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Urban Food Deserts and Cardiovascular Health: Evaluating the Impact of Nutritional Inequities on Elderly Populations in Santiago

Leslie Landaeta-Díaz [1,2,*], Francisco Vergara-Perucich [3], Carlos Aguirre-Nuñez [4], Francisca Cancino-Contreras [3], Juan Correa-Parra [3] and Felipe Ulloa-León [3]

1 Facultad de Salud y Ciencias Sociales, Universidad de las Américas, Santiago 7500975, Chile
2 Núcleo de Investigación en Nutrición y Ciencias Alimentarias, Universidad de las Américas, Santiago 7500975, Chile
3 Núcleo Centro Producción del Espacio, Universidad de las Américas, Santiago 7500975, Chile; jvergara@udla.cl (F.V.-P.); francisca.cancino.contreras@edu.udla.cl (F.C.-C.); juan.correa.parra@edu.udla.cl (J.C.-P.); feliulloaleon@gmail.com (F.U.-L.)
4 Escuela de Arquitectura, Universidad San Sebastián, Santiago 7510602, Chile; carlos.aguirre@uss.cl
* Correspondence: llandaeta@udla.cl; Tel.: +56-988693781

Featured Application: (1) The methodological approach based on multiscale geographically weighted regression provides a nuanced understanding of how urban factors influence health disparities. (2) The findings highlight the importance of food accessibility as a determinant of health, reinforcing the need for interdisciplinary approaches that combine public health, urban planning, and nutrition science. (3) Policymakers can use this data to identify priority areas for improving food access, particularly in economically disadvantaged neighborhoods. This could involve incentivizing grocery stores and markets to establish themselves in underserved areas or enhancing public transportation links to existing food resources. (4) The call for sustainable food systems to support public health highlights the importance of long-term strategies that ensure consistent access to healthy, affordable food. This can influence agricultural policies, support for local food producers, and the promotion of urban agriculture initiatives.

Abstract: This study examines the link between food deserts and cardiovascular health in older adults in Santiago's Metropolitan Region, Chile. As the population ages and chronic diseases rise, understanding the impact of food accessibility on health is essential. Using multiscale geographically weighted regression, we analyzed data from the Cardiovascular Health Program, socioeconomic indicators, and food desert maps, sourced from the Chilean Ministry of Health and other databases. Spatial analysis, including Voronoi diagrams, assessed the influence of food deserts on health outcomes. Findings show a significant correlation between limited access to healthy foods and higher cardiovascular disease rates, especially in economically disadvantaged areas. The regression model is significant to contribute to the explanation of disease prevalence, emphasizing the impact of food availability on health. This study highlights the importance of considering spatial factors in urban planning and public health policies. By showcasing the role of food environments in health disparities, it advocates for integrated health interventions. Targeted urban planning to address food deserts can enhance access to healthy foods, improving cardiovascular health and well-being among Santiago's elderly. The findings provide insights for policymakers to create healthier urban environments and stress the need for sustainable food systems to support public health.

Keywords: nutrition; food patterns; urban planning; cardiovascular health; geographically weighted regression

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1. Introduction

Chile is currently at a critical moment in terms of food health policies. The complexity of the global political and economic situation, the growing dependence on imported food, the degradation of our natural heritage and biodiversity, the marked migration from rural to urban areas, and the prevalence of malnutrition among the population underline the imperative need to reflect on our food system, policies, and especially on the food practices of the people [1].

In addition, during the last decades, transformations in food structures have undergone important changes attributed to the planning and urbanization of cities, the globalized market, and the growing presence of highly processed foods [1,2]. Likewise, it is understood that there are nutritional issues associated with people's access to these spaces rich in nutritional supply, which are important aspects for maintaining the health and well-being of the population [3].

In this context, there have been epidemiological and nutritional transformations in Chile that have marked a remarkable evolution in recent decades, manifesting in a persistent increase in overweight and obesity in people of all ages. This phenomenon is the result of the nutritional transition experienced due to the influence of demographic, economic, and epidemiological factors, as well as the development of public policies on food and nutrition during the last three or four decades [4].

Along the same lines, the concept of food security (FS) has gained considerable attention, defined as "when the entire population, at all times, has physical, social and economic access to safe and healthy food that meets their dietary needs and food preferences for an active and healthy life" [5]. Already in developed countries, the debate has focused on food quality. In contrast, in less developed countries such as Chile, the issue of food security focuses on aspects such as access and availability of food [5]. In this context, the concept of food insecurity is also introduced, which, unlike FS, refers to the limited capacity to acquire food that meets the nutritional needs essential for a balanced diet [6].

Research on the influence of food environments on health outcomes has been a persistent concern, addressing key components such as spatial food availability and structural policies that influence food choices and purchasing decisions [7]. This analysis focuses on possible connections between these components and risk factors associated with obesity, chronic diseases [8,9] and food insecurity [10,11]. The assessment of the spatial distribution of outlets, such as supermarkets, local stores, and markets, is also conducted to identify areas with lower availability of healthy food and to characterize food deserts under their more classical and binary definition of having or not having a place to buy healthy food [12–14]. However, other authors also consider non-geographical and infrastructural access issues, as individual and family characteristics, their food supply strategies, purchasing patterns, and social and cultural norms play a role [15].

This situation causes a certain group of people to compose their food baskets from easily accessible products, while those living in food deserts have limited access and thus develop diets of inferior nutritional quality [16–18].

On the other hand, the aging of the population poses new challenges to societies, which must adapt to this demographic reality and face the present and future challenges that derive from it. In this regard, Chile is one of the countries with the largest older adult population in Latin America [19]. Thus, the aging rate in Chile shows a gradual increase, and according to projections, the group aged 60 years and over will almost double by 2050, reaching approximately one third of the total population of the country (32.1%). In addition, in Chile, more than 82% of the elderly population lives in urban areas, in line with world trends.

For the year 2019 in Chile, the main causes of mortality in older people were related to diseases of the circulatory system, which include cerebrovascular diseases, hypertensive diseases, and acute myocardial infarction, accounting for 28.2% of all deaths in people aged 60 years or older [20]. In this sense, it is necessary to pay greater attention to age-related health problems linked to lifestyles and diet. However, in Chile, the Public Health

System developed the Cardiovascular Health Program [21], which focused on the overall cardiovascular health risk of individuals rather than addressing risk factors separately.

On the other hand, regarding diet, it has been found that most older adults are food secure (65.7%), and 83.8% have a diet in need of improvement according to the healthy eating index [22], regardless of their socioeconomic status. However, in recent studies of hospitalized elderly patients, 40% of the sample were at nutritional risk [23].

In this sense, the prevalence of noncompliance with dietary guidelines among Chilean older adults, according to Albuquerque-Araujo et al. [24], is based on a lower consumption of fish and fruits, this factor being more noticeable among those over 80 years of age. The perception of a barrier to following the guidelines is mainly associated with the cost of the products [25], given that the price of a healthy diet is higher than that of a less healthy one [26]. This aspect becomes relevant, especially if we consider that 22.1% of the older adult population is in poverty [27], and after the pandemic, 41.6% of older adults stated that their regular income is not sufficient to cover their [28]. In this context, another determinant element is the generalized increase in food costs, which has repercussions on the decrease in the purchasing power of buyers, affecting more the lower classes of society [1].

These trends suggest that socioeconomic status does not necessarily predict a specific dietary preference among older adults, but rather their ability to access quality foods. Although it is recognized that a healthy dietary pattern can prevent or reduce the risk of disease [29], areas with limited access to nutritious foods may encourage the consumption of low-quality diets, increasing the risk of mortality from chronic disease. However, urban accessibility to healthy foods for older adults and its relationship with the prevalence of cardiovascular health have not been studied in the case of Chile. Therefore, the aim of this study is to evaluate the relationship between the presence of food deserts and the prevalence of cardiovascular health in people over 60 years of age in Chile.

2. Materials and Methods

This was a retrospective study design. The data are obtained from the health statistics department of the Chilean Ministry of Health. The The data were obtained from the 2018 Chilean Ministry of Health's "Series A" monthly statistical summaries from the statistics department, wherein only persons over the age of 60 were indexed.

The cardiovascular health program is a strategy of the Ministry of Health that aims to reduce the incidence of cardiovascular events through the control and compensation of cardiovascular risk factors and to improve the control of people who have had a cardiovascular event to prevent morbidity and premature mortality, as well as to improve the quality of life of these people, through benefits delivered in Primary Health Care Centers [21]. We selected 2018 as our year of study because, in 2019, Chile experienced a significant social uprising that greatly impacted public service systems, particularly in Santiago. Subsequently, from 2020 to 2022, Santiago was under exceptional conditions due to the COVID-19 pandemic. Therefore, the decision to use 2018 as the specific year for case collection was based on the availability of updated demographic data and the need to avoid the statistical noise that could arise from the samples of the aforementioned periods. When using official data from the Health Ministry and the 2017 national census, the potential for inaccuracies or gaps in spatial and demographic information must be considered. Such data, while authoritative, may still contain inconsistencies due to outdated records, incomplete reporting, or errors in data collection. These issues can eventually affect the precision of spatial analyses, particularly at finer scales. Acknowledging these limitations is crucial, as they could influence the interpretation of results and the generalizability of findings. Therefore, it's important to approach conclusions with an understanding of these potential data limitations.

People who can enter the program are users over 15 years of age with a history of arteriosclerotic cardiovascular disease, diagnosed with arterial hypertension, diagnosed with diabetes mellitus, diagnosed with dyslipidemia with total cholesterol values $\geq$ 240 mg/dL and LDL cholesterol $\geq$ 160 mg/dL, and users over 55 years of age who are tobacco smokers. However, for the purposes of this study, only individuals over 60 years of age were considered. The study was conducted in accordance with the guidelines of the Declaration of Helsinki and was approved by the Scientific Ethics Committee of the University of the Americas, approval number CEC_FE_202301.

Section H of the database, marked with code 03030360, indicated the entries into this monitoring program, which allows indexing of persons with arterial hypertension, diabetes mellitus, dyslipidemia, a history of cardiovascular disease, and smoking. Within the political-administrative division of Chile, we only worked with data from the Metropolitan Region of Santiago. Access to public information was requested through the Transparency Law [30], specifically to the health statistics of the DEIS through electronic means.

From this data set, each of the establishments from which the reports originate is spatially located. From the location of these establishments, we can elaborate on the spatial location of the 272 establishments.

Figure 1 allows us to broadly identify the distribution of new cases in the cardiovascular program at the level of the metropolitan territory analyzed. The distribution of cases is based on statistics from the Department of Statistics of the Ministry of Health and indexes, for each identified center, and the number of new patients entering the program. In other words, this indicator measures new patients in the program for each health care facility indexed in the geographic database weighted by the total population in the area, normalizing the sample from 0 to 1 to ease its comparison between spatial units to visualize. From this point location, a distribution of influence of each establishment is applied using a Voronoi model represented in Figure 2, which assigns a range of influence from one point on the map until the influence of another point on the map begins. A Voronoi diagram is a spatial partitioning technique that divides a plane into regions based on the distance to a specific set of points. Each region, or Voronoi cell, consists of all points closer to a particular seed point than to any other seed point. These seed points are known as sites, and the edges of the cells are equidistant to the nearest sites, forming perpendicular bisectors between neighboring sites. The resulting shapes in a map are polygonal, with each polygon encompassing the area that is closer to its respective site than to any other site. Voronoi diagrams are useful in various fields such as geography, meteorology, and urban planning for analyzing spatial structures and distributions, optimizing locations, and modeling influence areas around points of interest. This allows for an equitable distribution of the levels of influence of each facility if the majority of people attending health centers tend to go to the facilities closest to their homes. Each shape resulting from the Voronoi transformation summarizes the number of new patients admitted to the Ministry of Health's cardiovascular program in 2018, which is expressed in the symbology at the bottom left of Figure 2. For ethical reasons, the health system does not share the exact address of each patient, so we can only work with an approximation such as the one presented here.

Next, the Voronoi layer is completed with information on food deserts on the map along with socioeconomic information provided by Correa-Parra et al. from the data used to identify a 15-min city in this same territory [31]. From the cadastre of urban functions, it is identified that access to sanitary products in Chile is distributed specifically in supermarkets and street markets. Then, with this premise, a base is created that identifies the blocks with access within 15 min of one of these two urban functions on a weighted basis of both urban functions. This mapping (Figure 3) scored the total absence of food deserts as 0 and the presence of food deserts as 1. It might be relevant to include this perspective because of the importance of reducing physical inactivity through a walkable neighborhood. There is evidence showing that reducing sedentary time is relevant in terms of improving metabolic and cardiovascular health, regardless of physical activity levels [32]. In this sense, the methodology considers this approach to observe the opportunities of a walkability-oriented city in a context where mobility is mainly on foot, followed by the private vehicle [33].

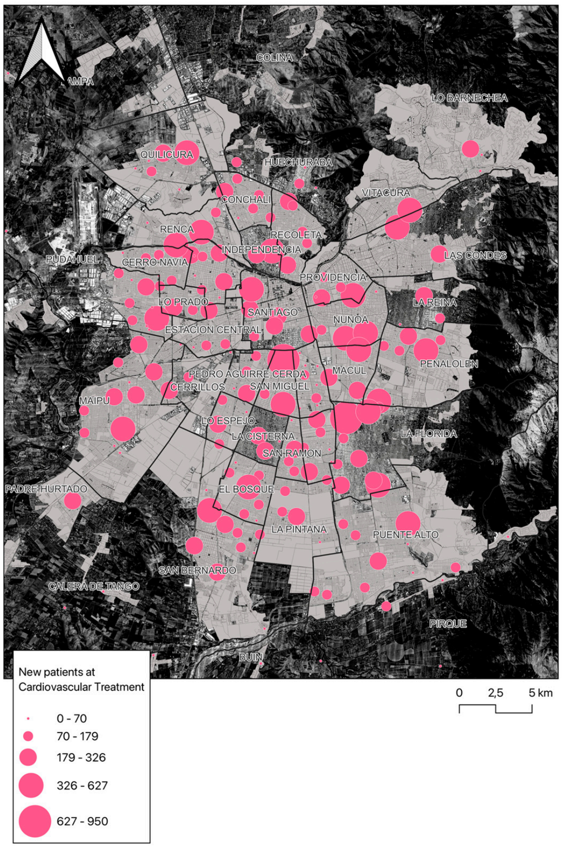

Figure 1. Geographic location of new patients in the cardiovascular program.

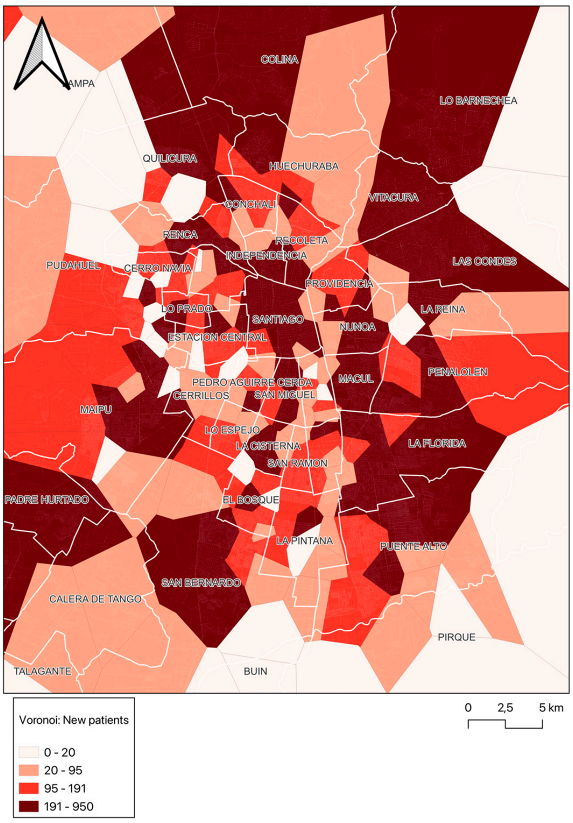

Figure 2. Voronoi distribution of new patients in the cardiovascular program.

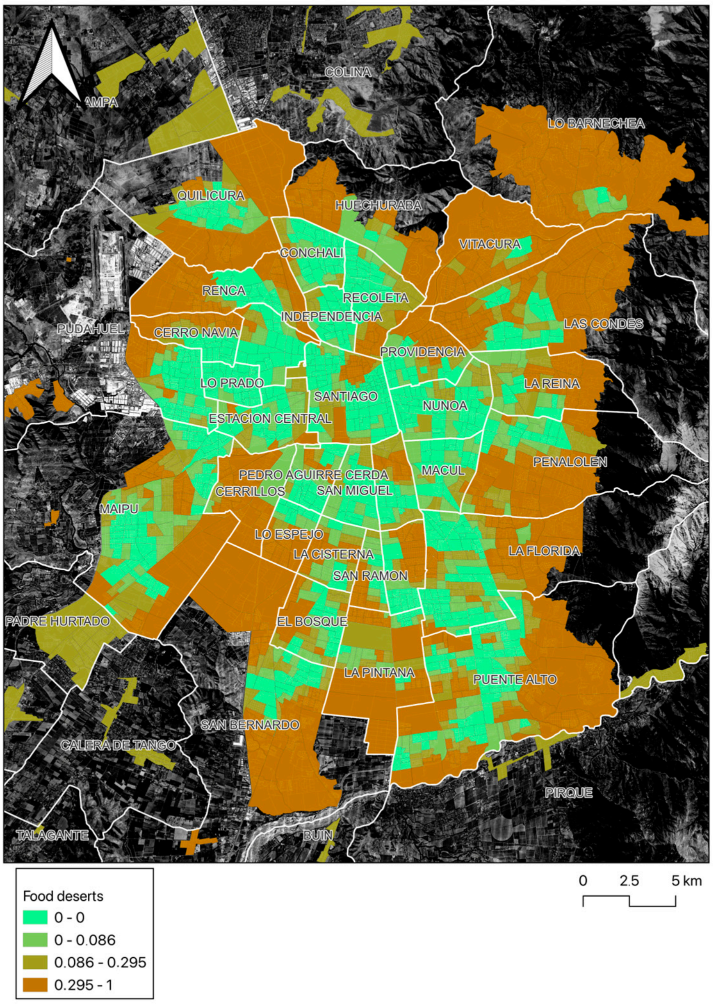

Figure 3. Food deserts in the Santiago metropolitan area.

In this process, we work only with areas within Greater Santiago, excluding rural areas, where the logics of approaching health centers and access to healthy food sources use different strategies from what occurs in urban territories, where in the case of the Metropolitan Region the use of automobiles predominates. As a result of this filtering process, 188 establishments are used out of an initial total of 249 (76% of the initial total) and their respective areas of influence. A multiscale geographically weighted regression (MGWR) model is applied to this geographic matrix [34]. This modeling aims to test whether there is a statistically significant relationship between the entry of elderly patients into the cardiovascular MOH program and the presence of food deserts. The MGWR model, while powerful in capturing spatial heterogeneity, has limitations, including potential biases from its assumption of smooth spatial relationships and reliance on accurate spatial data. To address these, we optimized bandwidth selection to minimize bias and used a high-precision spatial database. The model also assumes locally stationary relationships, which may not account for social or cultural dynamics, so we supplemented our analysis with contextual knowledge. Additionally, MGWR does not capture temporal dynamics, highlighting the need for future research to incorporate longitudinal data. These measures were taken to ensure the robustness and reliability of our findings.

The MGWR modeling performs a regression for each spatial unit under analysis, in this case, the Voronoi polygons indicated above, relative to the other surrounding spatial units and the local values that make up the information for each spatial unit analyzed. This allows us to capture the *p*-value of each set of relationships within the map and thus define how statistically significant this group of relationships is.

As mentioned above, the data used for this analysis is aggregated at the Census Zone Level. The location data is projected, ensuring that the spatial relationships are measured on a plane rather than a sphere, thus reducing potential distortions that might arise from spherical measurements. The MGWR approach was adopted because it extends the traditional Geographically Weighted Regression (GWR) by allowing each covariate to have its own bandwidth, thus capturing the multiscale effects of the covariates on the dependent variable. An adaptive bisquare kernel was employed to determine the spatial weighting scheme. The adaptive kernel ensures that each regression point uses a consistent number of nearest neighbors, which is particularly useful in areas with varying densities of observations. Also, the model used a bisquare function to ensure that weights decline smoothly to zero at the bandwidth distance, reducing the influence of distant observations. Bandwidth for each covariate was determined using the golden section search method, which optimizes the bandwidth selection by minimizing the corrected Akaike Information Criterion (AICc). AICc is an adjustment of the Akaike Information Criterion (AIC) that corrects for small sample sizes, providing a more reliable model selection metric in datasets with fewer observations. The general formulation of the MGWR model is as follows:

$$y_i = \beta_0(u_i, v_i) + \sum_{k=1}^{p} \beta_k(u_i, v_i) x_{ik} + \epsilon_i$$

where y_i is the dependent variable (number of cardiovascular patients) at location i; (u_i,v_i) represents the coordinates of location i; β_0 (u_i,v_i) is the intercept, which can vary spatially; β_k(u_i,v_i) are the coefficients for the k-th covariate xik, which can also vary spatially; and ϵi is the error term. The spatial variability of each coefficient β_k(u_i,v_i) is captured by allowing each covariate to have a different bandwidth.

This process of analysis allows a comparative review of whether the MGWR study improves in relation to a global regression and, specifically, allows us to see whether there is a statistical relationship between food deserts and cardiovascular health problems in patients in the public health system of the Metropolitan Area of Santiago, Chile.

3. Results

Initially, a global regression model was applied to investigate the relationship between food desert probability and the rate of elderly cardiovascular health patients (Table 1). The results of the global model indicate a very low r^2 value of 0.013, which suggests that the model explains only 1.3% of the variance in the dependent variable. Furthermore, the adjusted r^2 remains at 0.013, confirming the weak explanatory power of the model. The Akaike Information Criterion corrected for small samples (AICc) is 4584.193, which is relatively high and suggests poor model fit. The regression coefficient for food desert probability is estimated at 0.116 with a standard error of 0.025, resulting in a statistically significant t-value of 4.706 and a p-value of less than 0.001. This indicates a positive association between food desert probability and the rate of elderly patients in the cardiovascular program, albeit with limited predictive power.

Table 1. Global regression results.

Variables:	Intercept	Food Desert Probability
Estimated values	0.000	0.116
Standard Error	0.025	0.025
t-statistic	0.000	4.706
p-value	1.000	0.000

Diagnostic information: Residual sum of squares: 1599.128; Log-likelihood: −2289.089; AICc: 4584.193; r^2: 0.013; adjusted r^2: 0.013.

In contrast, the MGWR model, which allows for spatially varying relationships, provides a significantly improved fit. The MGWR model achieves an r^2 value of 0.520, indicating that it explains 52.0% of the variance in the rate of elderly cardiovascular health patients. The adjusted r^2 is slightly lower at 0.467, but still represents a substantial improvement over the global regression model. The Corrected Aikaike Information Criterion (AICc) for the MGWR model is 3767.512, a marked reduction from the global model, highlighting the superior ability of MGWR to capture spatial variations in the data (Table 2). The MGWR model utilizes an adaptive bisquare kernel to determine spatial weights and employs the golden section search method for optimizing bandwidth selection. The results show that the bandwidth for the intercept is 59, while the bandwidth for the food desert probability is 47, indicating that the spatial influence of these variables varies across the study area.

Table 2. MGWR results.

Variable	Intercept	Food Desert Probability
Mean	0.037	0.162
Standard Deviation (STD)	0.378	0.554
Minimum	−0.354	−0.709
Median	−0.063	0.055
Maximum	2.623	5.051
Bandwidth	59.000	47.000
Effective Number of Parameters (ENP_j)	65.682	93.718
Adjusted t-value (95%)	3.373	3.470
Degrees of Dependence (DoD_j)	0.434	0.386
Bandwidth Confidence Intervals (95%)	(50 63)	(45 47)

Diagnostic information: Residual sum of squares: 778.466; Log-likelihood: −1705.619; Corrected Aikaike Information Criterion (AICc): 3767.512; r^2: 0.520; adjusted r^2: 0.467.

The summary statistics for the MGWR parameter estimates revealed substantial spatial heterogeneity in the relationship between the variables. The mean estimate for the intercept was 0.037, with a standard deviation of 0.378 and a range from −0.354 to 2.623. This variability suggests that the baseline rate of elderly cardiovascular health patients varies significantly across different Census Zones. The mean estimate for food desert probability is 0.162, with a standard deviation of 0.554 and a range from −0.709 to 5.051, indicating that the impact of food deserts on cardiovascular health patient rates was also spatially variable. The substantial increase in r^2 from the global regression model to the MGWR model underscores the importance of accounting for spatial heterogeneity in the analysis. The MGWR model's ability to reveal localized variations provides a more nuanced understanding of the factors influencing cardiovascular health outcomes. Specifically, the spatial variability in the relationship between food desert probability and cardiovascular health patient rates suggests that interventions to address food deserts may need to be tailored to specific neighborhoods within Greater Santiago. The significantly lower AICc value for the MGWR model further confirms its superior fit and predictive capacity. This improvement suggests that the MGWR model more accurately captures the underlying spatial processes affecting cardiovascular health, thereby offering valuable insights for public health planning and policy development. Thus, the MGWR analysis shows a strong, spatially varying relationship between food deserts and cardiovascular health patient rates in Greater Santiago. The enhanced explanatory power and improved model fit highlight the critical need for spatially explicit approaches in public health research enabling more targeted and effective interventions.

Figure 4 illustrates the local r^2 values of the MGWR model applied to Greater Santiago. The map is divided into Census Zones, each shaded according to their local r^2 values, which indicate the proportion of variance in the rate of elderly cardiovascular health patients explained by the probability of food deserts within each zone. The color gradient ranges from light grey to dark blue, representing increasing values. The lightest shade (light grey) corresponds to the lowest local r^2 values, indicating areas where the MGWR model explains a minimal portion of the variance. These zones include parts of central and northern Santiago, such as Conchalí, Lo Prado, Estación Central, Cerrillos, and some areas of La Reina and Vitacura. The darkest blue areas represent the highest local r^2 values, suggesting a strong explanatory power of the model in these regions. Notably, these high r^2 zones are found in the southern and eastern parts of the city, such as San Bernardo, La Pintana, Puente Alto, and Lo Barnechea, mostly related to low-income communities. Nevertheless, the r^2 is also high in wealthier areas such as Vitacura, Ñuñoa, and Las Condes. On the other hand, the r^2 shows more heterogeneity in Providencia, Recoleta, and Santiago. Areas with higher r^2 values likely face a more pronounced impact from food deserts on cardiovascular disease rates, pointing to critical zones for targeted public health interventions. Conversely, regions with lower values may require additional factors to be considered to fully understand the drivers of cardiovascular health disparities.

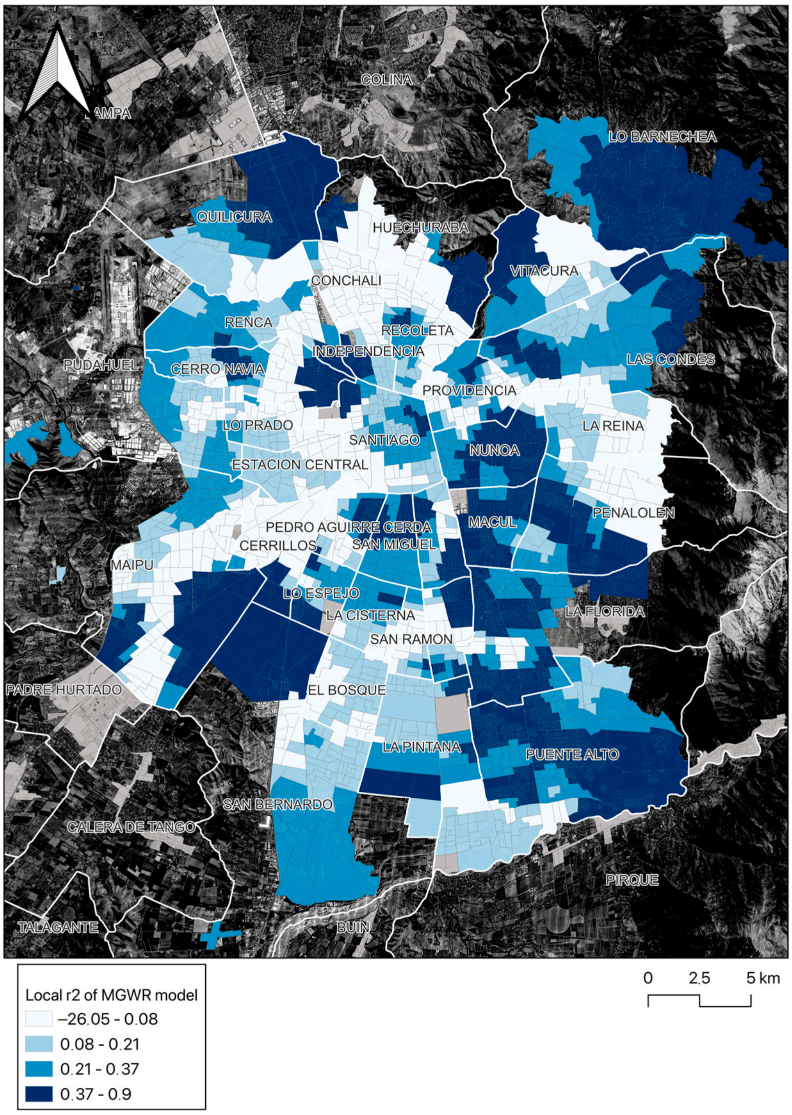

Figure 4. Local r^2 of MGWR in Greater Santiago.

Figure 5 presents the spatial distribution of residuals from the MGWR model for Greater Santiago. The residuals are color-coded, ranging from light pink (indicating negative residuals) to dark red (indicating positive residuals). Negative residuals suggest that the model overpredicted the rate of elderly cardiovascular health patients, while positive residuals indicate underpredictions.

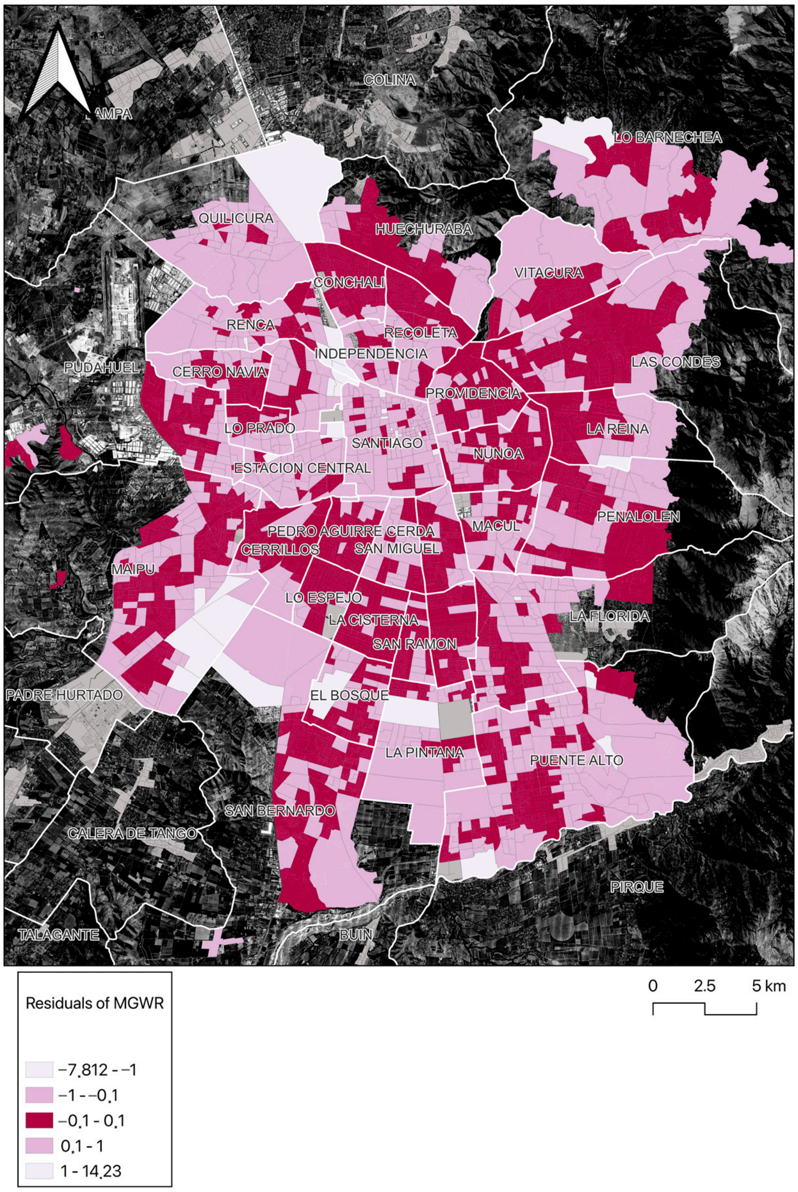

Figure 5. Residuals of MGWR.

Notably, central areas such as Santiago and Ñuñoa display mostly negative residuals, implying overestimation by the model. Conversely, southern zones such as La Pintana and Puente Alto exhibit positive residuals, suggesting underestimation. This spatial pattern highlights areas where the MGWR model's predictions are less accurate, indicating potential factors not captured by the model. The darker areas are where the model is more accurate, indicating that in relevant parts of the city the model works well. In all the municipal areas of the city there are at least two censal zones where the model offers small residuals, making it suitable to advance in a lower scale of analysis.

The MGWR model demonstrates considerable utility in predicting cardiovascular health diseases, specifically through its ability to capture spatial heterogeneity in the relationship between food deserts and the rate of elderly patients in cardiovascular programs. By allowing each covariate to have its own bandwidth, the MGWR model accounts for local variations that a global regression model cannot. However, the MGWR model also has limitations. One primary limitation is its complexity, which requires substantial computational resources and expertise in spatial statistics. The interpretation of results can be challenging, as the model produces location-specific coefficients that may vary widely across the study area. Additionally, the model's reliance on accurate spatial and demographic data means that any inaccuracies in these inputs could compromise the validity of the results. Lastly, while MGWR enhances predictive power for spatial relationships, it does not account for temporal dynamics, which are also crucial in understanding and predicting cardiovascular health over time.

4. Discussion

This study provides an in-depth analysis of the spatial relationship between food deserts and cardiovascular health among elderly populations in Greater Santiago, utilizing the MGWR model. The results underscore the significant impact of food accessibility on health outcomes, advancing our understanding of nutritional inequities and their implications for public health policy and urban planning. The reviewed literature highlighted the concept of nutritional transition [4], which describes the change from traditional diets—i.e., a dietary pattern based on home-cooked and natural foods, with a higher intake of cereals, legumes, and vegetables and low in meat and dairy products [35]—to diets dominated by highly processed foods due to economic and demographic changes. This shift is particularly pertinent in urban areas, where the availability of fresh, nutritious foods is often limited. The study's findings align with this theoretical framework by demonstrating a significant correlation between the presence of food deserts and higher rates of cardiovascular health among elderly residents. Specifically, the MGWR model, with an r^2 value of 0.520, indicates that food desert probability explains a substantial portion of the variance in cardiovascular health outcomes. This relationship emphasizes the critical role of food environments in shaping dietary habits and health. The findings support previous research suggesting that areas with limited access to healthy foods contribute to poorer dietary quality [16–18] and increased risk of chronic diseases [8,9]. The MGWR model's ability to capture local variations further illustrates how these effects are not uniformly distributed but vary significantly across different neighborhoods.

The spatial heterogeneity revealed by the MGWR model underscores the importance of tailored public health interventions. High local r^2 values in southern and eastern Santiago, such as in San Bernardo, La Pintana, and Puente Alto, indicate that these areas are particularly vulnerable to the negative health impacts of food deserts. These regions, often characterized by lower socioeconomic status, face significant barriers to accessing nutritious foods, which exacerbates health disparities, as observed in a recent study in US households [36]. Conversely, areas with lower r^2 values, such as central and northern Santiago, may require a different approach to complement the understanding provided by this study regarding their access to healthy food. This variability may be crucial in developing a hypothesis about the relationship between improving food access and additional factors, such as healthcare access, education, and socioeconomic conditions, which also play pivotal roles in determining health outcomes [37].

The aging population in Chile presents unique challenges for public health [19,20]. The study's focus on older adults in the cardiovascular program highlights a vulnerable group that is disproportionately affected by poor food environments, as has been observed in several recent studies [38,39]. Therefore, with projections indicating a significant increase in the elderly population, the findings of this study underscore the urgency of addressing nutrition-related health disparities to improve the quality of life for older adults. In this regard, one study identified four themes that demonstrate how food and nutrition affect quality of life: food access and choice, food preparation, health and vitality, and enjoyment of food [40]. Furthermore, the relationships among these themes suggest that food and nutrition have a broad effect on the factors influencing the quality of life for older people. While enhancing food access in high-risk areas is crucial, the study suggests that addressing cardiovascular health requires a holistic approach. Interventions should also focus on improving healthcare access, education, and addressing socioeconomic barriers. The MGWR model indicates that these factors interact in complex ways across different neighborhoods. Future interventions should be multifaceted and tailored to community needs. Although further research is needed, this study highlights the necessity of integrating public health with urban planning to create healthier, food-resilient urban environments. The evidence presented underscores the importance of coordinated efforts between policymakers to advance these critical issues.

Economic constraints are a significant barrier to healthy eating [27,28], as highlighted in the introduction. The study's findings that areas with high food desert probability correlate with higher cardiovascular health disease rates may support the notion that economic factors heavily influence dietary choices. The perception of cost as a barrier to healthy eating, especially among the elderly, underscores the need for policies that make nutritious foods more affordable and accessible. Nevertheless, a different study on this matter should confirm this assumption. Literature presented previously showed that a substantial proportion of elderly Chileans are food secure but still consume diets needing improvement [22]. This dichotomy highlights the complex interplay between food availability, economic capacity, and dietary quality. The study advances this understanding by providing spatial evidence that economic constraints coupled with poor food environments significantly impact health outcomes.

This research advances knowledge by providing robust spatial analysis of the relationship between food deserts and cardiovascular health, emphasizing the importance of localized interventions. The use of MGWR allows for a nuanced understanding of how these relationships vary across different neighborhoods, offering insights that traditional global regression models cannot provide. Future research should explore temporal dynamics to complement the spatial analysis presented here. Understanding how these relationships evolve over time could provide deeper insights into the long-term impacts of food environments on health. For example, assessing the shift from a food desert to a food oasis (areas with the presence of healthy food commerce) over time could reveal how these new dynamics influence people's health status by providing a greater supply of healthy foods (e.g., decreased incidence of cardiovascular diseases), improved mental and physical health, and overall quality of life. Conversely, in the worst-case scenario, if the food desert environment remains unchanged, prolonged exposure could further impact people's health. For instance, individuals with poorer diet quality have been reported to have mental health problems [41,42]. Additionally, incorporating other health determinants such as physical activity, healthcare access, and social support networks can offer a more comprehensive view of the factors influencing cardiovascular health. However, to produce this type of study at the census block scale, it would be necessary to carry out a different kind of survey with a level of precision comparable to what has been done for this study, at least concerning the independent variables to be measured. In the case of Chile, information at this scale remains scarce.

5. Conclusions

This study highlights the critical role of food environments in shaping health outcomes among the elderly in Santiago. This study illuminates the intrinsic connection between food deserts and the cardiovascular health or people over 60 years of age in Greater Santiago, emphasizing the importance of considering spatial variables in public health monitoring and intervention. Through the implementation of the MGWR model, we have provided a detailed and geographically sensitive analysis that highlights how socioeconomic segregation and urban planning contribute significantly to the formation of unequal food environments, directly affecting diet quality and, therefore, the cardiovascular health of this vulnerable population.

The application of the MGWR methodology has allowed for a more heralded and location-specific analysis of the interaction between access to healthy food and health indicators, demonstrating its ability to tailor policy and health responses to the specific needs of different communities within the Metropolitan Region.

Thus, it is essential to explore other correlations, such as mobility, consumption habits, and gender roles, all of which may be related to cardiovascular health. Therefore, further studies that include health and social variables, as well as spatial and geographical distribution, are necessary to further understand the phenomenon observed in this analysis. Based on the findings of this study, urban policy in Santiago should prioritize the development of targeted interventions to improve access to healthy foods in areas identified as food deserts, particularly those with high rates of cardiovascular health among the elderly. This could involve incentivizing the establishment of fresh food markets and grocery stores in underserved neighborhoods, as well as enhancing public transportation links to these areas. Additionally, integrating food accessibility considerations into broader urban planning and zoning regulations could help create more equitable and health-promoting environments across Greater Santiago.

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