

Article

Urban Sustainability of Quito Through Its Food System: Spatial and Social Interactions

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Abstract

This study explores the spatial and social implications of urban food systems in Quito, Ecuador, focusing on how food access inequalities reflect and reinforce broader urban disparities. The research addresses a critical problem in contemporary urbanization: the disconnection between food provisioning and spatial equity in rapidly growing cities. The objective is to assess and map disparities in food accessibility using a mixed-methods approach that includes field observation, participatory mapping, value chain analysis, and statistical modeling. Five traditional and emerging food markets were studied in diverse districts across the city. A synthetic accessibility function $F(x)$ was constructed to model food access levels, integrating variables such as income, infrastructure, transport availability, and travel time. These variables were subjected to Principal Component Analysis (PCA) and hierarchical clustering to generate three typologies of territorial vulnerability. The results reveal that peripheral areas exhibit lower $F(x)$ values and weaker integration with the formal food system, leading to higher consumer costs and limited fresh food options. In contrast, central districts benefit from multimodal infrastructure and greater diversity of supply. This study concludes that food systems should be treated as critical urban infrastructure. Integrating food equity into land use and mobility planning is essential to promote inclusive, sustainable, and resilient urban development.

Keywords: urban sustainability; food system design; spatial dynamics; food equity; quito



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1. Introduction

Urban food systems are increasingly recognized as key components in shaping spatial configurations and social interactions within cities [1,2]. As urban areas expand, the need to ensure sustainable, equitable, and resilient access to food has become a critical element in city planning. In the case of Quito, Ecuador's capital and one of the fastest-growing urban centers in the Andean region, the influence of the food system on the built environment and daily life is profound yet often overlooked in mainstream urban policy.

The theoretical framework guiding this study draws from three interrelated concepts: spatial justice, food-sensitive urbanism, and urban infrastructure inequality. Spatial justice, as defined by Soja [2], addresses the unequal distribution of urban resources and how such asymmetries reinforce social exclusion. In the context of food systems, this translates into disparities in market access, pricing, and infrastructure. The emerging paradigm of

food-sensitive urbanism [3] argues that food provisioning must be treated as a fundamental layer of urban planning, on par with housing, transport, and sanitation. Finally, urban infrastructure inequality highlights how investments in core services often favor formal, central areas while neglecting informal and peripheral zones. These frameworks are particularly relevant to Quito, where the distribution of food infrastructure both reflects and reproduces longstanding socio-spatial divisions. By engaging these perspectives, this study situates food access not as a logistical issue but as a political and spatial one, with direct implications for urban justice and resilience.

Historically, food systems have dictated the spatial distribution of human settlements, with markets emerging as foundational urban cores [4–6]. In Latin American cities, including Quito, colonial market structures defined not only economic hubs but also the morphology of public spaces and transportation routes. These markets functioned as more than spaces of commerce—they were places of social convergence and cultural exchange, embedding food deeply into the socio-spatial identity of neighborhoods.

In Latin America, food markets have long played a pivotal role in shaping urban morphology and social life. Major cities such as Mexico City operate more than 300 public markets, Bogotá manages around 44 plazas de mercado, and Lima has over 100 traditional markets administered at the municipal and district levels. Despite their centrality, many of these facilities face challenges, including infrastructure decay, informal competition, limited integration with public transportation, and governance fragmentation. Quito, with a population of over 2.8 million, has a network of 54 municipal markets, yet only 12 have adequate facilities such as refrigeration, public restrooms, or safe pedestrian access [7]. This contrasts sharply with the needs of peripheral neighborhoods, where more than 35% of residents lack access to a formal market within a 30 min walking distance. These data reveal that although food markets remain socially vital, their spatial and infrastructural integration into urban systems is increasingly uneven—particularly in secondary cities of the Global South.

These disparities are not evenly distributed across the urban territory. While central parishes enjoy dense provisioning networks, peripheral districts experience clear accessibility gaps. Figure 1 illustrates the estimated share of the population with pedestrian access to municipal markets in selected districts [8,9].

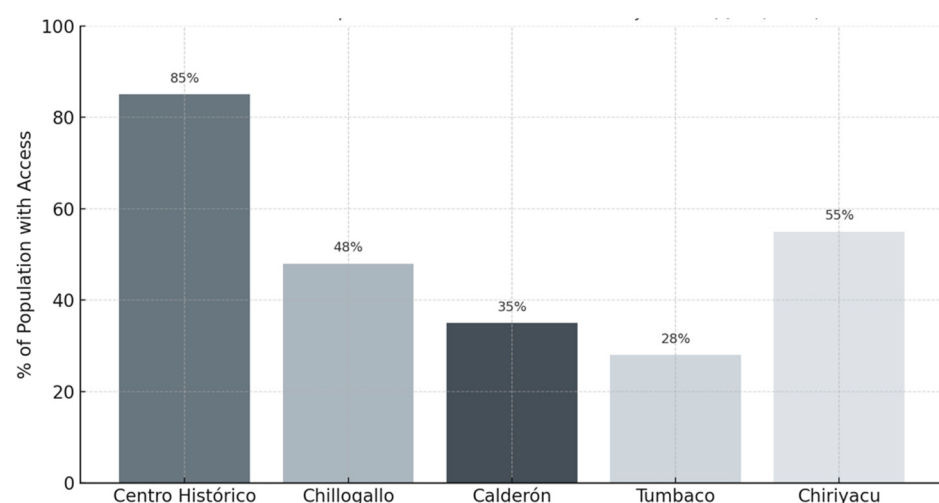


Figure 1. Access to municipal markets within a 30 min walk presented by district. The estimated percentage of the population with pedestrian access to municipal markets in five urban districts of Quito: Centro Histórico, Chillogallo, Calderón, Tumbaco, and Chiriyacu. The figure highlights spatial disparities in food infrastructure accessibility between the central and peripheral zones of the city.

These inequalities are the result of historical shifts—from colonial market centrality to modern supermarket dispersion—deeply influencing urban morphology. The decline in neighborhood-based provisioning in favor of centralized logistics has fragmented food flows and weakened the integration of food into urban planning agendas. In Quito, municipal markets such as Iñaquito, Santa Clara, and San Roque have long served as centers for fresh produce and community interaction. Located along key transportation corridors and surrounded by dense urban fabrics, these spaces illustrate how food distribution systems shape movement patterns and urban land use [10]. However, recent decades have seen a transformation in Quito's food landscape, characterized by the proliferation of supermarket chains, the emergence of informal street vendors, and the rise of digital delivery services. These new actors have reconfigured the spatial logic of food access, often privileging higher-income sectors and formalized commercial zones.

The increasing complexity of Quito's food network has revealed stark inequalities. While central districts enjoy abundant access to diverse food options, peripheral neighborhoods often face logistical and infrastructural barriers that limit access to fresh and nutritious products [11]. This spatial disparity contributes to food deserts and increases reliance on processed or less healthy alternatives. Such inequalities are exacerbated by a distribution model that concentrates wholesale logistics in a few central nodes, resulting in higher transportation costs and greater carbon footprints.

At the heart of these issues lies the urban configuration of food pathways—from production to consumption. Scholars argue for the integration of food systems into urban planning frameworks, advocating for “food-sensitive urban design” that considers how food-related infrastructures interact with housing, transport, and public services. In Quito, the alignment of urban development with food equity goals presents both a challenge and an opportunity. The city's topographic complexity, fragmented urban growth, and socioeconomic diversity require context-specific strategies that bridge spatial planning with food governance.

A growing body of research underscores the importance of localized food systems and shorter supply chains in enhancing urban resilience. Concepts such as proximity economies, agroecological corridors, and urban agriculture are gaining traction in policy and academic circles alike. Quito has responded to these ideas through municipal initiatives like bioferias and composting programs, yet the integration of these efforts into the broader urban framework remains uneven.

The historical evolution of Quito's food system is closely intertwined with the city's spatial morphology. During the colonial period, food markets were deliberately positioned at the core of urban life, embedded within plazas and transportation nodes. These markets—such as San Roque and Santa Clara—served not only as provisioning hubs but also as catalysts for commercial and residential density. The radial expansion of streets and the clustering of services around these markets contributed to compact, walkable neighborhoods. However, post-1970s urban growth shifted provisioning dynamics toward peripheral supermarket chains and wholesale logistics centers, driven by automobile dependency and land speculation [12]. This transition fractured the traditional urban fabric and displaced market-centered development, leading to mono-functional zoning and longer travel distances for low-income households. The erosion of neighborhood-based food infrastructure contributes to both spatial inequality and social disconnection. In Quito, the legacy of centrality remains visible in traditional markets, but newer urban extensions—such as Calderón or Tumbaco—reflect fragmented morphologies where food infrastructure is often absent or disconnected from everyday mobility flows.

Moreover, climate change and external shocks such as pandemics further stress the importance of robust urban food systems. The COVID-19 crisis exposed vulnerabilities in

global and local supply chains, highlighting the need for diversified, community-anchored food networks [13]. In Quito, informal markets and small retailers played a crucial role in maintaining food access during lockdowns, revealing their resilience and adaptability in contrast to centralized systems that temporarily collapsed.

Understanding Quito's urban food configuration, therefore, requires a multidisciplinary approach that bridges urbanism, environmental policy, public health, and socioeconomics. This paper adopts such a perspective, aiming to identify spatial and governance patterns that hinder or facilitate equitable food access in the city. By mapping key food distribution nodes, analyzing pricing structures, and evaluating planning interventions, this study proposes strategies to enhance food justice while supporting sustainable urban development.

In the sections that follow, this article delves into the methodological framework adopted, presents key findings from spatial and economic analyses, discusses implications for urban planning, and concludes with recommendations for policy and practice. To deepen the territorial dimension of these food logics, this study integrates a multivariable statistical model to evaluate access disparities across urban sectors.

The ultimate goal is to contribute to the global discourse on food-sensitive urbanism through the lens of Quito—a city marked by vibrant cultural traditions, geographic challenges, and a rapidly evolving urban fabric.

In recent years, the intersection between food systems and urban equity has gained increasing relevance, particularly in cities of the Global South. The concept of spatial justice [14] emphasizes the equitable distribution of urban resources, including food, infrastructure, and mobility. Spatial justice is not only about access to space, but about the ability of urban residents to live with dignity, access essential services, and participate in the shaping of their environment. In the context of food systems, this implies analyzing how infrastructure and planning decisions influence differentiated access to food across territories.

Food-sensitive urban planning, as proposed by scholars such as Ilieva [3] and Morgan [4], advocates for integrating food considerations into urban design, infrastructure development, and governance. This approach aligns food accessibility with broader urban agendas, including sustainability, public health, and poverty reduction. Particularly in Latin American cities, where informal food economies coexist with formal market networks, planning must consider the socio-spatial dynamics that shape food access and distribution.

Finally, the notion of infrastructure inequality [15] underlines how uneven investments in roads, transit, public space, and utilities often reproduce territorial exclusion. In peripheral urban areas, food deserts emerge not only due to distance from markets but also due to the cumulative effect of poor sidewalks, lack of lighting, and insufficient public transit. This study aims to address these gaps by modeling food accessibility through an integrated urban lens, linking infrastructure, location, and territorial equity.

2. Materials and Methods

2.1. Study Area and Methodological Approach

This research adopts a qualitative and quantitative integrative methodological framework to examine the intersections between Quito's food system and its urban spatial configuration. Rather than isolating analytical components, the methodology is designed as an interconnected process in which observation, stakeholder engagement, policy analysis, and spatial modeling inform one another in a recursive and contextual manner. This dynamic approach recognizes that urban food systems are not only logistical or nutritional concerns, but spatial and cultural systems embedded in political economies and everyday practices [16].

The research was conducted between October 2024 and February 2025, focused on five representative food markets in the city of Quito. The selection of the five municipal markets—Chiriyacu, Iñaquito, San Roque, Santa Clara, and Mercado Mayorista—was based on strategic representativeness within Quito’s urban food distribution network (Figure 2). These markets were selected according to a combination of spatial, functional, and demographic criteria:

- Geographic dispersion: The markets are distributed across central, intermediate, and peripheral areas, covering a wide urban spectrum.
- Functional typology: The sample includes wholesale markets (e.g., Mercado Mayorista), traditional and historic retail markets (e.g., San Roque), and upgraded municipal infrastructure (e.g., Santa Clara).
- Service capacity and demand intensity: Each market demonstrates significant daily user flow, serving as logistical and symbolic food nodes for large urban sectors.
- Socioeconomic diversity of surrounding neighborhoods: The selected markets are located in areas with distinct income levels, ethnic compositions, and urban morphologies, allowing comparative territorial analysis.

This methodological approach follows the guidelines proposed by Sonnino et al. [1], who advocate for typological and spatial diversity in market-based food system assessments.

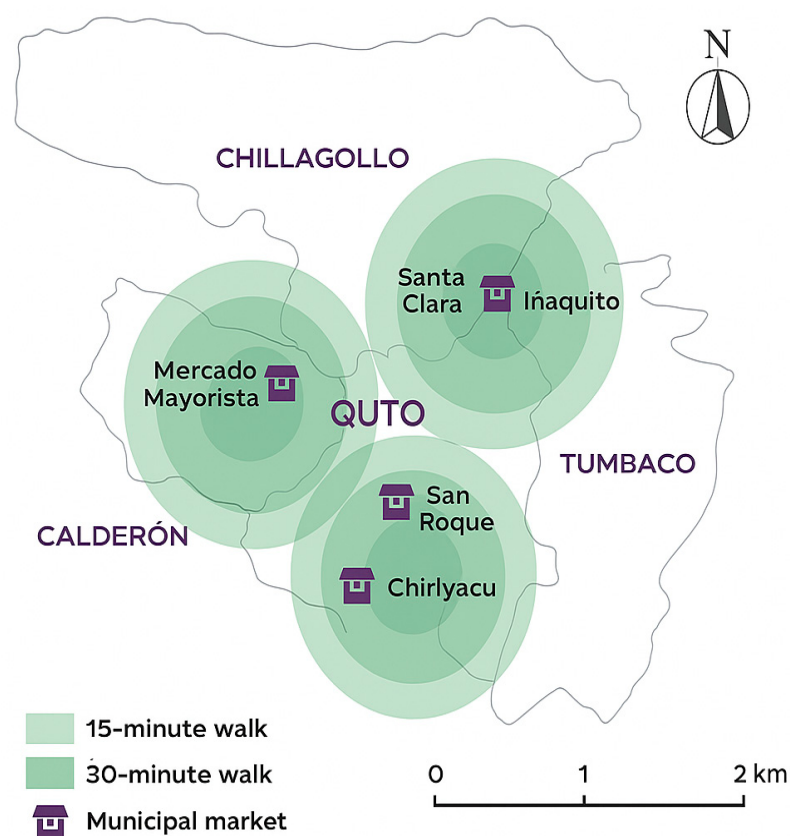


Figure 2. Spatial relationship between selected districts and the main wholesale markets analyzed in Quito.

These observations were supported by a documentary analysis of public policies, institutional frameworks, and territorial planning documents. Key references included the Metropolitan Plan for Development and Land Use (PMDOT), the 2020–2030 Quito Food Policy, and national instruments such as the Organic Law on Food Sovereignty and the White Paper on Circular Economy [17]. A qualitative content and discourse analysis approach was used to examine the underlying political and planning narratives.

The methodological steps followed in this research are summarized in Figure 3:

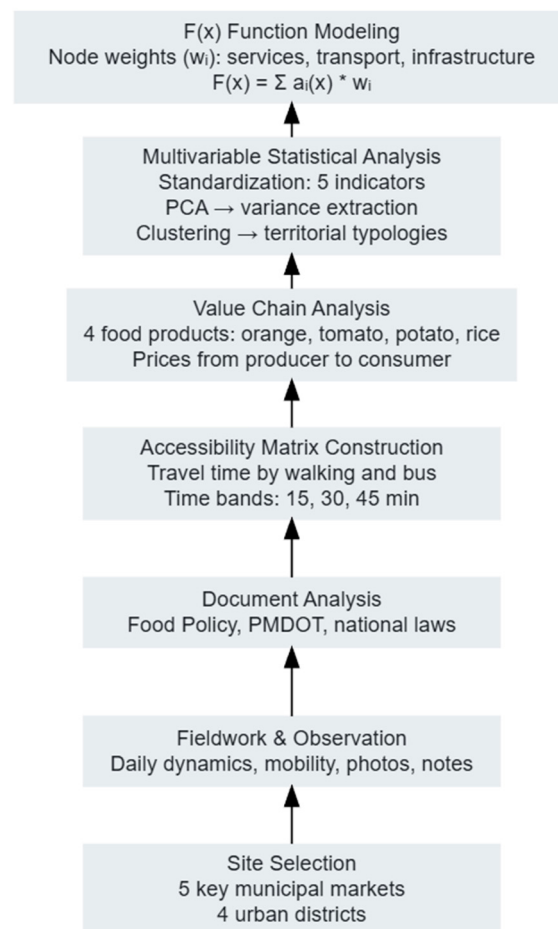


Figure 3. Methodological framework of the study. Diagram illustrating the sequential research process applied in the study, including site selection, field observation, documentary analysis, accessibility matrix construction, food value chain analysis, multivariable statistical processing (PCA and clustering), and final modeling through the $F(x)$ function. This framework allowed for the spatial stratification of food accessibility conditions across urban districts in Quito.

The review revealed clear tensions between dominant models of urban growth and the principles of food sovereignty and sustainability, as well as disconnections between formal planning rhetoric and the daily experiences of market users and small-scale producers.

To enrich the spatial characterization of food access, an accessibility matrix was built based on observed mobility patterns and approximate travel times to the nearest provisioning point. Four districts—Centro Histórico, Chillogallo, Calderón, and Tumbaco—were selected to illustrate the variation in market access across the city. Travel times were recorded for 15 min and 30 min walking intervals, as well as 45 min public transport trips (Table 1). The classification revealed clear structural barriers for peripheral zones compared to centrally located ones.

To complement the qualitative data, a value chain analysis was carried out for four emblematic food products: rice, tomatoes, oranges, and potatoes. The analysis tracked price changes from the point of origin to final sale. It revealed considerable markups along the chain, with intermediaries capturing the largest share of the profit margin. For example, the average retail price of oranges in supermarkets was between 150% and 180% higher than the farm gate price, depending on the distribution channel. This reflects the accumulation of transport, handling, packaging, and intermediary costs along the chain. These findings

were illustrated using a simplified Sankey diagram (Figure 4), which visualized value losses, transport costs, and profit flows across the chain [18–21].

Table 1. Access to food markets by time and mode.

Sector	Market Type	15 min Walk	30 min Walk	45 min by Bus
Centro Histórico	Traditional	✓	✓	✓
Chillogallo	Informal	✗	✓	✓
Calderón	Mixed	✗	✗	✓
Tumbaco	Supermarket only	✗	✗	✓

The checkmarks (✓) and crosses (✗) are used to indicate the presence or absence of access and are self-explanatory in the context.



Figure 4. Simplified Sankey diagram for the orange value chain in Quito. Illustrative diagram showing cost flow and value distribution from producer to consumer.

2.2. Data Collection and Indicators

To evaluate disparities in food access in a statistically rigorous manner, a multivariable dataset was constructed for 15 urban sectors in Quito. Five indicators were selected, derived from spatial analysis, field observations, and market-level data:

- Travel time to nearest municipal market (minutes): Calculated using a network-based accessibility matrix for walking and bus transport (15, 30, and 45 min bands).
- Availability of staple products (% of selected items available): Based on a field inventory of four core food products—orange, tomato, potato, and rice—within each market.
- Quality of public infrastructure in access routes (score 1–5): Assessed through direct observation of sidewalks, lighting, signage, and safety conditions.
- Public transport connectivity (number of access points within 300 m): Derived from the municipal transport network database.
- Average retail price of staple food items (USD/kg): Collected through market surveys as part of the value chain analysis.

All variables were standardized using the Z-score formula:

$$Z = \frac{X_i - \bar{X}}{\sigma} \quad (1)$$

where

X_i : observed value;

$\bar{X}$: variable's mean;
 σ : standard deviation.

To ensure consistency and reliability, the indicators were cross-validated with data from the Ecuadorian National Institute of Statistics and Censuses INEC, 2022, the 2020 Quito Urban Mobility Survey, and the Food and Agriculture Organization [13].

These harmonized and normalized indicators provided the input matrix for the multi-variate statistical procedures described in Section 2.4.

2.3. Modeling Accessibility with the $F(x)$ Function

To better understand how food systems integrate with urban dynamics and influence the physical and social fabric of the city [22], this study proposes a theoretical model inspired by graph theory and accessibility analysis. The urban food network is conceptualized as a graph $G = (V, E)$, where V represents nodes such as municipal markets, distribution centers, community gardens, and supermarkets, and E represents the connections between them—namely distribution routes that are weighted by factors like cost, travel time, reliability, and environmental impact (Figure 5).

$G = (V, E)$

Distribution routes - - - - -

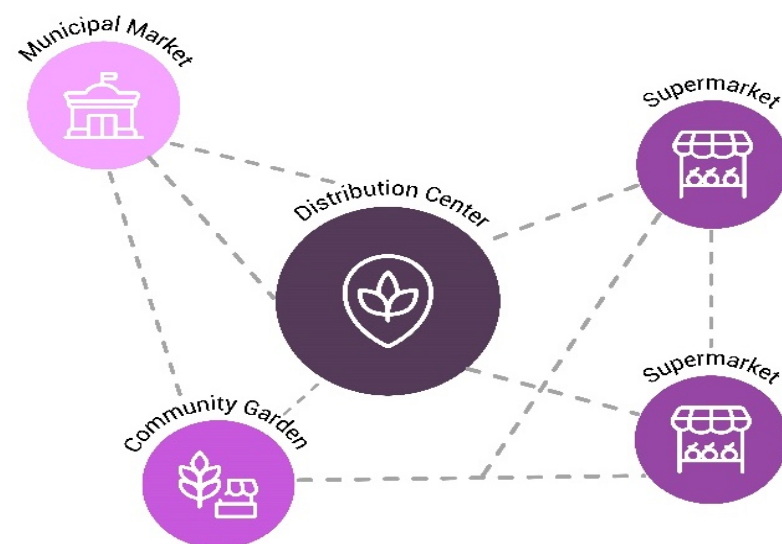


Figure 5. Conceptual representation of the urban food network in Quito.

To measure accessibility to food infrastructure from any urban location x , we define the function $F(x)$ as follows:

$$F(x) = \sum (w_i \times a_i(x)) \quad (2)$$

Here, w_i represents the relative weight or capacity of node i , considering factors such as availability of products, service frequency, infrastructure condition, and quality of access. The term $a_i(x)$ is the accessibility of node i from location x , calculated as an inverse function of travel time, congestion, and affordability. For example, if x corresponds to a low-income peripheral neighborhood and node i is a municipal market reachable only by two bus transfers and a 10 min walk, then $a_i(x)$ would be low, even if w_i is high (Figure 6).

$$a_i(x) = f(w_i, \dots)$$

w_i represents the weight or capacity of node i

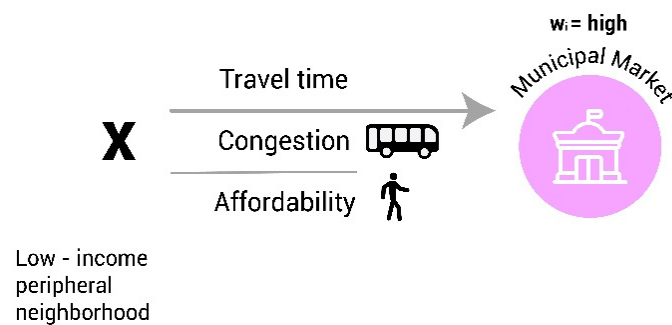


Figure 6. Graph-based model of urban food accessibility in Quito. A diagram illustrating food infrastructure nodes and weighted access routes.

All variables were normalized to a [0–1] scale to allow comparability, and a weighted average was calculated to obtain the final w_i values. The weights were determined through expert judgment and guided by previous research on food-sensitive urban planning. While no formal Analytic Hierarchy Process (AHP) or entropy-based method was applied, we conducted a sensitivity analysis ($\pm 10\%$ variation in weights) to evaluate the robustness of the results. The outcomes confirmed the model’s stability and reliability in classifying spatial food accessibility [23,24].

To illustrate this, imagine two neighborhoods: La Mariscal, located in the central district, and Carapungo, in the northern periphery. A municipal market near La Mariscal may have $w_i = 0.9$ (high quality and availability) and $a_i(x) = 0.95$ (high accessibility), producing a strong contribution to $F(x)$. In contrast, Carapungo may only be served by a supermarket with $w_i = 0.5$ and $a_i(x) = 0.3$, resulting in reduced access. Comparing the total $F(x)$ for each neighborhood provides an estimate of food accessibility disparities across the city.

The objective is to maximize $F(x)$ for all urban zones, subject to constraints on investment cost, carbon emissions, land use compatibility, and equity objectives. The model thus offers a replicable tool for planners to simulate different configurations of food infrastructure and optimize resource allocation while advancing spatial justice. Similar spatial optimization models have been used in urban transportation and health service planning [25,26], and here we adapt the logic to the food infrastructure context in Quito.

The conceptual underpinning of this research aligns with the paradigm of Food System Urbanism (FSU) (Figure 7), which positions food not merely as a commodity but as a driver of urban spatiality and socio-environmental metabolism [27]. This framework draws on the work of Soja on spatial justice [7], Bettini et al. on urban metabolic transitions [28], and Moreno and Arce on proximity economies [29]. These intersecting perspectives allow for a multiscale understanding of how food flows shape the material, political, and symbolic urban fabric.

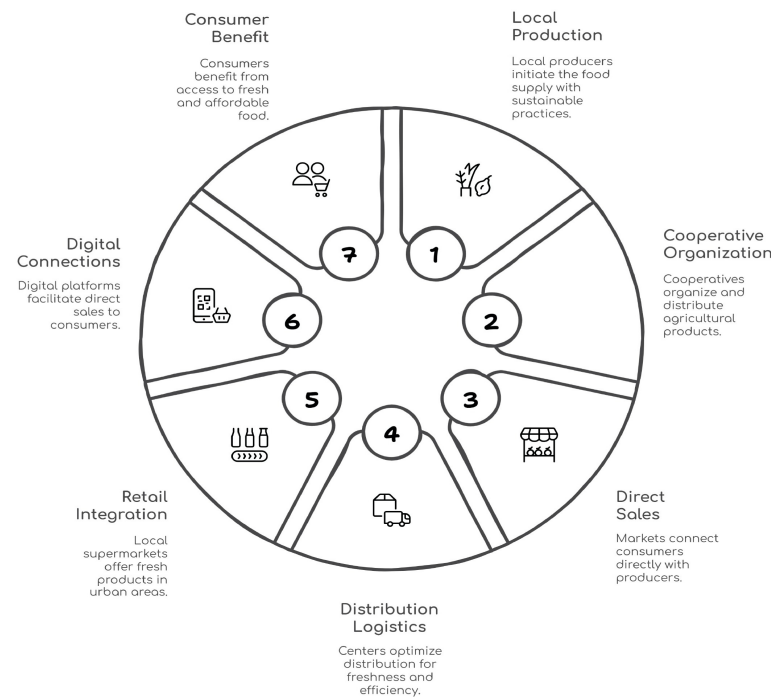


Figure 7. Conceptual framework of food system urbanism in Quito. Diagram linking food flows, spatial accessibility, governance, and urban metabolism.

2.4. Principal Component and Clustering Analysis

To complement the theoretical model $F(x)$ and identify empirical patterns in food accessibility, we conducted a multivariable statistical analysis using data from 15 urban sectors in Quito. The objective was to generate a territorial typology based on structural disparities in provisioning infrastructure, mobility conditions, and affordability of food access.

Five harmonized indicators were selected as input variables, derived from spatial analysis, field inventories, and market data:

- Travel time to the nearest municipal market (minutes), computed through a network-based accessibility matrix (walking and public transport at 15, 30, and 45 min intervals).
- Availability of staple food items (% of four selected products—orange, tomato, potato, and rice—available in local markets), based on field inventory.
- Quality of public infrastructure (score 1–5), evaluated by direct observation of access routes (sidewalks, lighting, signage, and safety).
- Public transport connectivity, measured as the number of bus lines or modal nodes within a 300 m radius of each market.
- Average retail price of staple products (USD/kg), compiled from on-site data during the value chain analysis.

All indicators were standardized (z-scores) to ensure comparability. A Principal Component Analysis (PCA) was applied to reduce dimensionality and detect latent spatial patterns [17]. The first two components explained 59.4% of the total variance, representing a combination of economic and physical accessibility dimensions. These components served as the input for a hierarchical clustering (Ward's method), which yielded three territorial typologies reflecting differentiated levels of food access and infrastructure integration:

$$PC_1 = a_1X_1 + a_2X_2 + \dots + a_nX_n \quad (3)$$

$$PC_2 = b_1X_1 + b_2X_2 + \dots + b_nX_n \quad (4)$$

where a_n and b_n are loading coefficients for each variable [24].

The application of PCA prior to clustering was selected for two main reasons. First, although the number of variables is moderate (five), they capture interrelated dimensions of food access—such as infrastructure quality, mobility, and affordability—that tend to exhibit statistical correlations. PCA allows us to extract orthogonal components that represent underlying accessibility structures, reducing redundancy and potential multicollinearity between input variables. Second, by projecting the data into a lower-dimensional space (principal components), the classification produced by hierarchical clustering becomes more stable and interpretable, as it groups urban sectors based on composite accessibility profiles rather than isolated indicators.

This approach follows established practices in urban spatial analysis and public health studies, where PCA is used to derive composite indices before segmentation (e.g., deprivation indices, service access typologies). The combined use of PCA and Ward’s clustering method allowed us to identify three territorial typologies that are both statistically distinct and spatially coherent, reinforcing the robustness of our classification.

After obtaining the PCA scores, hierarchical agglomerative clustering was employed to classify the 15 urban sectors into three statistically distinct groups. Clustering was performed using Euclidean distance and the complete linkage method:

$$D(A, B) = \max \{d(a, b) | a \in A, b \in B\} \quad (5)$$

This method is widely used in urban and public health research to identify latent typologies of territorial accessibility [25].

The results of this clustering procedure are shown in the dendrogram (Figure 8 and Table 2), which groups neighborhoods into three clusters according to their shared characteristics:

Cluster 0: Higher-income areas with strong transportation and infrastructure, e.g., Cumbayá and Tumbaco.

Cluster 1: Peripheral and vulnerable zones like Chillogallo and Guamaní.

Cluster 2: Mixed and traditional districts with variable infrastructure, such as Centro Histórico.

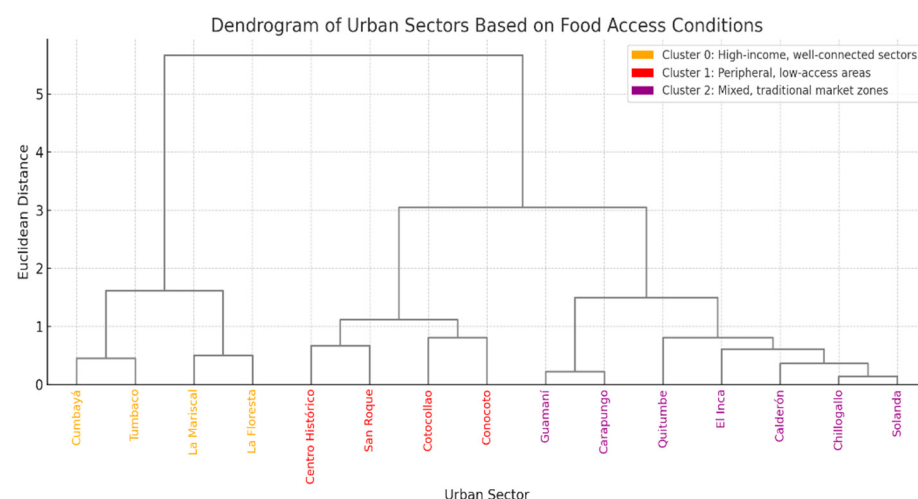


Figure 8. Hierarchical dendrogram of 15 urban sectors in Quito based on food access conditions. Sectors are grouped into clusters (orange, red, and purple) representing distinct territorial profiles. Cluster 0 = high access; Cluster 1 = vulnerable areas; and Cluster 2 = traditional mixed-use sectors.

Table 2. Classification of urban sectors by cluster (PCA-based).

Sector	Cluster	PC1	PC2	F(x) (Approx.)	Description
Cumbayá	0	+2.0	+1.5	>1.4	High-income, multimodal, and dense access
Chillogallo	1	−1.3	−0.9	<0.7	Peripheral, low-income, and weak transport
Centro Histórico	2	0.2	0.5	~1.0	Traditional, mixed-use, and central
...	...	...	...	...	...
X ₁₅	...	...	...	...	...

This multivariable classification not only revealed the spatial articulation of structural inequalities in food access but also underscored the critical role that urban form and market typologies play in shaping provisioning dynamics. The clustering results reinforce insights from field observations and policy analysis, offering a territorialized perspective that connects the material realities of food distribution with the broader logic of urban fragmentation in contemporary Quito.

The typologies were also validated by applying the F(x) function developed in Section 2.3, which aggregates the accessibility of each node weighted by service quality and reach. A strong correlation was observed between low PCA scores and low F(x) values, particularly in Cluster 1. This confirms the coherence of the spatial diagnosis and the applicability of the model for evidence-based food policy prioritization in Quito.

3. Results

The results build directly on the multivariable classification described above. By applying PCA to five urban indicators and clustering the outcomes, three territorial profiles emerged, each reflecting distinct accessibility conditions. These statistically derived clusters are then interpreted through the lens of urban structure, food infrastructure presence, and transport connectivity. The results of this study make visible the deep entanglement between Quito's food system and the spatial and social logic of its urban configuration. Food-related infrastructure has not only conditioned the morphological distribution of neighborhoods but also catalyzed distinct forms of social interaction, mobility, and urban centrality. The city's evolution reveals that food is not merely a logistical necessity but a territorial force that actively shapes both the built environment and collective urban experience.

One of the most significant outcomes observed is the transformation of Quito's urban fabric driven by the structure and evolution of its food systems. The configuration of food infrastructure has directly shaped neighborhood connectivity, mobility flows, and even land use patterns. Traditional markets located in central parishes function not only as economic hubs but also as spatial anchors around which commercial and residential development consolidates. Their presence fosters dense, mixed-use urban fabrics with pedestrian-friendly environments and multi-purpose public spaces [30].

In contrast, peripheral areas that lack formal food distribution nodes exhibit fragmented urban morphologies, characterized by mono-functional zoning, longer commuting distances, and informal land use. These zones often become heavily reliant on informal street vending or mobile fairs, which, although adaptive, lack the permanence and stability to consolidate cohesive urban structure. The spatial absence of formal food infrastructure contributes to irregular growth, diminished walkability, and weakened neighborhood identity [31].

Visual assessments and street-level surveys show that neighborhoods with higher $F(x)$ scores—such as those in the Centro Norte—tend to have finer street grids, higher land use diversity, and greater proximity to markets. In contrast, areas like Valle de los Chillos, with lower $F(x)$ values, exhibit more dispersed patterns and weaker integration of food infrastructure (Figure 9). These contrasts suggest that food provisioning systems not only respond to urban form—they actively shape it.

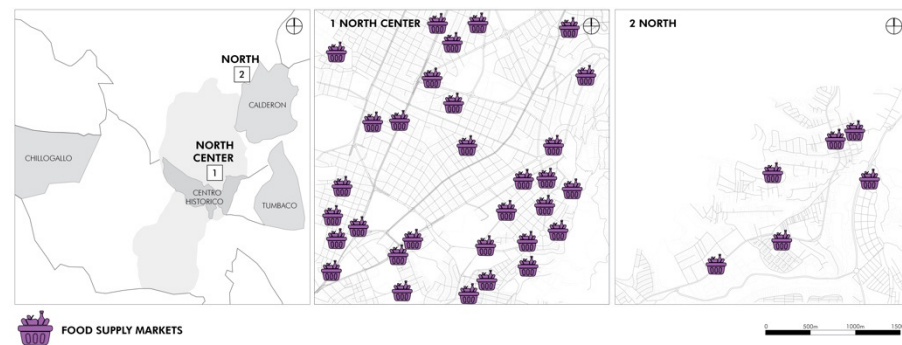


Figure 9. Relationship between $F(x)$ scores and urban morphology in Quito. A comparative diagram illustrating how neighborhoods with higher food accessibility function exhibit greater spatial integration and morphological complexity.

The impact of food systems on the urban fabric is also temporal. Data on market operating hours, delivery schedules, and informal vending periods indicate that these activities influence the daily rhythms of neighborhoods. Areas surrounding active food hubs exhibit higher levels of street activity, informal economic transactions, and social interactions throughout the day. This temporal density contributes to urban vitality and perceived safety, aligning with the concept of “eyes on the street,” as examined by Amiri and Crain (2020) [32]. In contrast, neighborhoods lacking food nodes tend to experience spatial and social voids, leading to a decline in public life and neighborhood cohesion.

In sum, Quito’s food system does not merely respond to the city’s spatial structure—it actively shapes it. The results suggest that equitable access to food infrastructure has cascading effects on urban morphology, mobility, public space quality, and social integration. Recognizing food systems as spatial producers opens up new dimensions for urban design and territorial justice [33]. The empirical findings of this study reveal profound spatial, economic, and governance asymmetries in Quito’s urban food system. These disparities not only reflect inequalities in physical access to markets and food outlets but also expose deeper socio-political dynamics embedded in the urban fabric [34]. The spatial analysis, field-based data, and multivariable classification converge on several key patterns that define Quito’s foodscape: the centralization of distribution networks, the fragmentation of infrastructural provision in peripheral areas, and the informal resilience mechanisms activated by communities under conditions of food precarity.

One of the most salient findings is the spatial concentration of infrastructure. As shown through isochrone and density mapping, central zones such as La Mariscal, El Ejido, and La Floresta enjoy an abundance of food outlets—including a dense mix of municipal markets, supermarkets, and bioferias—within walking distance. These areas also benefit from multimodal transport connections and high walkability scores. In contrast, peripheral zones like San Antonio de Pichincha, Carapungo, and Guamaní exhibit significantly reduced accessibility, often relying on a single outlet type (typically low-cost supermarkets or informal vending nodes), with limited transport options [35].

The participatory mapping confirmed and enriched these observations. Residents from neighborhoods like Solanda and Calderón reported difficulties in accessing affordable,

fresh produce, particularly on weekends when municipal markets are saturated. Moreover, the presence of physical barriers such as ravines, poor lighting, and a lack of pedestrian infrastructure in hilly zones further complicates access. These findings align with the accessibility scores derived from the mathematical model described in the methodology, which consistently ranked peripheral sectors lower in $F(x)$ values.

From an economic perspective, the analysis of four product value chains (oranges, tomatoes, potatoes, and rice) underscores systemic inefficiencies and inequalities (Table 3). As visualized in the Sankey diagram (Figure 4), the largest markups occur between wholesale and retail stages, largely attributed to intermediary control and transportation surcharges. Interviews revealed that farmers often sell products at minimal margins while bearing the brunt of price volatility and logistic uncertainty. Meanwhile, consumers in peripheral areas pay up to 30% more than their central counterparts due to longer supply chains and reduced competition [36].

Table 3. Price comparisons across food chain stages (USD/kg).

Product	Producer Price	Wholesale Price	Retail Price (Center)	Retail Price (Periphery)
Oranges	0.25	0.45	0.75	0.98
Tomatoes	0.35	0.65	0.95	1.20
Potatoes	0.20	0.40	0.60	0.75
Rice	0.50	0.60	0.75	0.90

These price variations are compounded by food quality issues. Informal and peripheral vendors often deal with second-grade produce due to their position at the tail end of supply chains. Such inequalities are further exacerbated during external shocks, as witnessed during the COVID-19 pandemic, when supply chain disruptions disproportionately impacted the city's most vulnerable neighborhoods [13].

The governance dimension also emerged as a key driver of food system performance. Policy fragmentation was evident in the disconnection between urban planning and food policy. While the city's PMDOT acknowledges the importance of proximity economies, there is minimal coordination between land use zoning and market allocation. For instance, the newly urbanized areas in Quitumbe and Calderón continue to expand without the parallel development of food infrastructure. Municipal efforts such as mobile fairs and compost programs remain underfunded and fail to address structural inequities [37,38].

However, this study also uncovered promising practices. Bioferias, despite their limited spatial reach, demonstrated strong producer–consumer relationships and offered affordable organic produce with minimal intermediaries. Urban gardens in La Gasca and San Blas have been successful in enhancing community resilience and food literacy. These cases illustrate the potential for integrated, bottom-up strategies to complement formal planning mechanisms and strengthen food sovereignty at the neighborhood level (see Figure 10) [39].

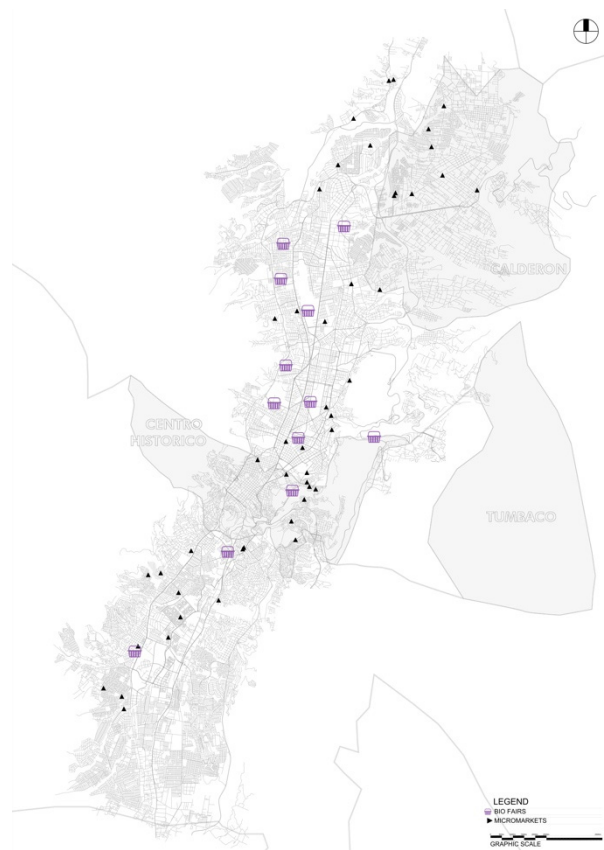


Figure 10. Community-led food initiatives in Quito. Photographic montage and GIS mapping of urban gardens, compost centers, and bioferias operating in the metropolitan area.

The accessibility function $F(x)$, when mapped across Quito (Figure 11), reveals a stratified foodscape. Central parishes such as La Mariscal score $F(x) > 1.4$, indicating dense, high-quality infrastructure with strong connectivity. In contrast, neighborhoods such as Carapungo, La Ecuatoriana, and Lucha de los Pobres score below 0.7, reflecting infrastructural scarcity and poor logistic integration. These findings validate the mathematical framework and provide an empirical base for targeted policy interventions.

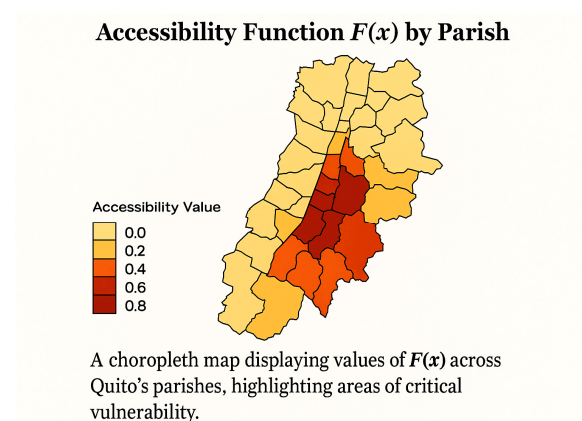


Figure 11. Accessibility function $F(x)$ by parish. A choropleth map displaying values of $F(x)$ across Quito's parishes, highlighting areas of critical vulnerability.

The $F(x)$ accessibility model reveals significant disparities between Quito's central and peripheral zones. Neighborhoods such as Guamaní, La Ecuatoriana, and Carapungo consistently recorded lower $F(x)$ values (<0.75), indicating weak infrastructural integration,

extended travel times, and limited food availability. These patterns are not isolated but rather symptomatic of deeper structural deficits in urban planning and public investment.

Field observations in low-F(x) areas revealed recurrent deficiencies, such as the absence of public lighting, lack of pedestrian sidewalks, deteriorated road conditions, and inadequate proximity to public transport nodes near food markets. These infrastructural shortcomings directly undermine residents' quality of life, limiting both physical and economic access to fresh food and increasing dependence on informal or ultra-processed alternatives, which tend to be more expensive and nutritionally inadequate.

These disparities also exacerbate social exclusion. Areas with limited food connectivity frequently correlate with higher poverty levels, longer commuting times, and poorer health outcomes. Households must invest more time and financial resources to obtain adequate food, reinforcing cycles of vulnerability and territorial inequity.

From a planning standpoint, these findings support targeted investments in multi-modal connectivity, market modernization, and spatial inclusion policies. Recommended strategies include enhancing walkable access routes, improving lighting and transport safety, and upgrading food infrastructure in underserved areas. These actions are crucial not only for improving nutritional outcomes but also for promoting territorial justice.

Moreover, the F(x) model is transferable to other urban contexts, particularly in Global South cities experiencing similar spatial fragmentation. Its incorporation into municipal food strategies offers a robust and replicable framework for identifying spatial inequalities, guiding investment decisions, and designing more inclusive, resilient, and sustainable urban food systems.

In conclusion, the results validate the hypothesis that Quito's urban structure and food provisioning systems are co-constitutive elements, reinforcing spatial and economic inequalities (Figure 12). Nonetheless, the findings also highlight opportunities for innovation and community agency. Bridging this divide requires reconceptualizing food infrastructure not as a secondary utility, but as a foundational pillar of urban justice and territorial cohesion.

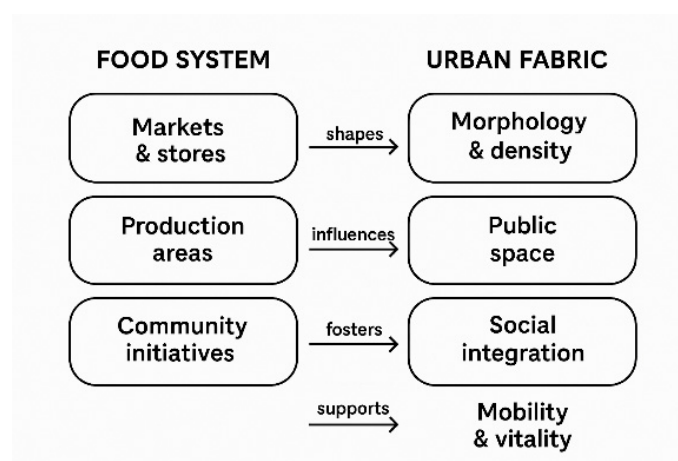


Figure 12. The urban food system as a generator of spatial and social structure in Quito. A conceptual diagram showing how key components of the food system (infrastructure, accessibility, mobility, and interaction) co-produce urban morphology and influence social behavior across neighborhoods.

4. Discussion

The results presented above illuminate the deep interrelations between Quito's urban form and its food provisioning system, revealing that spatial and social dynamics are mutually shaped by food accessibility, infrastructural distribution, and governance

mechanisms. This discussion contextualizes these findings within broader theoretical and empirical debates on urban food governance, spatial justice, and metabolic urbanism.

The PCA-derived clusters reinforce the spatial asymmetries discussed, validating the field-based observations through statistical segmentation. Zones classified as Cluster 1 consistently aligned with areas of low $F(x)$ scores, high commuting burdens, and reduced food infrastructure, confirming the territorial embeddedness of food inequality [40].

The spatial concentration of food infrastructure and services reflects long-standing patterns of centralization in Quito's development. Traditional markets and formal commercial nodes remain clustered around the historic core and affluent areas. While this pattern contributes to economic efficiency and urban vitality in central districts, it simultaneously exacerbates exclusion in peri-urban neighborhoods with limited access to comparable services. This aligns with Soja's theory of spatial justice, which underscores how uneven resource distribution reinforces social inequality [2].

Methodologically, this study integrates PCA and clustering techniques to identify territorial typologies of food accessibility. PCA was chosen for two primary reasons. First, despite the moderate number of variables ($n = 5$), high inter-correlation risked multicollinearity, which PCA mitigates effectively. Second, PCA enhances interpretability by revealing latent dimensions (e.g., the "infrastructure-connectivity axis") that informed robust segmentation. This dimensionality reduction ensured that clustering was based on orthogonal, policy-relevant axes.

While other methods, such as hierarchical clustering or spatial autoregressive models, could be explored, the selected approach balances statistical rigor and communicability for urban planning [41]. Future studies may incorporate geographically weighted PCA (GWPCA) or spatial lag models to address intra-urban heterogeneity.

The temporal dimension of food accessibility, although noted, warrants deeper exploration. Field data confirmed that market operating hours, peak congestion, and week-end closures significantly affect practical access. Even well-connected zones may experience time-sensitive food access gaps during off-hours or holidays. Incorporating temporal variables into $F(x)$, potentially via hourly network simulations, could enhance its diagnostic power.

This study also recognizes its limitations. Notably, it lacks fine-scale nutritional data and omits informal markets, which are dynamic yet essential elements of Quito's food system [42]. Though harder to georeference, these informal points of sale (e.g., street vendors) are vital to food access. Their exclusion may lead to underestimation in some sectors. Nonetheless, the $F(x)$ framework retains value as a replicable diagnostic and planning instrument.

Beyond description, the $F(x)$ model is actionable as a policy tool. Its ability to spatially represent systemic food gaps supports evidence-based interventions that integrate physical, social, and governance dimensions of urban sustainability.

Food infrastructure not only enhances urban vibrancy and functional diversity but also shapes temporality and sociality. Markets serve as sites of economic exchange, cultural interaction, and informal surveillance, reinforcing Jacobs' (1961) emphasis on "eyes on the street" [24,32]. However, community-led initiatives such as bioferias and urban gardens, while promising, remain systemically vulnerable due to unstable financing and weak institutional integration. Scaling these requires stronger policy frameworks and decentralized governance models. Here, principles from circular economy and metabolic urbanism—such as those articulated by Bettini et al. and de Zeeuw & Drechsel—offer a foundation for aligning material flows (food, energy, and waste) with spatial systems [25,39].

There is a pressing need to reposition food provisioning as core urban infrastructure, on par with water, energy, and transport systems. Currently treated as a secondary market-

driven service, food infrastructure must be integrated into land use planning, zoning codes, and investment strategies to ensure health, sustainability, and spatial equity (Figure 13) [43].



Figure 13. Integrative framework: food systems as drivers of urban transformation in Quito. This infographic synthesizes how the components of the food system—distribution infrastructure, accessibility, mobility, environmental flows, and governance—interact to shape spatial configurations and social dynamics in the city. It highlights the role of food systems as both a physical and relational infrastructure influencing Quito’s morphology and community resilience.

The case of Quito echoes trends observed in other Latin American cities—such as Lima, Bogotá, and São Paulo—where informal economies, urban expansion, and governance fragmentation challenge the right to food [34,44]. Comparative research suggests that food-sensitive urban planning can foster cohesion, support environmental goals, and stimulate economic diversification [45].

Ultimately, Quito’s urban planning must be re-envisioned through the lens of food systems. This shift addresses both short-term access gaps and long-term urban sustainability goals [46]. It also offers a transformative path toward inclusive, adaptive, and resilient cities in the context of climate change and socio-political uncertainty.

To ensure the robustness of the territorial typologies generated in this study, a combination of statistical and empirical validation strategies was employed. Statistically, the use of Principal Component Analysis (PCA) enabled dimensionality reduction and orthogonal variable construction, minimizing multicollinearity before clustering. The clustering results were evaluated for internal coherence, and their spatial distribution was assessed for geographic contiguity. Empirically, the typologies were cross-referenced with fieldwork data and known patterns of infrastructure distribution, affordability levels, and transit accessibility in Quito. This dual validation—analytical and contextual—supports the reliability of the typologies as a tool for planning and highlights their relevance for identifying territorial inequalities in food access.

In light of these findings, it is essential to consider their implications for public policy and urban planning. The findings of this study offer several implications for urban policy and planning. First, the spatial disparities in food access underscore the need for public interventions to promote equitable food environments, especially in peripheral and socioeconomically vulnerable areas. Municipal governments should prioritize integrated land use policies that combine housing, food retail, and transportation infrastructure. Additionally, policy frameworks should incentivize the development of decentralized food supply chains, public markets, and community-supported agriculture. These strategies can help mitigate urban food deserts and strengthen the resilience of urban food systems in cities like Quito.

5. Conclusions

This research confirmed that the food system in Quito is a decisive element in shaping the city's urban form, mobility patterns, and social dynamics. Far from being a neutral background service, food provisioning structures profoundly influence the daily experience of residents, particularly in terms of access, equity, and spatial inclusion.

Through a mixed-methods approach combining direct field observations, value chain analysis, participatory mapping, and multivariable statistical modeling, this study identified clear structural disparities in food access across different sectors of the city. The multivariable analysis—applying PCA and hierarchical clustering—enabled a data-driven classification of urban areas into three distinct territorial profiles. These clusters revealed how variables such as income, population density, infrastructure availability, and transport access interact to create zones of vulnerability, consolidation, or transition. This methodology not only validated qualitative insights but also provides a replicable tool for planners to prioritize interventions.

The findings show that central districts like La Mariscal and La Floresta benefit from dense, multimodal food infrastructures and high accessibility. In contrast, peripheral neighborhoods such as Guamaní, Carapungo, and Chillogallo face systematic disadvantages: longer distances to provisioning centers, weaker connectivity, limited diversity of food supply, and higher end-consumer prices. These conditions are further worsened by fragmented urban growth, inadequate planning, and limited state investment in food-related infrastructure. The $F(x)$ accessibility function has proven to be a valuable tool for quantifying spatial disparities and identifying priority zones for intervention. These findings confirm that urban planning must address food as a core component of territorial justice and urban resilience.

The implications of this research are threefold. First, urban design and land use policies must include the strategic location of food infrastructure as a criterion for equitable development. Second, community-based food initiatives should be supported and institutionalized to build bottom-up capacity for food sovereignty. Third, a paradigm shift is needed in governance frameworks to position food as a critical urban system, alongside housing, water, and transportation.

Future research should explore the integration of digital platforms and real-time data to enhance food distribution efficiency, particularly in peripheral zones. Additionally, longitudinal studies are needed to assess how changes in infrastructure impact long-term spatial behaviors and social cohesion. As Quito continues to grow, its food system must evolve not only to nourish bodies but to support inclusive and spatially just urban environments.

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