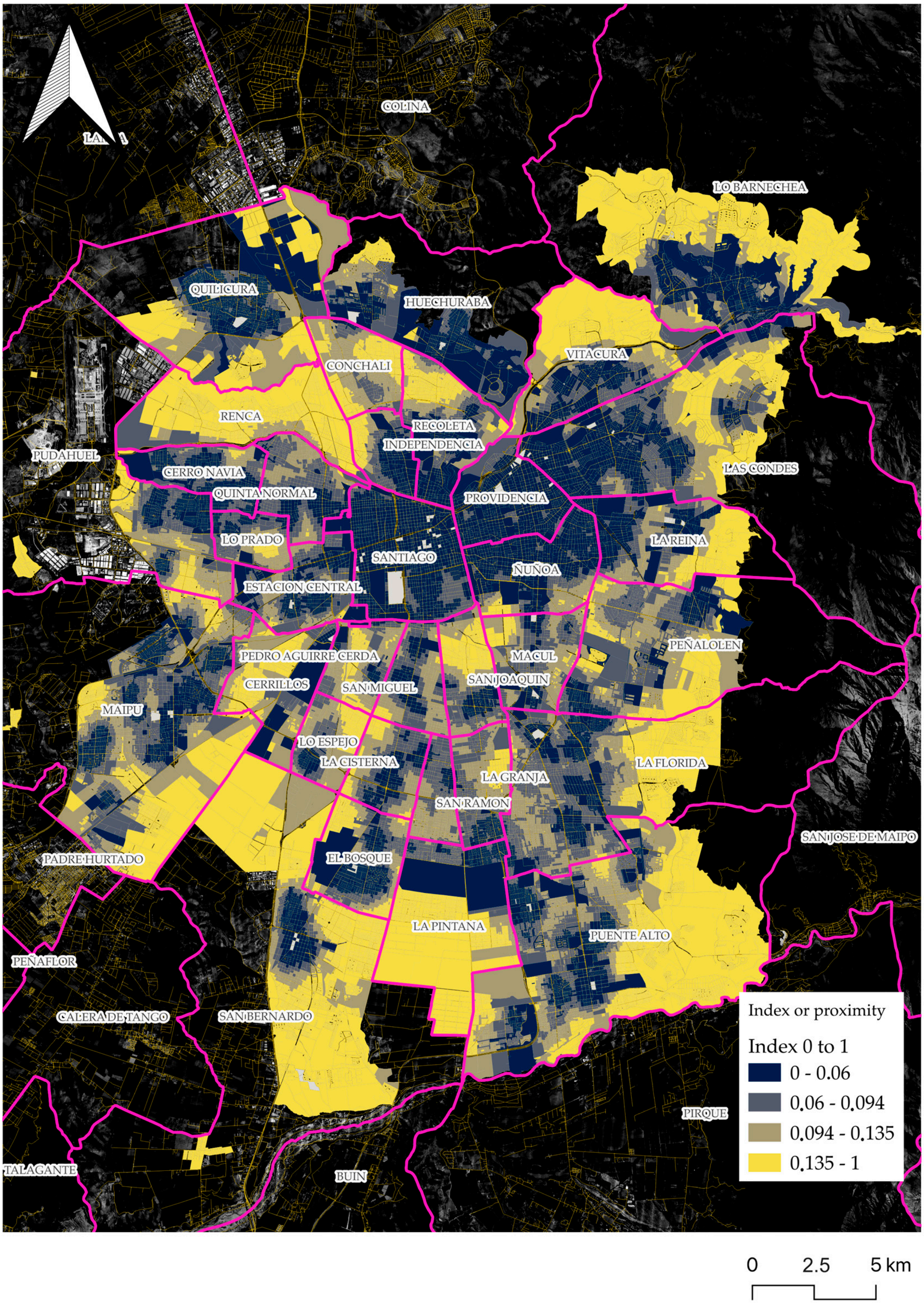

Figure 3. Map of food deserts in Santiago.

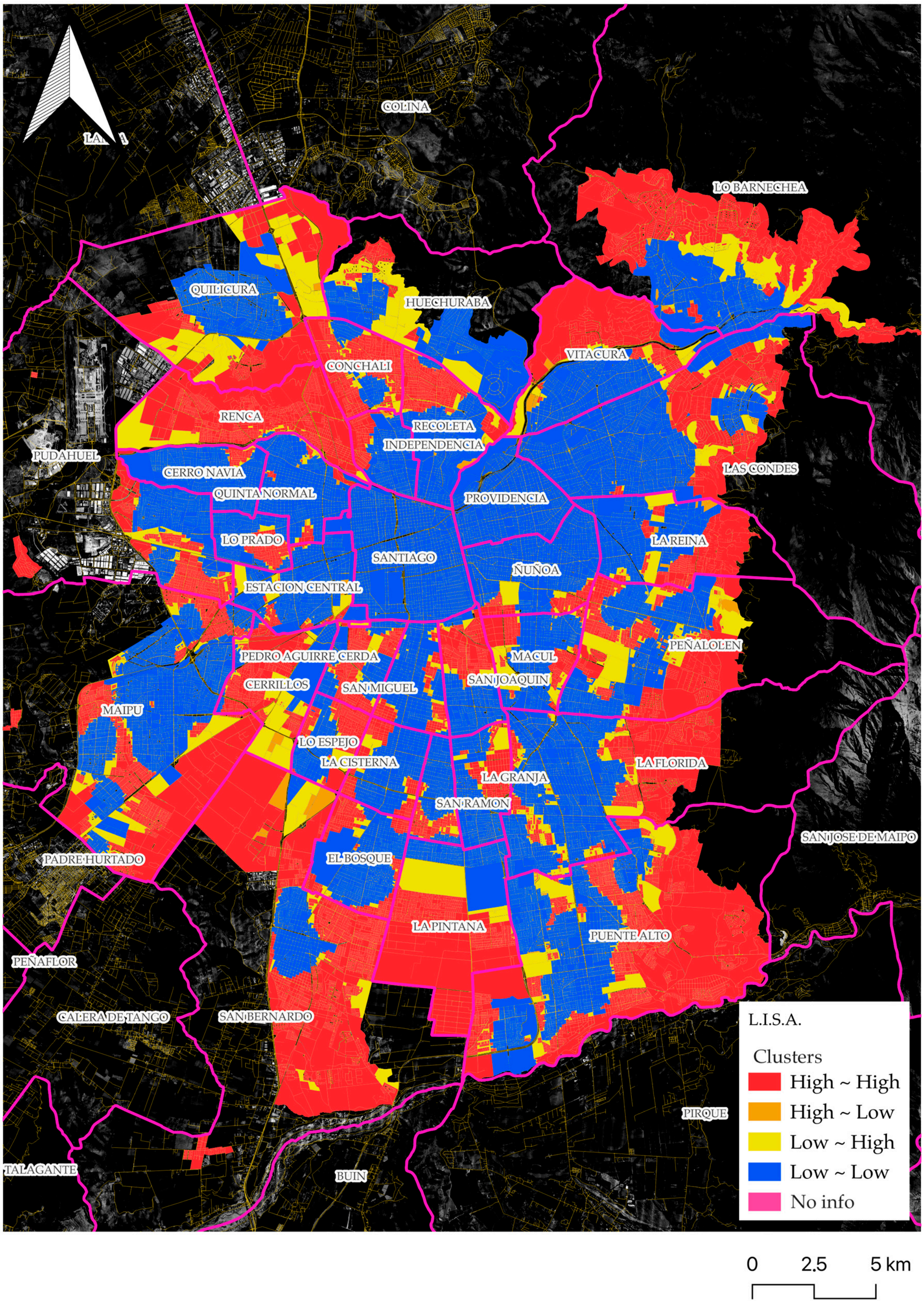

Figure 4. LISA of food deserts in Santiago de Chile.

Figure 5 shows the food deserts in relation to the location of healthy food suppliers. Tables 2 and 3 provide a statistical comparison of various socioeconomic and demographic indicators between food deserts (High-High LISA cluster) and food oases (Low-Low LISA cluster) in Santiago. The data reveal significant disparities between these two types of areas. Food deserts exhibit a higher index of distance to healthy food, indicating that residents in these areas have less access to nutritious options compared to those in food oasis. A food oasis is an area with abundant access to healthy, affordable food options, such as supermarkets, greengrocers, and farmers' markets. In contrast to food deserts, residents in food oases can easily obtain fresh produce and nutritious food, contributing to better dietary and health outcomes. This disparity is further reflected in the socioeconomic levels of the populations. Food deserts have a higher proportion of households in lower socioeconomic categories (C3, D, and E), while food oases are predominantly populated by households in higher socioeconomic categories (ABC1 and C2) defined by NRS social grades. The income distribution also differs significantly between the two areas. Food deserts have a substantially higher percentage of households with incomes below 40% of the median income, highlighting the concentration of poverty in these areas. In contrast, food oasis has a much lower percentage of households in this income bracket.

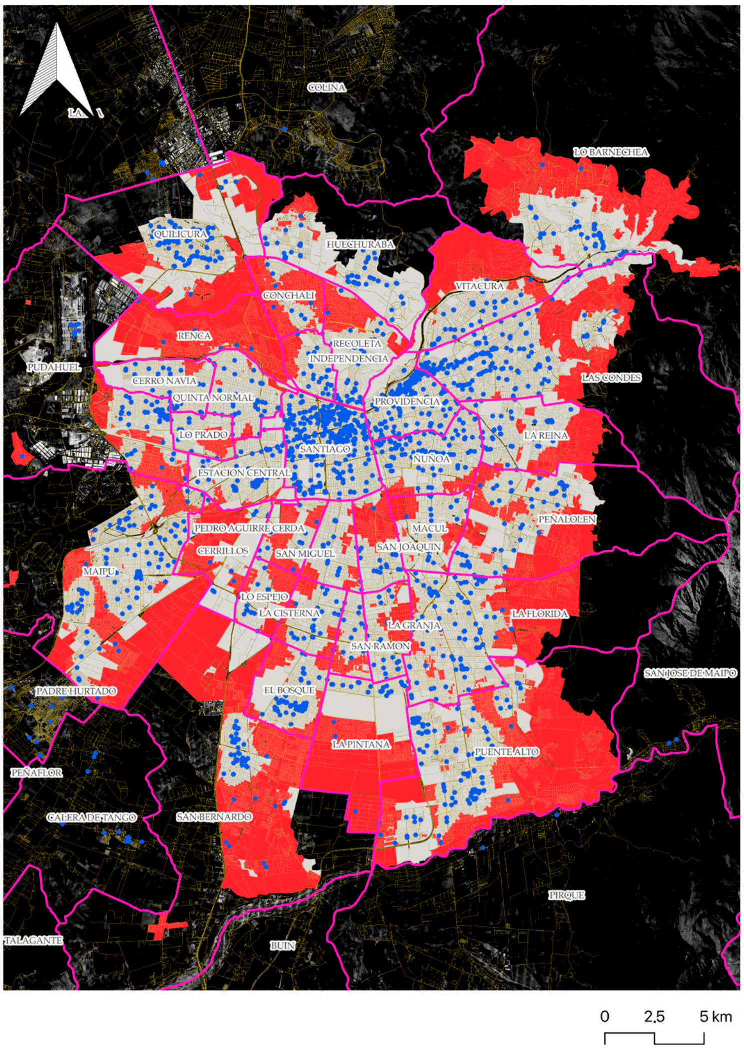

Figure 5. Clusters of food deserts (High~High in LISA) in Santiago in relation to shops indexed.

Table 2. Sociodemographic characterization of food deserts (High-High) based on LISA results.

Socioeconomic Level	ABC1	C2	C3	D	E	Total
Index of distance to healthy food	0.2209	0.2006	0.1619	0.1740	0.1313	0.1756
Mín. Index of distance to healthy food	0.1089	0.1086	0.1085	0.1086	0.1147	0.1085
Máx. Index of distance to healthy food	0.6862	0.8383	0.5977	1.0000	0.1548	1.0000
Std.Dev. index of distance to healthy food	0.1114	0.1349	0.0614	0.0815	0.0209	0.0870
household at 40% less incomes	0.0338	0.1238	0.3355	0.6270	0.6250	0.4837
Inmigrants	10,789	7912	12,454	43,954	-	75,109
Elderly over 65 years old	6545	16,765	35,738	130,784	-	189,832
Active population	71,987	157,285	302,726	869,638	17	1,401,653
Young 6 to 14 years old	16,669	29,499	47,411	149,973	-	243,552
Infants	7097	18,568	27,818	96,114	-	149,597
Women	55,615	119,309	223,151	648,265	8	1,046,348
Men	48,935	109,577	206,224	624,055	13	988,804
Population	104,615	229,133	429,572	1,272,863	42	2,036,225
Land Value (UF of 2018)	64.1866	30.1454	22.3622	17.0657	34.9342	21.3378
Socio-Material Territorial Index	0.9095	0.8632	0.8114	0.7552	0.4105	0.7853

Table 3. Sociodemographic characterization of food oasis (Low-Low) based on LISA results.

Socioeconomic Level	ABC1	C2	C3	D	E	Total
Index of distance to healthy food	0.0538	0.0563	0.0653	0.0674	-	0.0642
Mín. Index of distance to healthy food	0.0020	0.0018	0.0020	0.0019	-	0.0018
Máx. Index of distance to healthy food	0.1083	0.1085	0.1085	0.1085	-	0.1085
Std.Dev. index of distance to healthy food	0.0262	0.0283	0.0263	0.0247	-	0.0263
household at 40% less incomes	0.0434	0.1203	0.3373	0.6074	-	0.4215
Inmigrants	32,854	120,819	91,939	96,319	-	341,931
Elderly over 65 years old	36,437	112,609	92,981	190,452	-	432,479
Active population	187,821	728,445	645,857	1,121,921	-	2,684,044
Young 6 to 14 years old	23,146	73,184	86,056	179,059	-	361,445
Infants	18,976	58,950	56,260	117,134	-	251,320
Women	145,157	517,338	468,317	835,128	-	1,965,940
Men	124,966	472,326	435,439	803,490	-	1,836,221
Population	270,229	991,583	904,039	1,639,400	-	3,805,251
Land Value (UF of 2018)	67.5742	41.0489	24.2466	18.1708	-	26.2913
Socio-Material Territorial Index	0.9044	0.8711	0.8133	0.7598	-	0.8009

Tables 2 and 3 are structured to compare various socioeconomic and demographic indicators across different socioeconomic levels (ABC1, C2, C3, D, E) and the total population. It includes columns for each socioeconomic level and a Total column for aggregated data. Each row represents a specific variable, such as the Index of Distance to Healthy Food, Minimum and Maximum values of this index, Standard Deviation, percentage of households with 40% less income, number of immigrants, elderly population, active population, youth (6–14 years old), infants, women, men, overall population, land value (in UF of 2018), and the Socio-Material Territorial Index. Demographic differences are also evident. Food deserts have a higher proportion of elderly residents (over 65 years old) and a lower proportion of immigrants compared to food oasis. The working-age population (those aged 15–64) is more prominent in food oases, indicating a greater concentration of individuals currently employed or seeking employment compared to areas where a higher proportion of residents are of retirement age. Land values are 6% lower in food deserts compared to food oases, reflecting the economic disparities between these areas. The Total value of the Socio-Material Territorial Index, a composite measure of socioeconomic conditions, is also lower in food deserts, further emphasizing the disadvantaged position of these communities. Table 4 illustrates significant socioeconomic and demographic disparities between food deserts and food oases in Santiago. From Table 4, it can be seen that these areas have a lower active population, but also lower incomes, with land values 19% lower than in the food oases and a socio-material index that is also lower, albeit by 2%.

Table 4. Comparative differences between food deserts and food oasis in Santiago.

Comparative Factors	Food Oasis	Food Deserts	Differences
Index of distance to healthy food	0.0642	0.1756	1.7352
Mín. Index of distance to healthy food	0.0018	0.1085	59.2778
Máx. Index of distance to healthy food	0.1085	1.0000	8.2166
Std.Dev. index of distance to healthy food	0.0263	0.0870	2.3080
household at 40% less incomes	0.4215	0.4837	0.1476
Inmigrants	341,931.0000	75,109.0000	−0.7803
Elderly over 65 years old	432,479.0000	189,832.0000	−0.5611
Active population	2,684,044.0000	1,401,653.0000	−0.4778
Young 6 to 14 years old	361,445.0000	243,552.0000	−0.3262
Infants	251,320.0000	149,597.0000	−0.4048
Women	1,965,940.0000	1,046,348.0000	−0.4678
Men	1,836,221.0000	988,804.0000	−0.4615
Population	3,805,251.0000	2,036,225.0000	−0.4649
Land Value (UF of 2018)	26.2913	21.3378	−0.1884
Socio-Material Territorial Index	0.8009	0.7853	−0.0195

4. Discussion

The purpose of the study is to investigate the socio-spatial distribution of food deserts in Santiago de Chile, aiming to understand how urban planning and socioeconomic factors influence access to nutritious food. The results section of the study provides a detailed spatial analysis of food deserts in Santiago, utilizing georeferenced data from OpenStreetMap and census information to visualize and characterize these areas. The maps reveal a significant concentration of food deserts in the peripheries of the city, particularly in lower socioeconomic regions with less developed infrastructure. The LISA analysis further identifies clusters of high and low access to healthy food, indicating pronounced spatial inequality.

The spatial distribution of food deserts in Santiago underscores the city's socioeconomic disparities and urban planning challenges. The concentration of food deserts in the peripheries suggests that residents in these areas face significant obstacles in maintaining healthy diets due to the lack of convenient and affordable access to fresh produce and other nutritious options. This spatial pattern aligns with broader patterns of inequality observed in other studies about Santiago. Building on the work of Sabatini et al. [18] and Herrera-Marin et al. [19], which highlight Santiago's deep-seated segregation and the consequences of deregulated urban planning, this study empirically identifies and maps food deserts, revealing stark spatial patterns that confirm these earlier analyses. The results align with Mena et al. [21] and Vergara-Perucich et al. [20], who link poor health outcomes to the city's fragmented infrastructure, as the identified food deserts are concentrated in areas with inadequate urban amenities. Moreover, the findings resonate with Pradeilles et al. [3] and Cockx et al. [5] by illustrating how economic constraints limit access to nutritious food, particularly in lower-income areas. This research thus not only corroborates existing studies but also advances the understanding of Santiago's urban inequalities through the lens of nutritional access. The presence of food deserts in peri-central areas such as San Miguel, San Joaquin, Macul, Lo Prado, and Renca, as well as in high-income areas like Las Condes, Vitacura, and Lo Barnechea, suggests that food deserts are not solely a problem of poverty but also of urban planning and infrastructure. The unexpected presence of food deserts in high-income areas, as discussed in the paper, suggests a complex interplay of factors beyond mere economic capacity. The inference that these areas may exhibit an excessive dependence on cars to compensate for the physical inaccessibility of healthy food supply points is grounded in urban design and lifestyle patterns typical of affluent neighbourhoods. In these food deserts in high-income areas, residents often rely heavily on private vehicles, which can lead to the development of urban environments less conducive to walkability and local access to amenities, including food stores. This car-centric infrastructure might result in fewer local shops and supermarkets, creating pockets of inaccessibility despite wealth. In contrast, lower-income areas typically exhibit higher dependency on public transport or walking, making proximity to food sources more critical. This suggests that solutions to food deserts need to consider not only socioeconomic factors but also urban design and transportation infrastructure. Effective interventions need to consider the unique aspects of urban food environments, as suggested by Osei-Kwasi et al. [9]. This includes enhancing the availability and affordability of healthy foods, regulating food marketing, and improving the overall quality of urban food environments.

The results also align with the broader discussions on the need for comprehensive strategies to address malnutrition and obesity in urban settings, as highlighted by Rodríguez-Osiac [13]. The spatial characterization of food deserts in Santiago indicates a significant policy gap in urban planning and public health. The study suggests that urban planning tools need to be better integrated with public health initiatives to address the challenges of food deserts effectively. This could include the implementation of urban gardens, subsidies for healthy foods, and improved infrastructure to enhance access to nutritious food in underserved areas.

The study also highlights the importance of using diverse data sources and advanced GIS techniques to understand and address food access issues. The use of georeferenced data from OpenStreetMap and census information provides a robust methodological approach that can be replicated in other cities. This approach allows for a nuanced understanding of food deserts and the identification of areas most in need of intervention.

Future research should build on these findings to develop targeted interventions that address the specific challenges of food deserts in Santiago. This could include community-based programmes, educational campaigns, and policy measures aimed at improving access to healthy foods. The study provides a valuable framework for understanding the socio-spatial dynamics of food deserts and offers a replicable methodological approach for other urban settings.

5. Conclusions

The spatial representation of nutritional inequality in Santiago de Chile reveals a complex issue at the intersection of urban planning and public health. The identification of food deserts, areas with limited access to nutritious and affordable food, highlights a critical need for integrated strategies to address these inequities. This study shows that nutritional inequality is not just a reflection of economic disparities but is also deeply rooted in urban infrastructure and planning decisions. The concentration of food deserts in both peripheral and peri-central areas underscores the role of urban design in shaping access to essential services.

The findings that even high-income areas suffer from food deserts suggest that traditional measures of affluence and poverty are inadequate to fully understand this issue. The problem is embedded in the urban fabric, where infrastructure and urban design—or the lack thereof—play critical roles in determining access to healthy food.

Given these findings, several questions arise for further research. How can urban planning and public health policies be better integrated to address food deserts? What specific urban design features contribute to their creation in both low- and high-income areas? Additionally, how can transportation policies be adapted to improve access to healthy food in car-dependent neighbourhoods?

Further research should explore the effectiveness of interventions such as urban gardens, local food markets, and community-based programmes in reducing food deserts. Investigating the role of policy, including subsidies for healthy foods, taxes on unhealthy foods, and zoning laws that encourage the establishment of fresh food markets in underserved areas, could also provide valuable insights. Understanding the effectiveness of these strategies in other contexts will help tailor approaches to Santiago's unique urban environment.

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