The Impact of Public Transportation Systems on Food Insecurity in Allegheny County: The Use of Data Analytics to Improve the Built Environment

by

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Food insecurity is a pervasive issue for Allegheny County, as 161,000 residents, or one in five, currently experience food insecurity. Food insecurity is linked to chronic health conditions like heart disease and hypertension. In the United States, food insecurity disproportionately affects minority communities. There are multiple dimensions used to measure regional food insecurity, one of which is food accessibility. Prior research has examined the linkages between food access and food insecurity, and this study aims to further explore the relationship between equitable access to sustainable food. This study examines food outlets in Allegheny County to determine if there is a significant relationship between food outlet availability and food insecurity. Both the presence and accessibility of these food outlets were examined. To measure accessibility, the walking distance to the nearest public transportation stop was calculated for each public transportation stop. The minimum distance to each food outlet was compared to food insecurity rates on Zip Code and Census Tract levels. There is no statistically significant relationship between the distance from public transportation stops to grocery stores and rates of food insecurity. However, communities without grocery stores did, on average, have higher rates of food insecurity. Census tracts provided more statistically significant results than zip codes, proving to be a more effective level of analysis for regional assessment. Altogether, sole reliance on distance as an indicator of food insecurity can be misleading, and there should be a greater focus on walkability within the community as opposed to distance.

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Preface

This work was supported by the University of Pittsburgh David C. Frederick Honors College and the Food21 of Pennsylvania nonprofit organization. I am immensely grateful for the support and guidance from everyone at both organizations. I completed this work as a part of an ongoing initiative with Food21 and the University of Pittsburgh David C. Frederick Honors College to measure regional food insecurity more effectively in order to establish impactful development projects that bring fresh, sustainable, healthy, culturally relevant food to marginalized communities in Western Pennsylvania.

I dedicate this work to my maternal grandfather Michael King, for catalyzing my passion to address food insecurity, and to my late paternal grandfather Ralph Firestine, whose strength and perseverance greatly inspired my academic journey.

1.0 Introduction: Food Security Overview

The USDA defines food security as "access by all people at all times to enough food for an active, healthy life (Coleman-Jensen et al., 2023)." This definition is further expanded in the literature to emphasize the need for access to sustainable and culturally relevant food options for all individuals within a community (Murrell & Jones, 2020). In the United States, there are currently over 34 million people experiencing food insecurity, nine million of whom are children (Institute for Local Self Reliance, 2018). The negative public health effects of food insecurity are apparent, as studies show food insecurity is linked to the prevalence of chronic disease, particularly type 2 diabetes, and hypertension, in communities across the U.S. and around the world (Seligman et al., 2010; Laraia, 2017). In Pittsburgh, one in five residents is considered to be food insecure, and in Allegheny County there are over 161,000 food insecure people (City of Pittsburgh, n.d.; Greater Pittsburgh Community Food Bank, 2021). These food insecurity rates for southwest Pennsylvania were exacerbated by the COVID-19 pandemic (Gulish, 2020). In many cities, job-insecure individuals experienced food insecurity directly related to the pandemic (Men & Tarasuk, 2021). In light of the evolving challenges of maintaining resiliency in regional food systems, this research explores the relationship between public transportation access and rates of food insecurity. If a grocery store is present in a community, but the nearest public transportation stop is a long walk away, members of the community may elect inadequate alternatives to meet their food needs. This may render communities with long walks to food outlets for food insecure, perpetuating barriers to access established by the built environment in urban, mid-urban, and suburban areas.

1.1 Defining & Measuring Food Insecurity

A lack of access to food has been traditionally defined by the presence of a grocery store or supermarket, and roughly one third of all zip codes in the U.S. do not have either food outlet (Whitacre et al., 2009). However, the term "food desert" has evolved. Karen Washington (Karen Washington, n.d.), food justice activist and founder of Rise & Root Farm, coined the term "food apartheid" so emphasize the systemic racism and economic inequality that influences food insecurity in marginalized communities (Brones, 2018). Economic inequality has often been associated with food insecurity, as studies have shown affluent communities often have greater access to nutritious food (Burns & Inglis, 2007; Ball et al., 2009). Increased access to healthy food is generally associated with lower rates of type 2 diabetes, and one study found that black Americans have generally less physical proximity to food (Union of Concerned Scientists, 2016). Another study found that as neighborhood poverty increased, presence of grocery stores and supermarkets increased, and predominately black census tracts had the lowest presence of supermarkets (Bower et al., 2014). In the U.S. the odds of having type 2 diabetes are higher for black Americans than any other race, and these odds are further increased for lower income individuals (Gaskin et al., 2014). Food apartheids are inherently complex, as a number of root causes can contribute to the prevalence of food insecurity in a community. The concept of "food mirages" asserts that even though there may be a grocery store present in a community, the prices of healthy food within the grocery store are not affordable to individuals in the low-income bracket (Breyer & Voss-Andreae, 2013). The research begins to further expand the perception of food apartheids beyond solely the presence of a grocery store in a community. A food mirage ultimately leads to more infrequent shopping trips and less purchase of produce due to in-store pricing (Everett, 2011). As the definition of food deserts evolves, it's evident that the traditional grocery

store measure does not account for the complexity of food access (Bedore, 2013). Several studies have revealed that after food retail intervention projects, there is no significant impact on fruits and vegetable consumption (Sadler et al., 2013; Cummins et al., 2014). In these studies, the perception of food access increased amongst community members, but their healthy food consumption remained unchanged (Sadler et al., 2013; Cummins et al., 2014). From these studies it's clear that a multidimensional approach to addressing food insecurity is necessary to incite change within a community, and that other factors besides the mere presence of healthy food in a community play a role in dietary habits and community health. Further continuing the development of a multidimensional approach, my study seeks to test the efficacy of using distance as a dimension to measure food insecurity, which is a crucial component of access to healthy food. In addition to this development, research shows that a combination of environmental factors in the community as well as widespread, equitable, education is necessary to influence behavior within a community (Sadler et al., 2016).

1.2 The Food Abundance Index

In 2011, researchers at the University of Pittsburgh developed a proprietary tool to measure regional food insecurity called the Food Abundance Index (Murrell & Jones, 2020). This approach sought to capture the multidimensional nature of food insecurity in a community. The index assesses food security across five dimensions: Access, Affordability, Diversity, Density, and Quality (Murrell & Jones, 2020). The access dimension scale examined the accessibility of local grocery stores via public transportation, where a grocery store with a bus stop within a quarter mile was considered to be accessible (Murrell & Jones, 2020). In 2021, three of the five dimensions of

the Food Abundance Index were assessed in the mid-Monongahela valley of Pittsburgh (Murrell et al., 2022). This study revealed that there were a series of food outlets in Pittsburgh communities that did not have sufficient access via public transportation (Murrell et al., 2022). This study also implicated that for future research, it is necessary to account for environmental structures like bridges and highways that may impede travel to the grocery outlets (Murrell et al., 2022).

1.3 Elements of the Built Environment

Public transportation and environmental structures mentioned in this previous research are key elements of the built environment. The Environmental Protection Agency defines the built environment as "the man-made or modified structures that provide people with living, working, and recreational spaces," which essentially encompasses the infrastructure of a community (US EPA, 2017). An early study conducted on the connection between the built environment and obesity adopts the framework to define three different spaces within the built environment: the residential space, the activity space, and the connectors between these spaces (39). Expanding on this framework, a study exploring the relationship between the built environment and heart disease conducted in Australia examined the built environment across six dimensions: Density, Diversity, Design, Destination, Distance to Transit, and Demand Management (Giles-Corti et al., 2014). Research has indicated an association between obesity, specifically childhood obesity, and aspects of the built environment like walkability (Papas et al., 2007; Le et al., 2016). Food outlet access plays a role, as higher rates of obesity in children is seen in communities with more fast-food restaurants and convenience stores within walking distance of a residential neighborhood (Le et al., 2016). The built environment has also been connected to the level of trust and collective

efficacy within a community, where communities with more parks and less alcohol outlets were perceived to harbor more trust (Cohen et al., 2008). Another study found a similar positive association between walkability and destination space access in a community to social capital, which is the prevalence of positive social relationships (Mazumdar et al., 2018). Finally, research has shown that modifications to the built environment can contribute to eliminating disparities within a community, especially in the context of improving access to vital destination spaces like grocery stores, healthcare, and recreation (Hutch et al., 2011).

1.4 The Purpose of This Study

This study is a comprehensive examination of the food system infrastructure in Allegheny County, assessing location trends in the establishment of key food outlet types like grocery stores and food banks. Also, my goal is to further explore the relationship between these food outlets and the public transportation system in Allegheny County. I will focus on the accessibility of these food outlets by analyzing the walking distance from Port Authority public transportation stops to food outlets across four different categories. Ultimately, my goal is to determine if disadvantaged communities with food outlets that do not have public transportation stops within walking distance experience elevated levels of food insecurity. Also, I'll incorporate a review of the contention in the literature regarding effective levels of analysis for aggregating regional food systems. My focus will incorporate census tracts and zip code tabulation areas (ZCTA) to assess which leads to greater statistical significance for comparability. By examining the relationship between public transportation, walking distance, and food outlets, my goal is to develop a roadmap for policymakers to develop informed initiatives that address food access challenges in disadvantaged

communities. This study will also critique existing methodologies regarding regional food system analysis and seek to identify areas where aggregate regional analysis using publicly available data may generate misleading insights. Ultimately, the implications of this research will aid in more effective data collection and analysis of regional food systems in order to accurately capture disparities in disadvantaged communities in Allegheny County.

2.0 Methodology

This study consisted of two primary analyses. The first examined the food outlet landscape in Allegheny County with emphasis on areas that did not contain a particular type of food outlet. On both the ZCTA and census tract level, the relationship between the presence of four different types of food outlets and the food insecurity rate was examined. The second analysis incorporated both ZCTA and census tract levels, but instead focused on distances of public transportation stops to the food outlets in the area identified by the first analysis.

2.1 Data Acquisition and Cleansing

For this study, I used data from three primary outlets: the Western Pennsylvania Regional Data Center (WPRDC) (Western Pennsylvania Regional Data Center, 2022), the United States Census Bureau (United States Census Bureau, 2021), and Feeding America (Feeding America, 2022). The first tranche of data pulled from the WRPDC contained all the registered food outlets in Allegheny County. Classification of these food outlets was already established in the dataset, however only the classifications related to Grocery Stores (GS), Convenience Stores (CS), Food Banks (FB), and Farmer's Markets (FM) were retained for the analysis. The classification was recoded from a previous delineation between chain and non-chain facilities, where chain and non-chain supermarkets were reclassified to be simply GS. This is the same, but more up-to-date, data that was used in the application of the Food Abundance Index to the Mid-Mon valley region in Pittsburgh (Murrell et al., 2022). Food outlet licensing data as of June 2022 was used in this study.

The second tranche of data from WRPDC contained all of the Port Authority Public Transportation stops in Allegheny County (Western Pennsylvania Regional Data Center, 2022). This data primarily focused on ridership associated with the various Port Authority routes in the region. My focus, however, was on extracting all of the stop locations in order to obtain a holistic view of the transportation environment in the region. Once I had every unique stop, I synthesized this data with the food outlet data. Using the Google Maps API in R, I determined the closest public transportation stop to each food outlet. I selected the Google Maps API over other methods like the Euclidean distance due to the greater accuracy in the walkable path to the food outlet. Since Pittsburgh is a city of many bridges, there may be scenarios in which a public transportation stop would be close by as the crow flies, but in reality, the individual would have to take an alternative route in order to reach the food outlet. The use of the Google Maps API accounts for this, and I was able to derive the distance of each route in meters, as well as the walking time in seconds. The master dataset contained each food outlet across the four categories and the closest public transportation stop. In order to determine the level of food insecurity for each ZCTA and census tract in Allegheny County, I worked with Feeding America to obtain their Map the Meal Gap data for all of the ZCTAs and census tracts in Pennsylvania. Feeding America uses a comprehensive methodology to estimate food insecurity rates based on a series of demographic variables (Feeding America, 2022). The Map the Meal Gap study is publicly available on a county level, but this ZCTA and census tract disaggregation is a specialized request completed by Feeding America using relevant regional data (Gundersen et al., 2022). Along with the estimate rates of food insecurity in each ZCTA and census tract in Pennsylvania, Feeding America also provided key demographic information related to food insecurity, like the percent of households enrolled the Supplemental Nutrition Assistance Program. The final component of the analysis was to obtain

key demographic information for each ZCTA and census tract in Allegheny County. For these metrics, the American Community Survey from the Census Bureau was queried for each ZCTA and census tract in Allegheny County (United States Census Bureau, 2021). From the 5-year estimate tables for 2021, key demographic factors like median household income and population were appended to the data provided by Feeding America. Feeding America uses the ACS data and the Food Security Supplement of the Current Population Survey to calculate the food insecurity rates, and as a result many demographic dimensions have strong correlation with the food insecurity estimates. In order to avoid multicollinearity, these demographic factors were not considered as predictors in any portion of the study.

2.2 Level of Analysis

The levels of analysis for the statistical analysis were ZCTAs and census tracts. All ZCTAs in Allegheny County were included in the aggregate dataset, which was then filtered based on a series of parameters in order to reflect the region more accurately. First, eight ZCTAs (15222, 15086, 15031, 15091,15123, 15127, 15231, 15275) were removed because they did not have a large enough sample size for Feeding American to establish a food insecurity rate estimate. An additional ZCTA (15213) was removed because due to the high population of college students, a food insecurity estimate was unable to be projected by Feeding America. The final aggregate dataset used in the analysis contained 101 ZCTAs in Allegheny County. To assess the efficacy of using ZCTAs as a level of analysis, the same statistical comparison tests were conducted at the census tract level. Figure 1 depicts the ZCTAs included in the study.

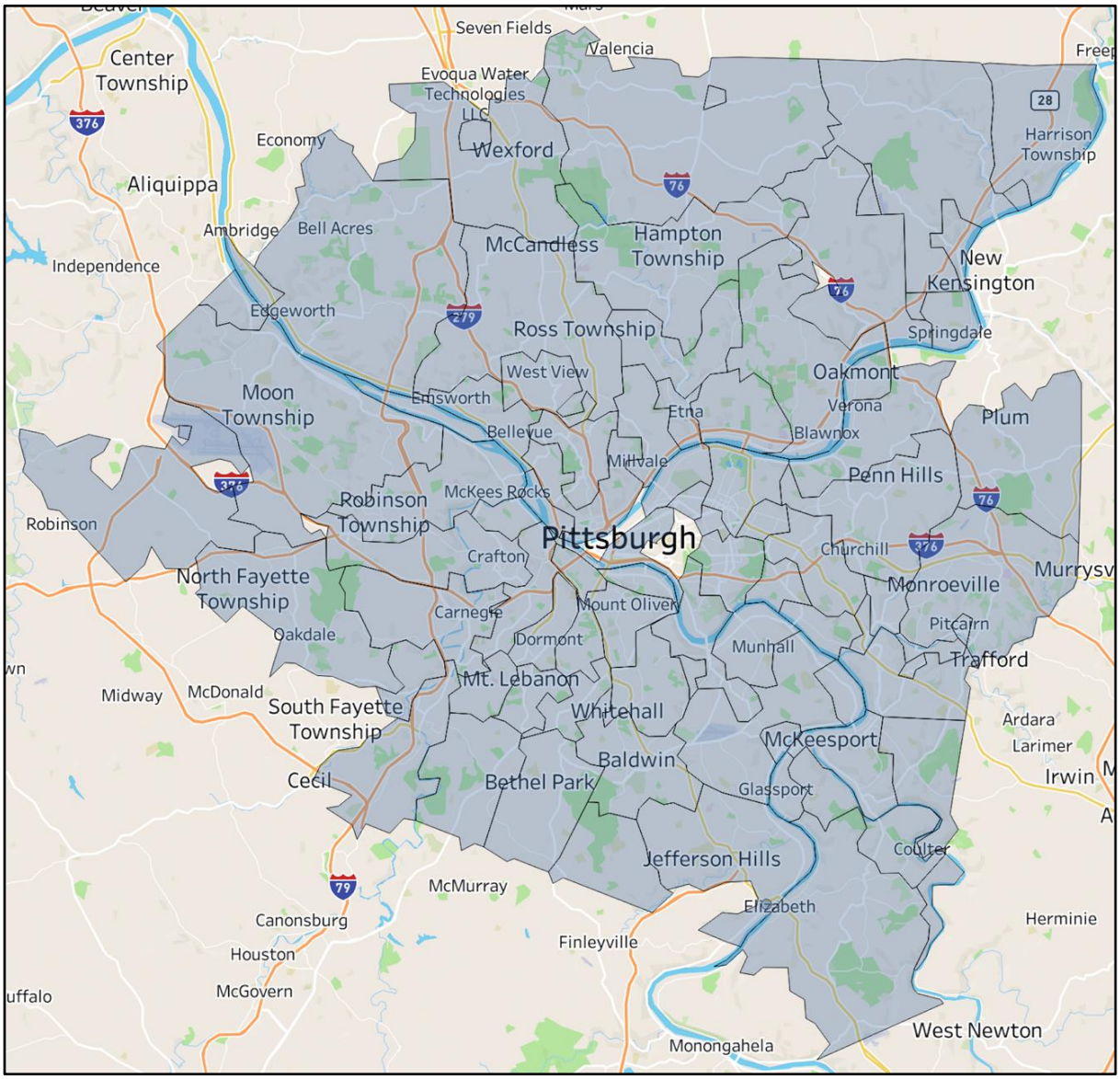


Figure 1 Allegheny County Zip Codes Included in the Analysis

The census tracts underwent a similar cleaning process to the ZCTAs, where all the tracts that did not contain a sufficient population to produce a food insecurity estimate were removed. Appendix A lists the census tracts that were excluded from the statistical analysis. Figure 2 depicts the census tracts that were included in the analysis for this study.

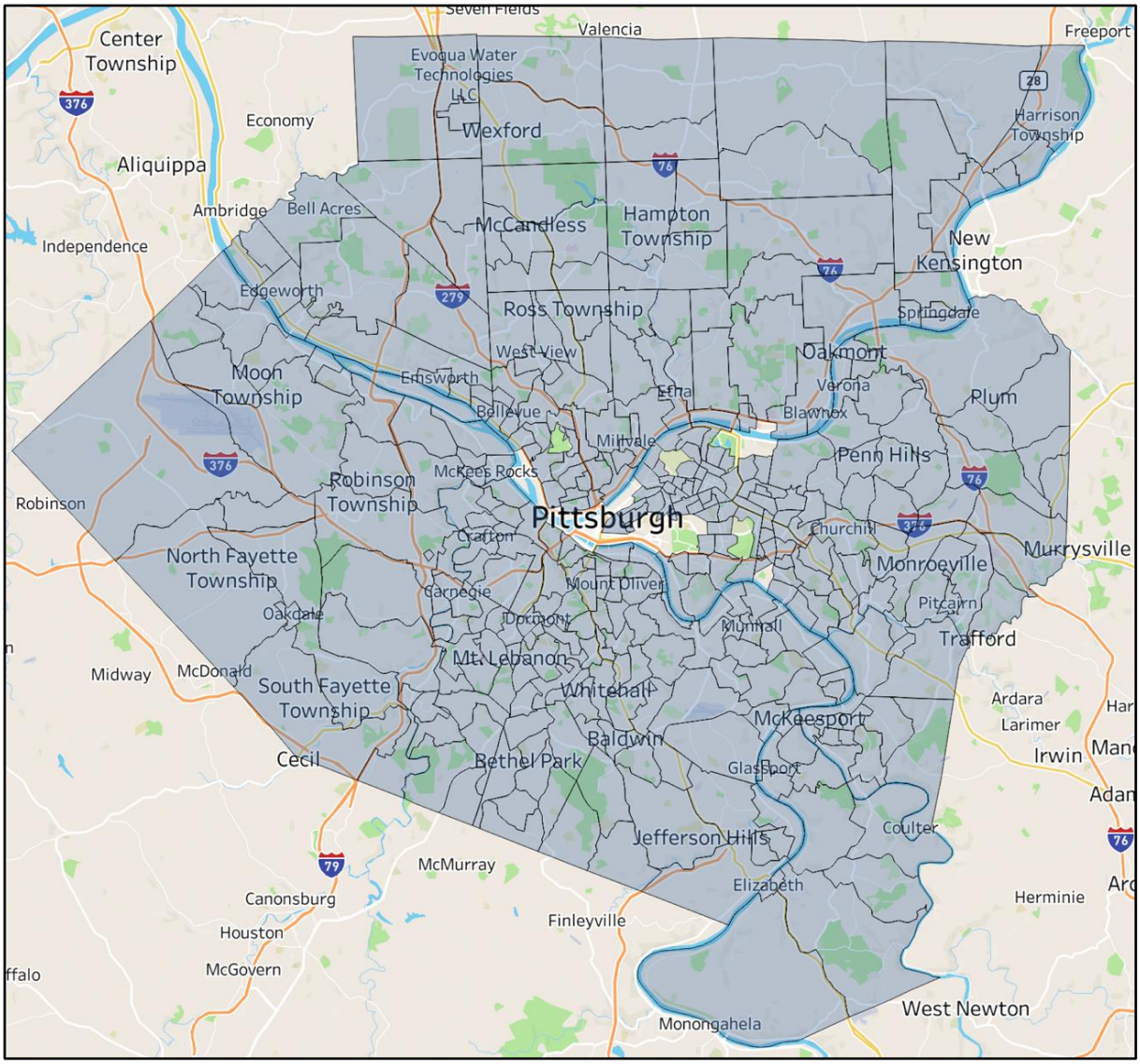


Figure 2 Allegheny County Census Tract Included in the Analysis

2.3 Analysis One Method

The purpose of this first analysis was to gain an understanding of the food outlet landscape in Allegheny County. Traditional methodologies to measure food insecurity have revolved around the presence of a food outlet in a community, but research has revealed that often this approach does not paint the entire picture of a community. However, to further explore the landscape of Allegheny County, the ZCTAs were first assessed for their overall classification and its relationship with the Feeding America rate of food insecurity. First, ZCTAs and census tracts with high rates of food insecurity were identified and mapped. These maps were compared to the mapping of the population breakdown and median household income for each area. For each ZCTA and census tract, a binary classifier was appended to indicate the presence, or lack thereof, of each of the four food outlets at the focus of this study. In the first phase of this analysis, the data was separated into two parts: the ZCTAs and tracts that had at least one of the respective food outlets and the ZCTAs and tracts that did not. For example, one set contained ZCTAs that had a grocery store and the other contained ZCTAs that did not. This was completed for all food outlets on both the ZCTA and census tract level. This data was mapped in order to visualize areas in Allegheny County that lacked the basic presence of the four types of food outlets. Next, the average rate of food insecurity was calculated for each set of data, and a two sample Welch t-test with a 95% confidence interval was used to determine if there was a significant difference in the mean rate of food insecurity of the two sets. Further statistical documentation on this analysis is available in Appendix B. The null hypothesis for each test was that the mean rate of food insecurity does not differ between areas with and without each of the food outlets. The alternative hypothesis was that the mean rate of food insecurity did differ between areas with and without each of the food outlets. The second phase of the analysis employed the same process, but the data was filtered to

only incorporate ZCTAs that fell below the median household income of $69,091 in Allegheny County per the American Community Survey's inflation adjusted reporting for the current year. A trend in the data emerged that in high-income communities with low rates of food insecurity, the public transportation stops were a great distance from the food outlets. The assumption behind this trend is that in these communities, members are less likely to use public transportation to travel to a food outlet, and most likely own cars as a means of transportation, and the food outlets could be zoned for parking lots instead of public transportation access. The ZCTAs and census tracts that fell below this median were subject to the same process as the first phase of the statistical analysis.

2.4 Analysis Two Method

The second analysis conducted for this study delves further beyond only an assessment of the food outlets in Allegheny County to address the accessibility of these food outlets via public transportation, effectively incorporating one of the most important aspects of the built environment. The Food Abundance Index considers food outlets that have a public transportation stop greater than 0.25 miles away to be inaccessible and thus lowers the overall Food Abundance score for the region (Murrell & Jones, 2020). This concept was used to determine the accessibility of food outlets in various ZCTAs and census tracts in Allegheny County. Food outlets with a public transportation stop within 0.25 miles were considered accessible, while food outlets with a stop greater than 0.25 miles away were considered inaccessible. For each area, the minimum and average distance for each of the four food outlet classifications was calculated. I elected to use the minimum because this would theoretically represent the food outlet that is the most accessible via public transportation in terms of the stop proximity to the store. The areas were mapped based on

the minimum and the average distances to the different types of food outlets. The statistical phase of the second analysis also involved the use of the two sample Welch t-test with a 95% confidence interval to determine if there was a difference in mean rates of food insecurity in areas with accessible food outlets compared to those with inaccessible food outlets. This statistical test was first conducted on all the areas in the scope of the study, and then repeated using only areas below the Allegheny County median income. The first test incorporated only the minimum distances, while the analysis of the bottom 50% areas examined both the minimum and average distanced for each ZCTA and census tract.

3.0 An Analysis of the Allegheny County Food System

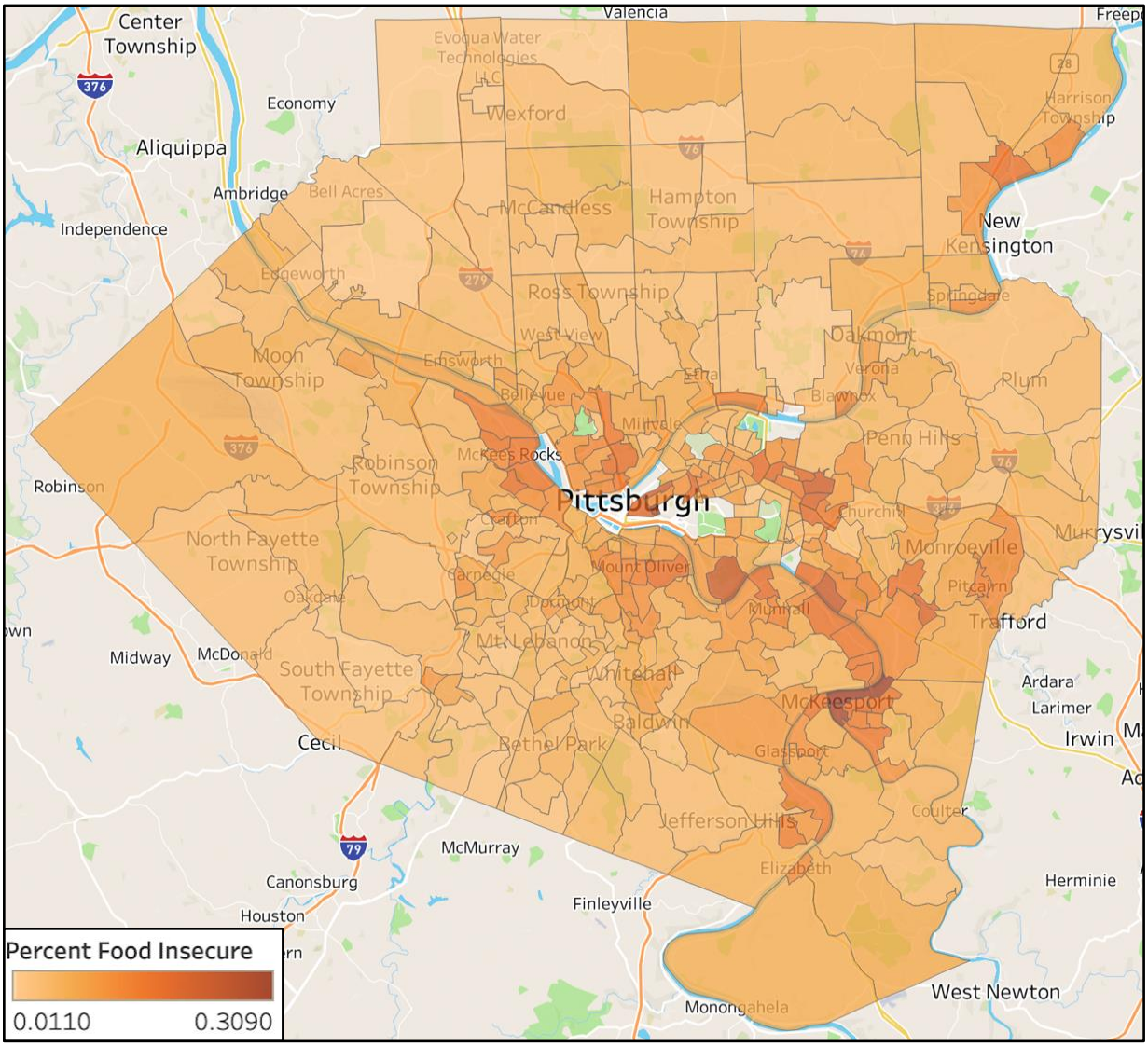


Figure 3 Allegheny County Percent Food Insecure By Census Tract

On a ZCTA level, Figure 3 displays the rate of food insecurity. The ZCTAs with the highest rates of food insecurity are 15007, 15148, 15104, 15219, and 15110 with an average rate of food insecurity of 22% across all five locations. Figure 3 displays the rate of food insecurity on a ZCTA level.

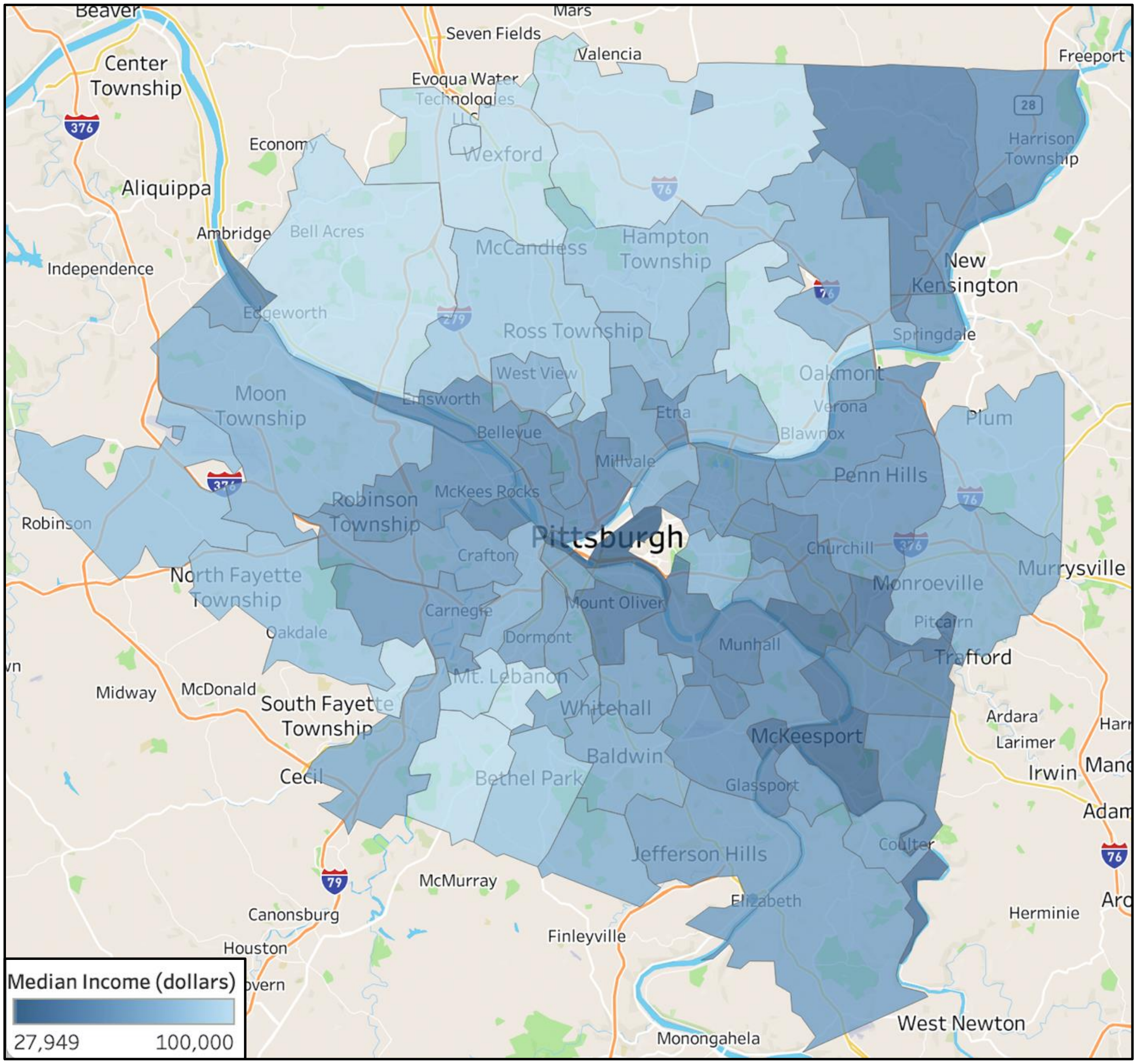


Figure 4 Allegheny County Median Income By Zip Code

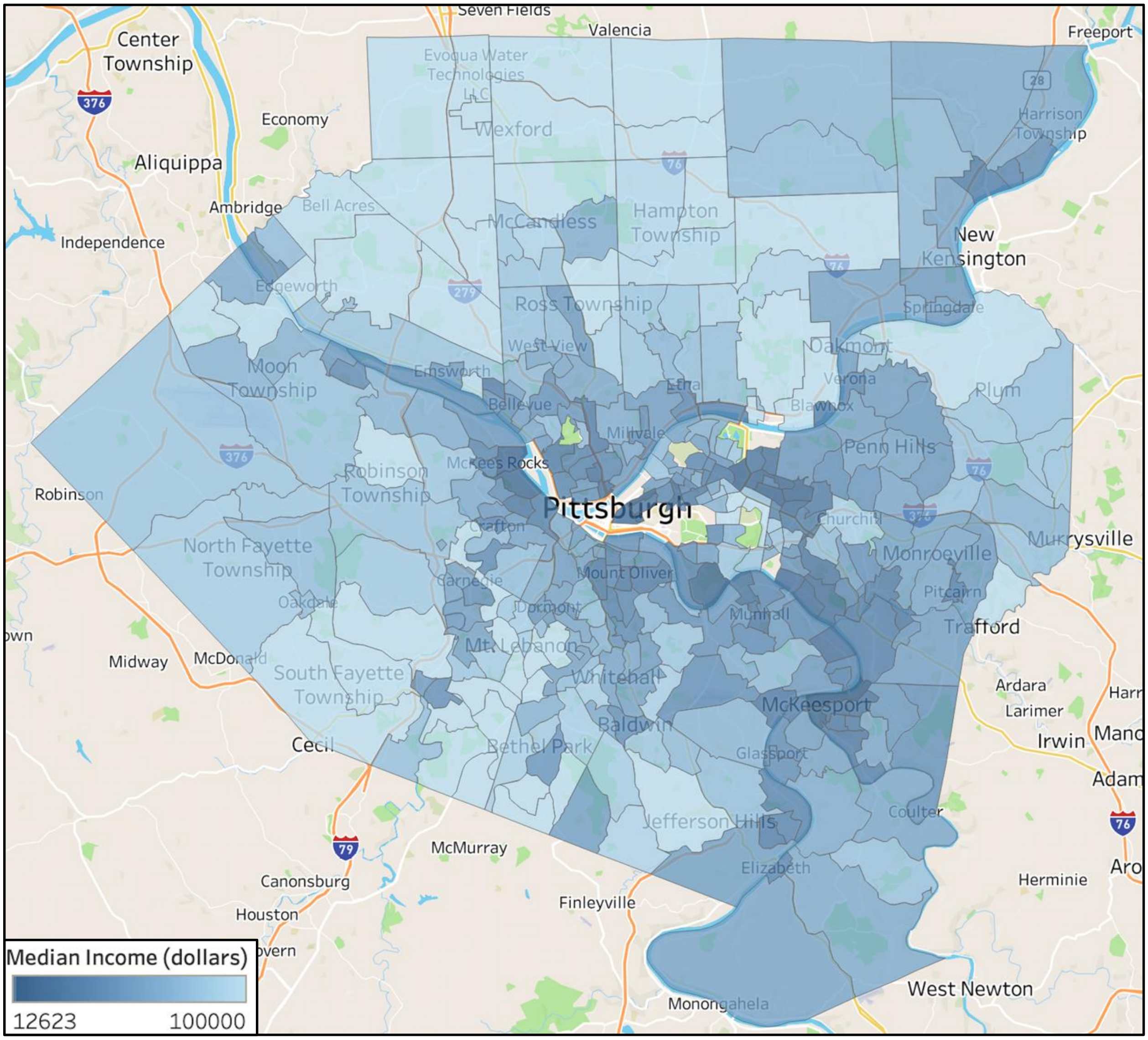


Figure 5 Allegheny County Median Income By Census Tract

Median income for ZCTAs in the Pittsburgh area trend in a similar fashion to the rates of food insecurity, which is displayed in Figure 4. The top of the range, displayed in light blue, include ZCTAs that had a median income of $100,000 or above. Figure 5 displays the median income by census tract.

3.1 Analysis One Results

In order to obtain a better understanding of the food outlets in Allegheny County, Figure 6 displays a map of the county where each point represents one of the four types of food outlets in this study. This figure also incorporates the ZCTA boundaries of all the areas considered for the study.

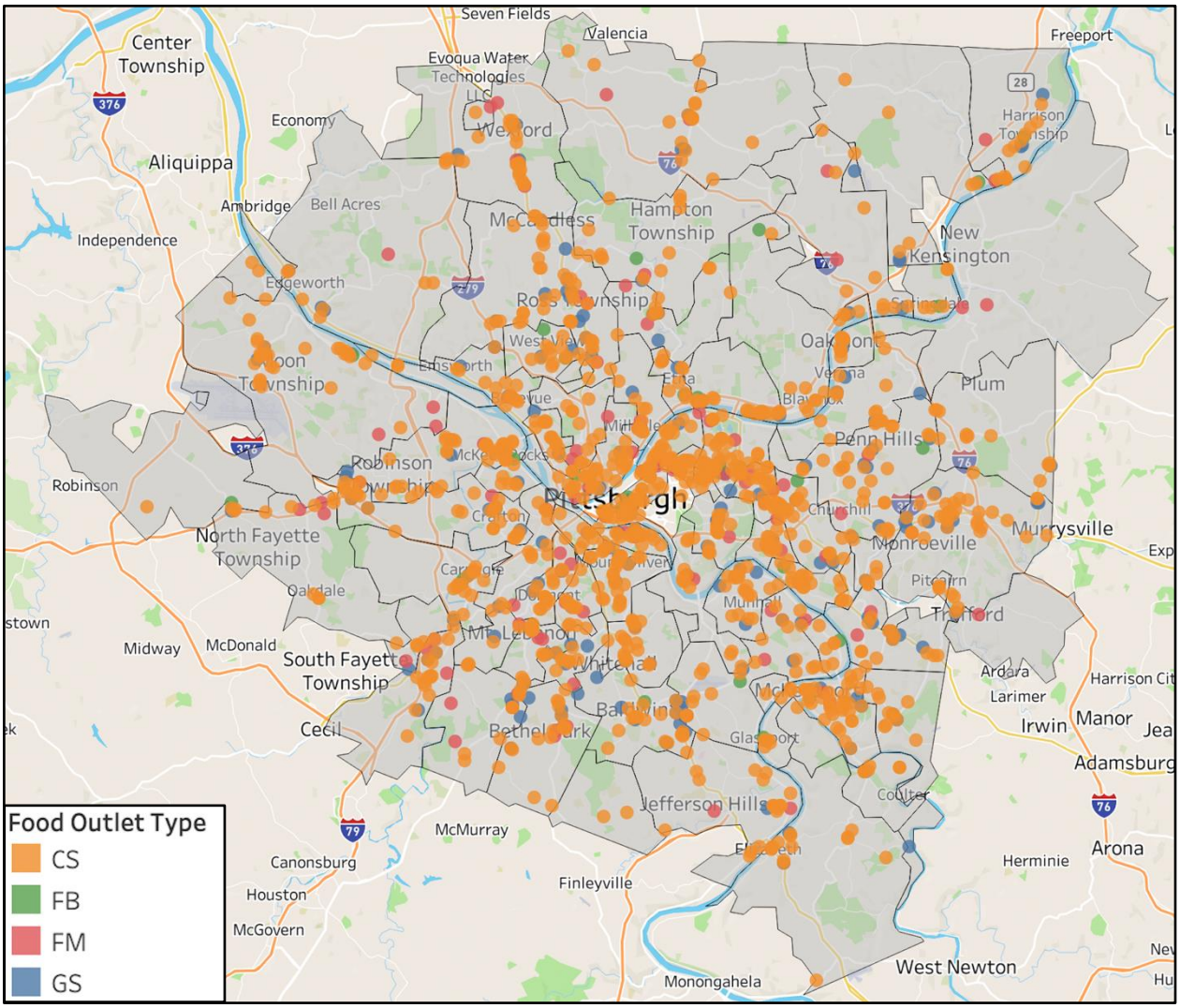


Figure 6 Allegheny County Food Outlets

As mentioned in the method section, this list is not entirely exhaustive of all the ZCTAs in Allegheny County, as the Map the Meal Gap Data may be inaccurate in some areas due to a low sample size or other confounding variable. Figure 7 is a visualization of all the Allegheny County ZCTAs in the study classified based on the presence of a grocery store. 29% of the ZCTAs selected for this study did not have a grocery store.

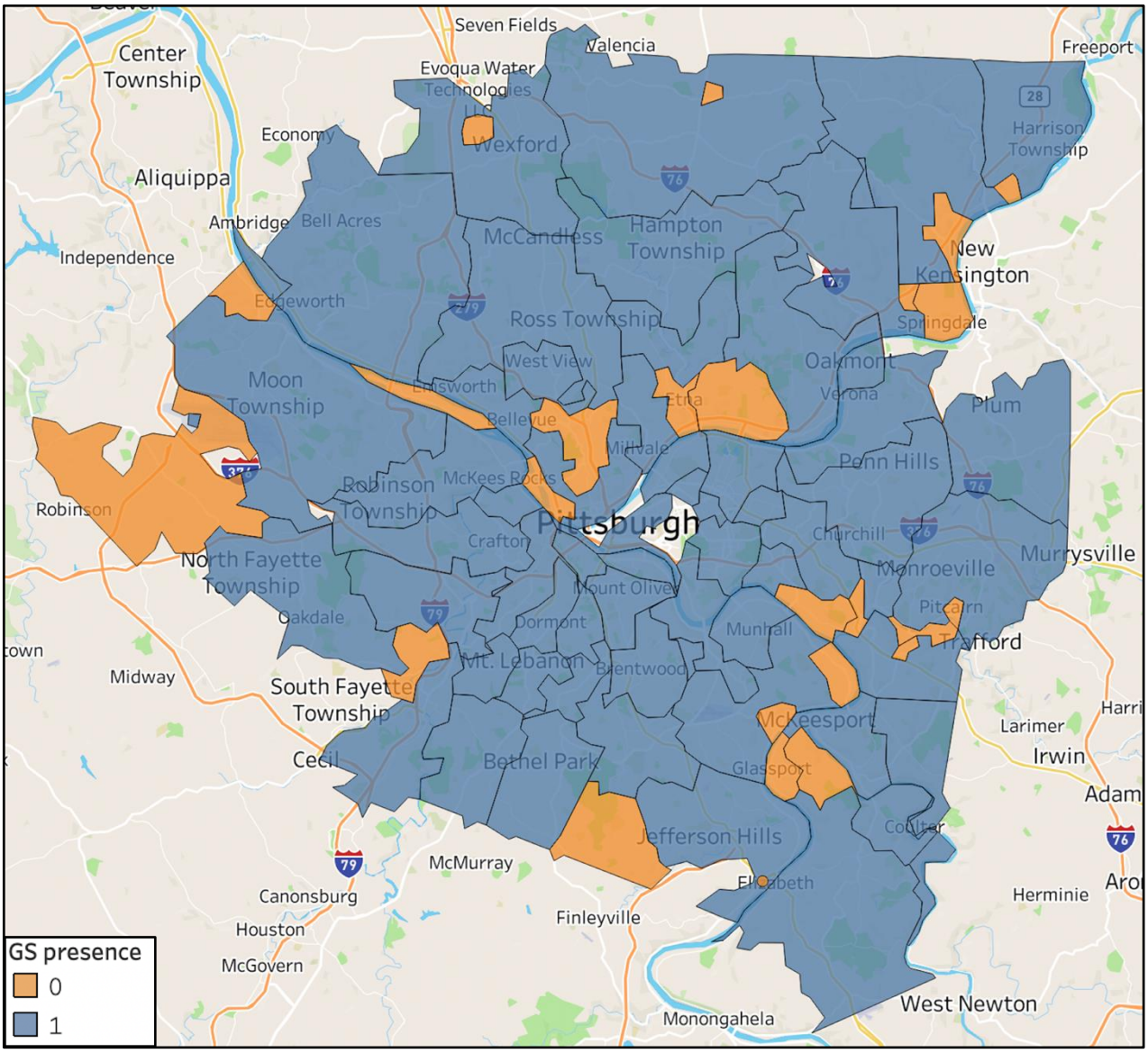


Figure 7 ZCTAs With at Least One Grocery Store

This analysis was completed for each of the food outlet classifications and can be found in Appendix C. Table 1 depicts the average rates of food insecurity for ZCTAs with and without each of the four food outlets.

Table 1 Analysis 1 Average Food Insecurity Rates for All ZCTAs:

With and Without Each Food Outlet

	Present	Not Present	P-Value
GS	8.84% n=61	12.02% n=25	0.0348
CS	9.53% n=82	14.58% n=4	0.2095
FB	10.59% n= 24	9.45% n=62	0.7209
FM	8.48% n=46	11.25% n=40	0.0135

Corroborating previous research, I determined that there is a significant statistical difference in the average rate of food insecurity in ZCTAs with and without grocery stores. In Allegheny County, ZCTAs without the presence of a grocery store experience a food insecurity rate four percentage points higher on average. A similar relationship is true of convenience stores, however a lack of ZCTAs without convenience stores in the population of this study suggest this result may not be statistically significant. Higher rates of food insecurity were seen in ZCTAs with food banks, which logically makes sense due to the prioritization of food insecure areas in the establishment of food banks. However, this result was also not determined to be significant. When the analysis was applied to farmer's markets in the county, the results suggest a significant difference in the average rate of food insecurity in ZCTAs with and without food outlets, where a

lack of the presence of a farmers market correlates with a rate over two percentage points higher on average.

In order to control for confounding variables, the previous analysis was conducted on a subset of the ZCTAs selected for the study with a household income below the average for Allegheny County. Table 2 displays the results of this analysis where the percentage of food insecurity is listed for each food outlet type and the ZCTAs classification based on the presence of these food outlets. For this subset of ZCTAs, 33% did not have a grocery store present.

Table 2 Analysis 1 Average Food Insecurity Rates for ZCTAs Below Median Income: With and Without Each Food Outlet

	Present	Not Present	P-Value
GS	10.78% n=39	14.10% n=20	0.0269
CS	11.71% n=55	14.58% n=4	0.4358
FB	12.91% n=16	11.53% n=16	0.3107
FM	0.1102692 n=26	12.60 n=33	0.1828

Similar to the previous analysis, prior research was corroborated as ZCTAs without the presence of grocery stores did have a statistically significant lower rate of food insecurity when than ZCTAs with grocery stores for Allegheny County. A similar relationship was identified for farmers markets and convenience stores, though neither was determined to be statistically significant. Higher average rates of food insecurity were measured in ZCTAs with a food bank present, though this difference was also not statistically significant.

I elected to complete the same analysis on the basis of food outlet presence and public transportation distances but on a census tract level. Of the census tracts selected for the analysis, 63% did not contain a grocery store. Table 3 depicts the results of the statistical analysis on the comparison of average food insecurity rates for all census tracts in the analysis.

Table 3 Analysis 1 Average Food Insecurity Rates for All Tracts:

With and Without Each Food Outlet

	Present	Not Present	P-Value
GS	9.05% n=135	10.04% n=233	0.1349
CS	9.91% n=310	8.42% n=58	0.1415
FB	14.37% n=28	9.29% n=340	0.0051
FM	9.14% n=82	9.83% n=286	0.3954

On the census tract level of analysis, tracts with grocery stores and farmers markets had marginally lower rates of food insecurity, but these differences were deemed insignificant. There was, however, a statistically significant difference in the average rate of food insecurity in tracts with and without food banks. Tracts without food banks had lower rates of food insecurity. Table 4 displays the results of the statistical analysis for tracts that were below the median income in Allegheny County.

Table 4 Analysis 1 Average Food Insecurity Rates for Tracts Below Median Income: With and Without Each Food Outlet

	Present	Not Present	P-Value
GS	11.47% n=84	13.50% n=142	0.0164
CS	12.58% n=203	14.22% n=23	0.3516
FB	16.47% n=23	12.32% n=203	0.0265
FM	13.32% n=41	12.62% n=185	0.5326

In census tracts without a grocery store, there was a statistically significantly higher rate of food insecurity when compared to tracts without any grocery stores present. I reached the opposite conclusion for tracts without food banks, which had statistically significantly lower rates of food insecurity. Tracts with farmers markets or convenience stores also had higher rates of food insecurity, but this difference was not found to be statistically significant.

3.2 Analysis Two Results

As I mentioned in the literature review, the mere presence of a grocery store or a particular food outlet in a community is not holistically indicative of the food security environment of the area. In order to gain a better understanding of this environment along the dimension of public transportation, ZCTAs were further divided based on the proximity of the food outlet in the

community to public transportation stops. Figure 8 portrays a map of the ZCTAs selected for the study and all of the grocery stores listed in the Allegheny County database. Appendix D contains this analysis for the other three food outlet types. For each grocery store, a second point represents the closest public transportation stop by walking distance.

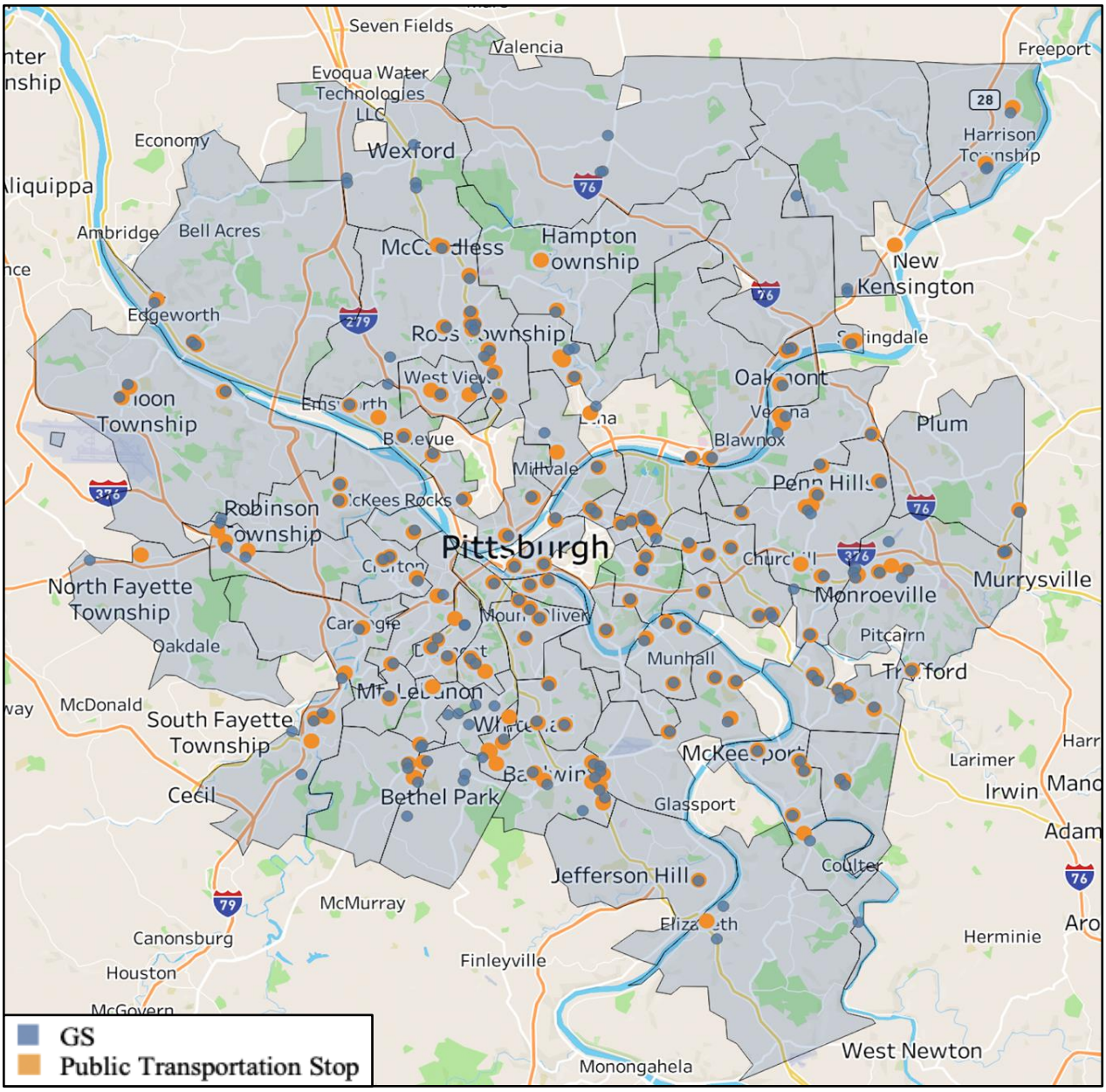


Figure 8 Allegheny County Grocery Stores and Nearest Public Transportation Stop

The first statistical analysis examines the minimum distance of stops for each type of food outlet in the ZCTAs being studied. Table 5 displays the rate of food insecurity for each food outlet category and whether or not it has an accessible public transportation stop based on the minimum distance.

Table 5 Analysis 2 Average Food Insecurity Rates for All ZCTAs:

With and Without Minimum Accessibility to Each Food Outlet

	Accessible	Inaccessible	P-Value
GS	9.13% n=38	8.37% n=23	0.4629
CS	9.86% n=60	8.63% n=22	0.2578
FB	10.34% n=14	10.95% n=10	0.7603
FM	8.40% n=22	8.55% n=24	0.9007

ZCTAs with accessible grocery stores and convenience stores actually had average higher rates of food insecurity than ZCTAs with inaccessible outlets. The opposite was true for food banks and farmers markets, where inaccessible outlets had marginally higher average rates of food insecurity. However, all of these differences were found to be statistically insignificant. As a result of this analysis, I decided to further segment the data based on income. When analyzing the raw data, some ZCTAs with high rates of food insecurity did have inaccessible stops, but also communities with very low rates of food insecurity had food outlets that were deemed inaccessible on the basis of public transportation. In order to control for this variable, Table 6 depicts the same dimensions of results but filtered to only include communities with below the median income for Allegheny County.

Table 6 Analysis 2 Average Food Insecurity Rates for ZCTAs Below Median Income: With and Without Minimum Accessibility to Each Food Outlet

	Accessible	Inaccessible	P-Value
GS	11.05% n=25	10.30% n=14	0.533
CS	12.48% n=38	10.00% n=17	0.0287
FB	13.93% n=8	11.90% n=8	0.3877
FM	11.08% n=12	10.99% n=14	0.9492

The results for grocery stores and convenience stores remains the same, but the analysis for food banks and farmers markets flips, where there is a higher average rate of food insecurity observed in ZCTAs with public-transportation accessible outlets. All of these results are statically insignificant except for convenience stores, where ZCTAs with accessible convenience stores have a rate of food insecurity two and a half percentage points higher than ZCTAs with inaccessible convenience stores, on average. Table 7 depicts this same analysis on ZCTAs below the median income for Allegheny County, but the data is aggregated on the basis of the average distance to public transportation stops for each food outlet type.

Table 7 Analysis 2 Average Food Insecurity Rates for ZCTAs Below Median Income: With and Without Minimum Accessibility to Each Food Outlet

	Accessible	Inaccessible	P-Value
GS	10.61% n=24	11.05% n=15	0.7166
CS	11.09% n=25	12.23% n=30	0.3802
FB	13.93% n=8	11.90% n=8	0.3877
FM	12.37% n=10	10.19% n=16	0.1030

When assessing ZCTAs below the median income in Allegheny County, I found that ZCTAs with grocery stores and convenience stores deemed inaccessible by public transportation had a marginally higher rate of food insecurity, but this result was statistically insignificant. Beginning with the minimum distance for each census tract, I conducted an analysis of the accessibility of the food outlets for all tracts selected for this study. Table 8 displays the results for this analysis, all of which were deemed to be statistically significant.

Table 8 Analysis 2 Average Food Insecurity Rates for All Tracts:

With and Without Minimum Accessibility to Each Food Outlet

	Accessible	Inaccessible	P-Value
GS	10.53% n= 97	5.27% n= 38	2.943e-11
CS	11.13% n=245	5.30% n=65	2.2e-16
FB	16.13% n=22	7.93% n=6	0.02062
FM	12.13% n=43	5.85% n=39	2.804e-06

In census tracts where the closest grocery store was inaccessible by public transportation, there was determined to be lower overall average rate of food insecurity. In fact, for every outlet type, the tracts where the closest outlet was inaccessible had lower rates of food insecurity. In order to account for income differences, Table 9 displays the same analysis of minimum distance on only the census tracts below the median income for Allegheny County.

Table 9 Analysis 2 Average Food Insecurity Rates for Tracts Below Median Income: With and Without Minimum Accessibility to Each Food Outlet

	Accessible	Inaccessible	P-Value
GS	12.03% n=73	7.77% n=11	5.289e-07
CS	13.10% n= 181	8.25% n= 22	1.203e-07
FB	16.70% n=21	14.15% n=2	0.7229
FM	14.14% n=32	10.41% n=9	0.07012

The same trend, however, was determined in this analysis, where the average rate of food insecurity was lower for tracts with food outlets that were inaccessible. This comparison was only significant for grocery stores and convenience stores. It is important to note that when filtered by income, the average rate of food insecurity for tracts with inaccessible grocery stores increased significantly. Table 10 depicts the distance analysis on the census tract level but instead aggregated by the average distance from food outlets to public transportation.

Table 10 Analysis 2 Average Food Insecurity Rates for Tracts Below Median Income: With and Without Average Accessibility to Each Food Outlet

	Accessible	Inaccessible	P-Value
GS	11.26% n=58	11.94% n=26	0.6275
CS	12.82% n= 97	12.31% n= 106	0.5437
FB	16.42% n=12	16.54% n=11	0.973
FM	13.35% n=18	13.30% n=23	0.9793

I found no statistically significant differences in the average rates of food insecurity for either classification across all four of the food outlet categories. However, tracts with grocery stores and food banks that were on average, inaccessible, did have marginally higher rates of food insecurity.

4.0 Recommendations, Implications, and Directions for Future Research

Based on this analysis, it is evident that there are still areas in Allegheny County that do not have a local grocery store for community members to access. In accordance with traditional food desert research, these areas have higher average rates of food insecurity. Allegheny County also corroborates the trend across the United States where one third of ZCTAs do not have a local grocery store or supermarket. From the results of the statistical analysis regarding transportation, it was determined that there is no strong logical relationship between distances to public transportation stops and rates of food insecurity. This is a dangerous conclusion, however, because it is widely known that improving physical access to food, especially in the context of affordable transportation, enables members of marginalized communities to access healthy, sustainable food. A significant relationship that did emerge was that there were actually higher rates of food insecurity with higher perceived access to food. Obviously, the solution is not to make food more inaccessible, but instead reconsider the methodology we use to measure regional food insecurity. For this study, confounding variables that may be difficult to measure could influence the results. These variables include aspects of the built environment along the route that are not present in current regional data. However, when assessing the relationship between convenience store accessibility and food insecurity, there was a significant correlation. Census tracts with more accessible convenience stores had significantly higher rates of food insecurity, which corroborates the notion of food swamps, where there is a high level of access to unhealthy, innutritious food options (Cooksey-Stowers et al., 2017). When examining the mapping of the convenience stores compared to the public transportation stops, it seems that the convenience stores were poised at locations that followed the mapping of the transit system. Another trend that emerged was the

clustering of mid-urban areas that had lower access to grocery stores via public transportation and higher rates of food insecurity. It was determined that areas experiencing severe poverty within the urban environment, like 15219, had high rates of food insecurity but also high access to public transportation. On the other end of the spectrum, areas in a suburban environment with low rates of food insecurity had low access to public transportation, presumably because many residents had access to a car. The key areas experiencing marginalization in the context of this study were a collection of mid-urban areas with high rates of food insecurity and low access to public transportation.

A secondary objective of this study was to compare the statistical efficacy of using ZCTAs compared to census tracts for this type of analysis. While the data collection related to ZCTAs was convenient, and these ZCTAs more closely aligned with different neighborhoods, the census tracts produced more significant results. Census tracts also appear to be more representative of the area, as they are generally balanced in population allowing for more reasonable comparison. Prior literature has also supported the notion of ZCTA inferiority (George & Tomer, 2021). A key challenge is that ZCTAs are not entirely contained to one county, while census tracts are. There are drawbacks of this style of regional analysis as well. A food outlet could be situated on a border, being accessible to those in an area but not appearing in an analysis of presence. When conducting this style of analysis in the future, it may be more effective to use more advanced spatial regression techniques and USGS grid structures. Additionally, the incorporation of other variables may add greater insight to the accessibility of different food outlets in the region. Population density appears to play a role, as areas with high population density in Allegheny County have high access to public transportation stops. Additionally, incorporating the density of public transportation stops into the model would more effectively address disparities within each study area. For example, if

a ZCTA does have a grocery store and a public transportation stop nearby, but a particular segment of that ZCTA does not have any nearby stops, access for individuals within that segment may be limited. Incorporating density accounting for the holistic accessibility of public transportation stops in the region. Finally, Allegheny County has significant variation in topography, which impact the walkability of the routes from the public transportation stops to the food outlet. While a food outlet may appear to by s short distance away, this route could incorporate a steep incline, which is especially strenuous to navigate when carrying groceries.

The focus on accessibility of food outlets should deviate from a holistic focus on distance calculation and instead focus on walkability. While large scale data analysis of regional factors like the analysis conducted for this research is convenient and can garner some insight, it should not be used as the basis for policy and action. For these changes, it is crucial to avoid pure emphasis on distance and instead look at walkability. Distance analysis can be misleading when taken at face value. Instead, this distance analysis can be used as a roadmap for further investigation into key areas in need of support. Once disparities are identified through a distance analysis, grassroots data collection to gain a better understanding of the walkability and individual experience of community members is necessary to effectively address accessibility issues. Policy should be driven by walkability and qualitative analysis of the built environment of at-risk communities, not simply a distance calculation. Surveying methodology, especially when used in conjunction with regional analysis, can provide insight into consumer behavior and social trends in the region. In the context of transportation, research has found that people often travel outside of their own domain to go to preferred stores for food (George & Tomer, 2021). For future analysis, the synthesis of individual behavior within a community, vehicle access, and walkability will provide greater insight into the accessibility of food outlets within a community.

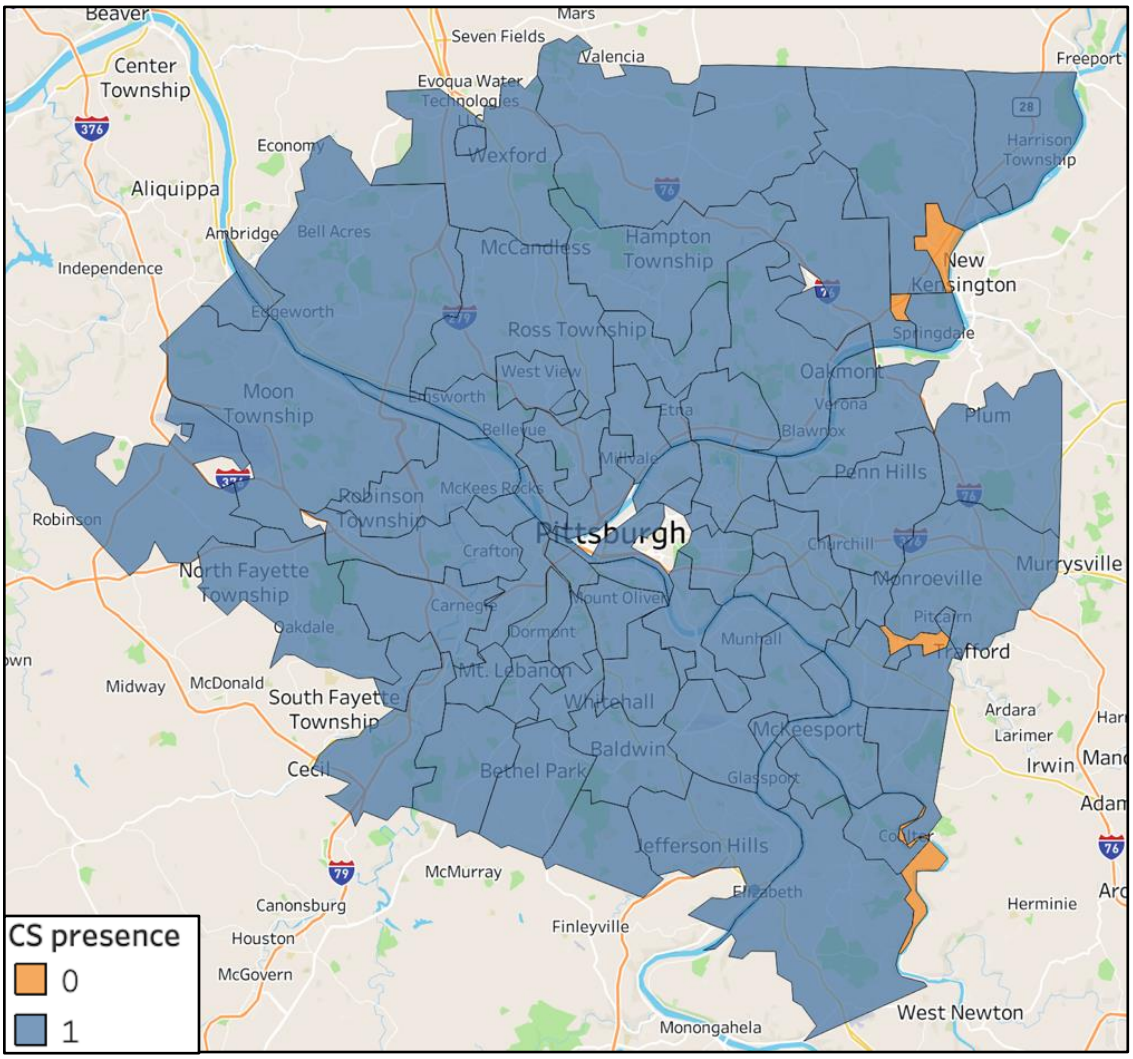
Appendix A Census Tracts Removed

42003010301, 42003010302, 42003020100, 42003020300, 42003040200, 42003040500, 42003040600, 42003040900, 42003051000, 42003140100, 42003515300, 42003563201, 42003980000, 42003980100, 42003980300, 42003980400, 42003980500, 42003980600, 42003980700, 42003980800, 42003980900, 42003981000, 42003981100, 42003981200, 42003981800, 42003982200.

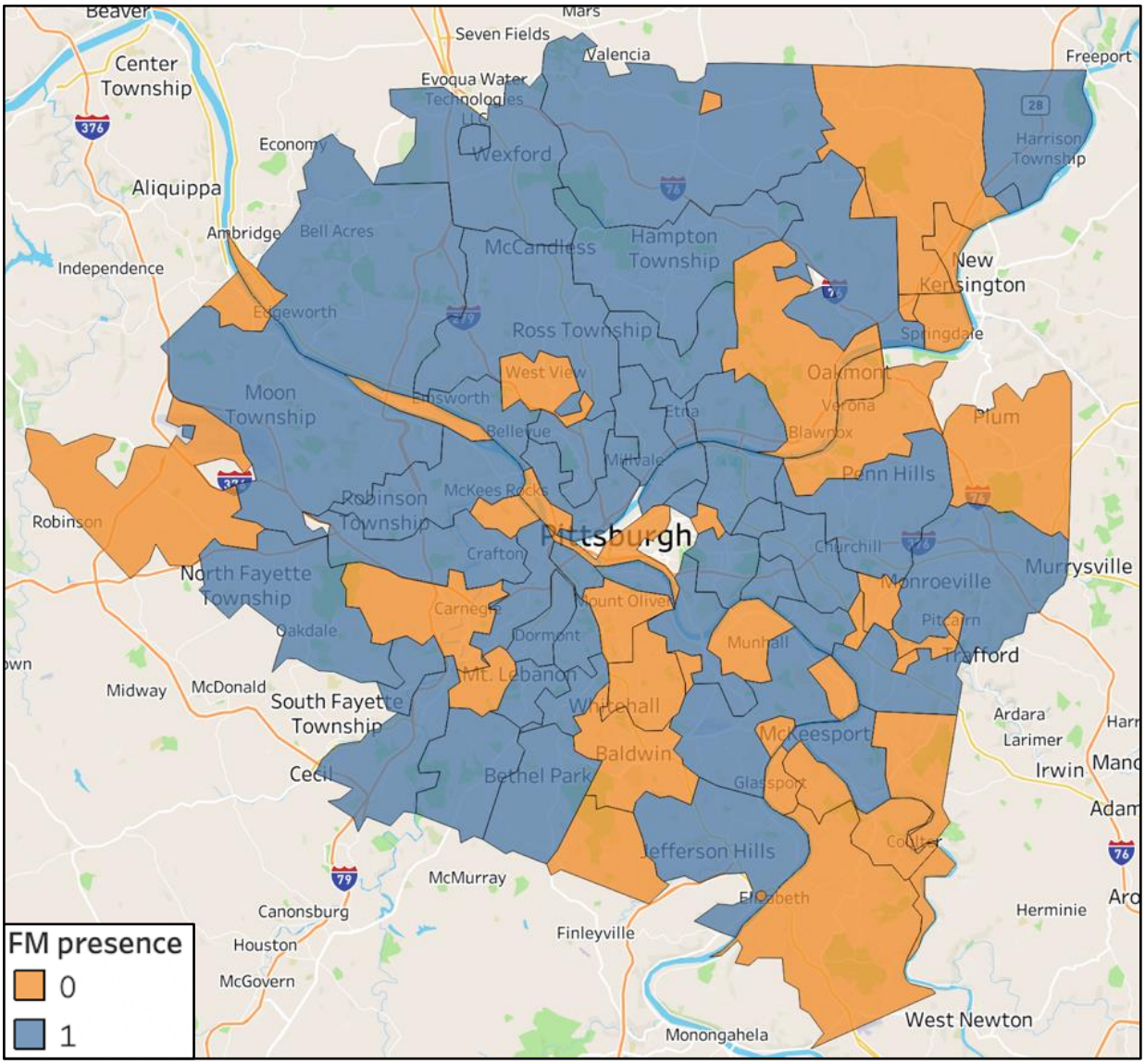
Appendix B Welch Unpaired Two Sample T-Test for Comparison of Means

$$t = \frac{\overline{X}_1 - \overline{X}_2}{\sqrt{\frac{s_1^2}{N_1} + \frac{s_2^2}{N_2}}} = \frac{\overline{X}_1 - \overline{X}_2}{\sqrt{se_1^2 + se_2^2}}$$

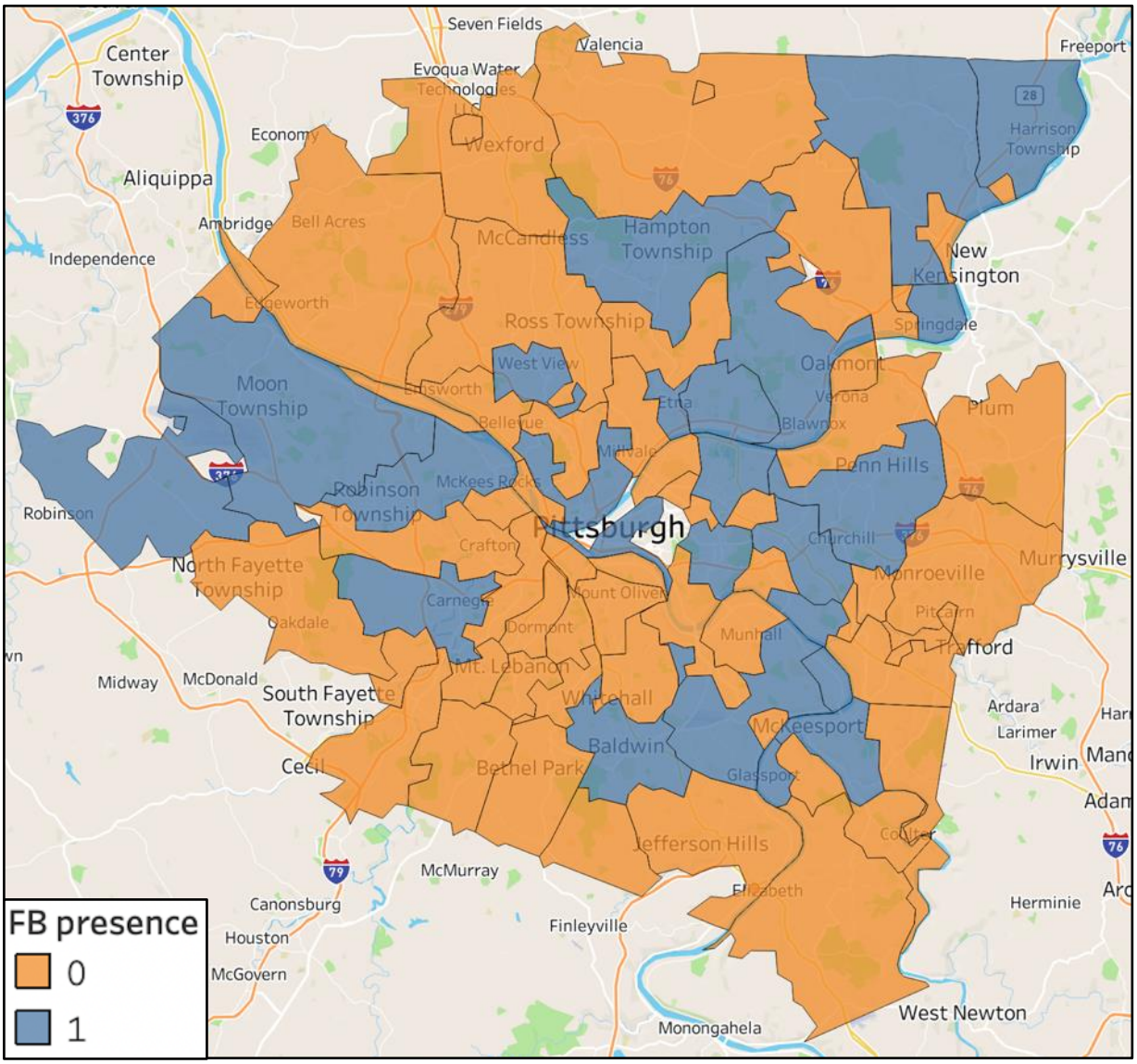
Appendix C Additional Presence Figures



Appendix Figure 1 ZCTAs With at Least One Convenience Store

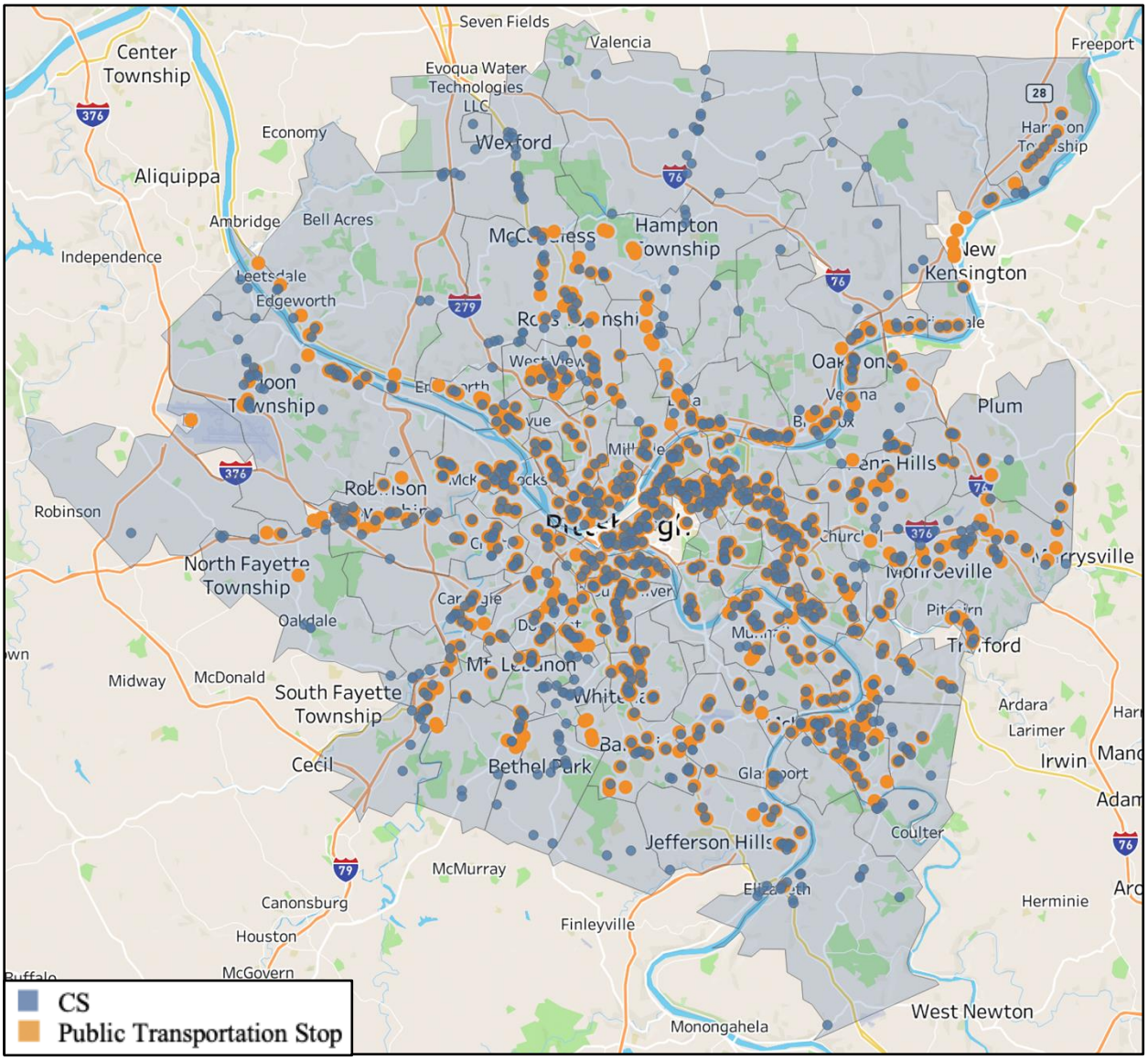


Appendix Figure 2 ZCTAs With at Least One Farmer's Market

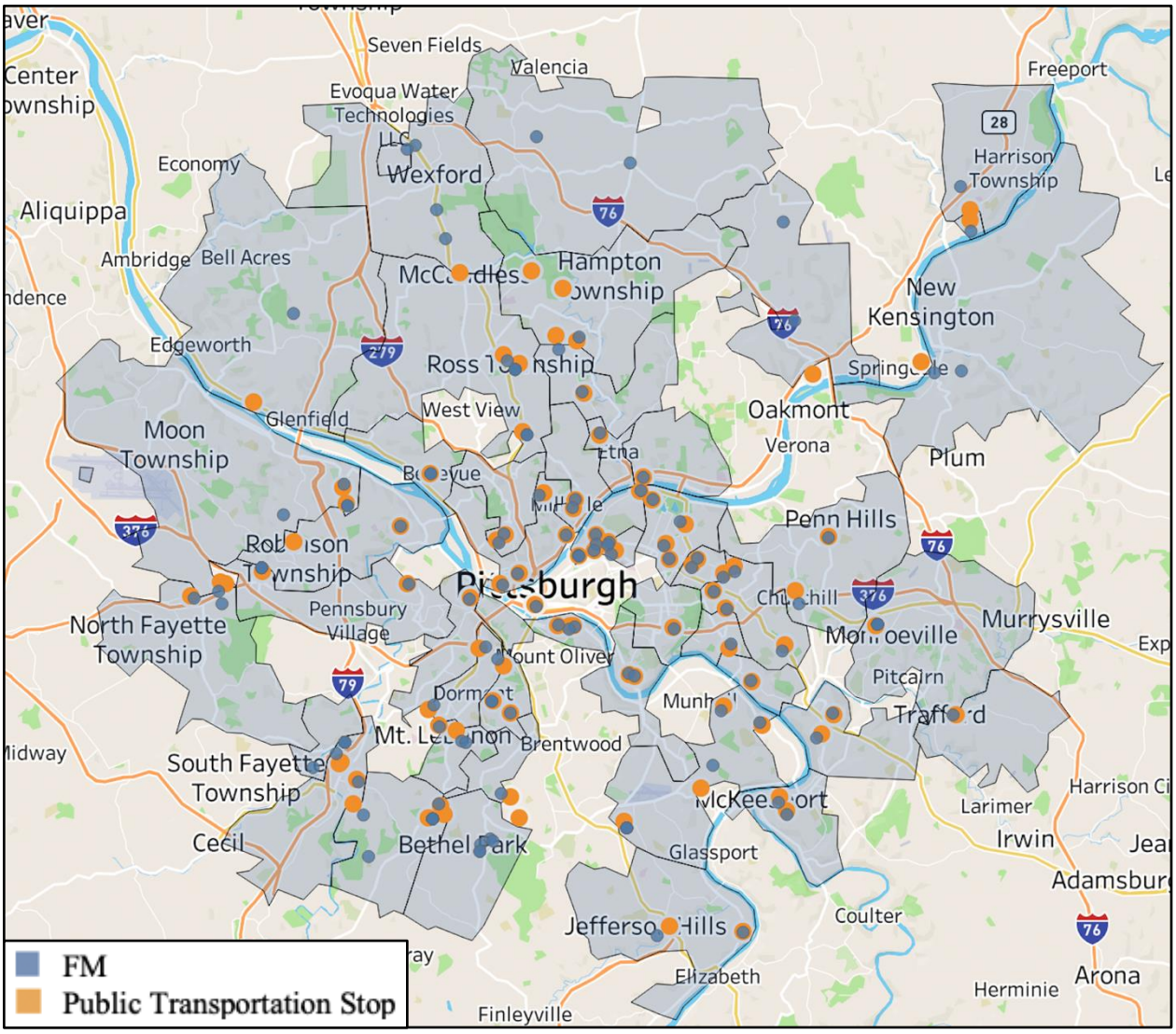


Appendix Figure 3 ZCTAs With at Least One Food Bank

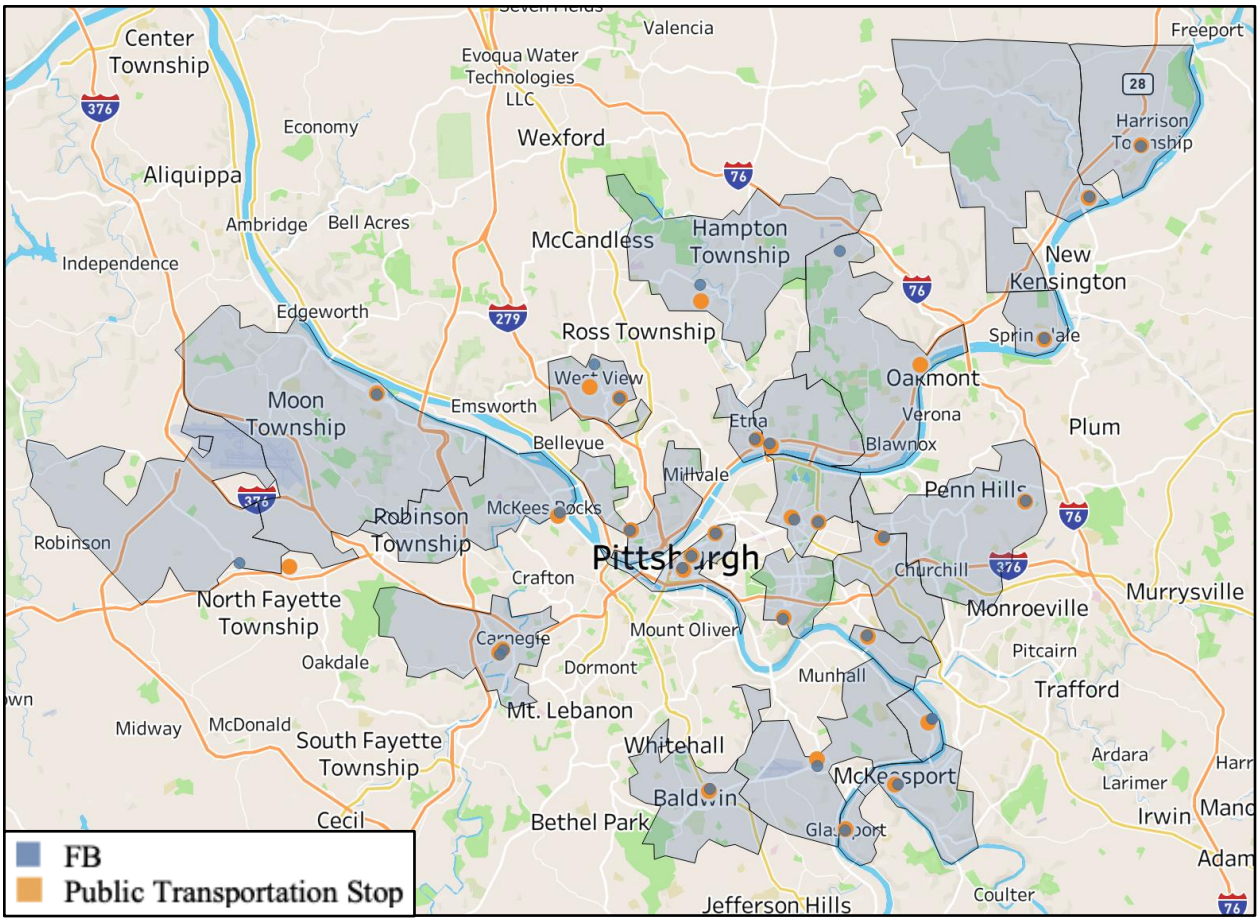
Appendix D Additional Food Outlet and Transportation Figures



Appendix Figure 4 Convenience Stores and Nearest Public Transportation Stop



Appendix Figure 5 Farmer's Markets and Nearest Public Transportation Stop



Appendix Figure 6 Food Banks and Nearest Public Transportation Stop

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