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Precision approaches to food insecurity: A spatial analysis of urban hunger and its contextual correlates in an African city

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Abstract

Although progress has been made in addressing hunger and poor diets in African cities, many urban residents still suffer from food insecurity, and there is large heterogeneity within cities. We examine spatial variations in hunger and dietary quality using a representative study of 983 households and 440 food retailers in a South African secondary city. Substantial variation existed both between and within urban neighborhoods: high-income neighborhoods were not free of hunger, and low-income neighborhoods varied in diet quality according to individual characteristics. After controlling for income and gender, individual characteristics including access to consumer technologies for food transportation and storage, and informal food assistance from neighbors, were protective against hunger and poor quality diets. Results suggest that meaningful variations exist at smaller geographic units than the city-level or neighborhood-level statistics typically reported in food security research. Average socioeconomic status of neighborhoods may not be a sufficient proxy for their food insecurity, as poor areas vary substantially in their food access options and food choices. Precision estimates of hunger and poor diets are needed to target interventions at those neighborhoods and those households with the greatest need, and to tailor interventions for the specific and different needs of urban residents within neighborhoods.

Keywords: food security; urban; food environment; secondary city; social-ecological systems; Africa; South Africa

Precision approaches to food insecurity: A spatial analysis of urban hunger and its contextual correlates in an African city

Urban food insecurity is now recognised as a major development theme in rapidly growing cities of the global south. No longer considered only a rural problem (Crush & Frayne, 2011), food systems in cities are increasingly under scrutiny (Battersby, 2011; Frayne et al., 2009.; Haysom et al., 2017). Rapidly growing cities face two key transformational processes: transformations in the urban food environment, including globalisation of the retail sector and the rise of supermarkets (Battersby, 2017; Crush & Frayne, 2011; Peyton et al., 2015; Wanyama et al., 2019), and transformations in consumer diets towards consumption of energy-dense, nutrient poor, highly processed and readily available foods (Forouhi & Unwin, 2019; Monteiro, Moubarac, Cannon, Ng, & Popkin, 2013; Steyn et al., 2012). These food environment and individual food system transformations are often correlated, and therefore must be considered in combination when trying to address hunger and diet quality in cities (Aparecida Borges et al., 2018; Baker et al., 2006; Chen & Yang, 2014; Drimie et al., 2013; Dubowitz et al., 2015; Frayne & McCordic, 2018; Herforth & Ahmed, 2015; Kroll et al., 2019; Pitt et al., 2017; Story et al., 2008).

African cities are a critical innovation ground for solutions to urban hunger. By 2050, 70% of the world's population will live in cities, and Africa will account for more than two thirds of this growth, with growing pressures to manage the supply of sufficient healthy food (Newell et al., 2019). Simultaneously, changes in African urban dietary patterns parallel global changes, with concerns about rising consumption of meat and milk, sugar and fats, and highly processed foods (Daly, 2005; Igumbor et al., 2012; Wells et al., 2020). This "nutrition transition" has been linked to an increasing prevalence of overweight, obesity, and diet-related non-communicable diseases (Brown, 2018; Steyn & Mchiza, 2014). Fruits and vegetables are additionally a focus of global and African health targets, as these are consumed at lower than recommended levels worldwide, especially in poorer communities (Drimie et al., 2013; Garcia et al., 2020). Therefore, if the world is to reach the Sustainable Development Goal of ending all forms of malnutrition by 2030, then Africa must be able to respond to these challenges for managing urban hunger, including balanced diets (Faber et al., 2009; Kennedy et al., 2011) and food security (Coates et al., 2006; Leroy et al., 2015). Food security is a broad term that typically includes four dimensions: availability, access, utilization, and stability (Committee on World Food Security, 2012). The present paper focuses on sufficient economic and physical access to food retail options in cities, on food utilization through individual food choices, and on the complex linkages between food access, food utilization, and socio-economic dynamics (May, 2018).

Socio-economic dynamics of food insecurity are well-researched, including reliance on informal housing and infrastructure (Drimie et al., 2013), informal sector employment (Blekking et al., 2020; Crush & Frayne, 2011; Haysom et al., 2017), and education (Brown, 2018). Poverty is a main cause of food insecurity (Bharti et al., 2019), especially in cities. For urban households, most food is purchased, and therefore poverty is a direct indicator of food access in South Africa (Battersby, 2011; Rose & Charlton, 2002), Southern African cities (Kroll et al., 2019) and cities worldwide (Cohen & Garrett, 2010). If a household has inadequate income to purchase a basic subsistence diet, it may be considered to be in food poverty.

Poverty is a main cause of urban hunger, but it is not the only driver. Underlying contextual drivers of dietary behavior, such as food environments, can contribute a great deal to improving food security. Previous studies characterise urban "food environments" as the collective physical, economic, and sociocultural surroundings that influence people's food choices, although there are variations in socio-ecological and agri-food approaches

(Holdsworth & Landais, 2019). Here we take a social-ecological systems perspective (Ostrom, 2009; Ostrom & Cox, 2010), in which dietary choices are considered a product of complex interactions between the individual person and their food environment (Dean & Sharkey, 2011; Pereira & Ruysenaar, 2012; Pitt et al., 2017).

In the social-ecological perspective, the urban food environment is considered a combination of social, physical, and macro-level interactions (Holdsworth & Landais, 2019). The social food environment includes social interactions with family and neighbours, including food sharing and food assistance. The physical food environment includes physical locations where people may produce food, such as urban gardens (Scholtz & Von Bormann 2016). The geographic variability of different food retail types is important to the physical food environment, including formal retail sources, such as supermarkets, and informal sources, such as temporary and semi-permanent small and roadside stores (Battersby & Peyton, 2014; Haysom et al., 2017; Greenberg, 2017; Lake, 2018). The macro-level food environment includes distal factors such as advertising policies, trade, and geopolitics, but it is difficult to analyse geographic variation in these macro-level interactions within a city (Battersby, 2011). In the present paper, therefore, we focus on the influence of urban social and physical food environments on the accessibility of healthy food.

Geographic analyses of the urban food environment have historically focused on differences between neighborhoods, but these approaches may mask important variability at the household and individual level, particularly regarding food retail options. For example, one study of food environments and obesity in the United States found that predominantly Black neighborhoods had higher obesity and more fast food restaurants than other neighborhoods (Block, Scribner, & DeSalvo, 2004), while another study found that low-income neighborhoods had higher food insecurity and fewer supermarkets than high-income neighborhoods (Gottlieb et al., 1996). However, the choice to focus on neighborhood income level or racial mix may risk reducing the complexity of food insecurity or obesity to a single, neighborhood-level issue that masks important variations at household and individual levels. A study of food choices in California found that the correlation between food retail access and diet-related non-communicable disease was seen across all geographic regions and not limited to certain neighborhoods (Babey et al., 2008), and a study of food access in Ohio found that individuals' race, income, and other demographic characteristics could not predict the likelihood of residing in an area of lower than average food access (Eckert & Shetty, 2011). Thus, while neighborhood-level analyses have much to offer, they may also obscure important variability between households and individuals, and thereby prevent the identification of potential improvements to urban social and physical food environments.

The cost of collecting spatially disaggregated data has been a barrier to their use. Recently, however, the availability of hand-held devices, costing less than $100, and capable of both computer assisted interviewing (CAPI) and accurate recording of geo-referenced information, has been found to reduce costs by up to 75% (Leisher, C., 2014). In general, the potential benefits of spatially disaggregated data must be weighed against their increased costs.

Improvements to urban social and physical food environments can have positive impacts on urban hunger. For example, consumer technologies improve household food security and nutrition, beyond their monetary value as indicators of household wealth (Ingram, 2011; Statistics South Africa, 2014). Cars allow independent transport to out-of-town shopping centres and the secure transport of food in large quantities (Caraher et al., 1998; Caraher et al., 2010; Coveney & O'Dwyer, 2009), and food storage and preparation technologies, such as fridges and microwaves, allow households to access a wider set of foods, including perishable fresh foods (Faber et al., 2009). As a second example, food assistance schemes such as school meals, community-based nutrition programmes, and faithbased feeding schemes can be an important food source for poor households in urban areas (Battersby & Peyton, 2014). A third example, urban agriculture, is increasingly the focus of research efforts to improve food security and diet quality in urban households (Blekking et al., 2020; Crush & Frayne, 2011; Ingram, 2011; Statistics South Africa, 2014). A global review found that urban agriculture could increase households' access to fresh foods, improve household food availability, and improve dietary diversity (Coveney & O'Dwyer, 2009). Urban agriculture is also a potential method for supplementing incomes in South African cities (Crush, Hovorka, & Tevera, 2011). These innovations are some examples of improvements to urban hunger.

However, without an integrated approach, these innovations can also have unintended consequences on urban food systems. The above-mentioned example of car transport can lead to inequalities if urban planning prioritises cars over other forms of transport, because food retailers may adjust their locations to suit cars, making these retailers difficult to access for households without a car and thereby contributing to inequalities in food access (Dixon et al., 2007). Similarly, technologies for refrigeration and food storage are less accessible to small informal traders than they are to large supermarkets (Roos et al., 2016; Battersby, 2011), and this inequality in technology access can lead to the displacement of informal local food retailers by formal corporate chains and a potential threat to food access in poorer communities (Dixon et al., 2007; Drimie et al., 2013; Igumbor et al., 2012). The example of food assistance schemes, particularly school feeding schemes and food packages, can lead to inequalities if these schemes mask the underlying inability of households to afford food (Pereira & Drimie, 2016), or if they are not properly implemented (Gresse, Nomvete, & Walter, 2017; Sibanyoni, Tshabalala, & Tabit, 2017). The example of urban agriculture can have unintended consequences in some communities, where agriculture carries a negative stigma due to the legacy of apartheid and colonial eras that confined small-scale black farmers to subsistence agriculture (Thornton, 2008), or where programs do not assist with social or political issues in implementation (Ruysenaar, 2013). Trade-offs like these indicate that food choices should be analysed within their wider social-ecological context, especially in cities, where improvements in one aspect of food security could have unintended consequences on other parts of the urban food system.

One option for reducing unintended consequences, while addressing geographic variation, is precision approaches: the use of disaggregated data at a higher spatial resolution than city or neighborhood level. Although city-level and neighborhood-level estimates are useful for comparison and benchmarking, they may mask local inequalities in hunger, diet quality, and social-ecological contexts. In contrast, precision approaches quantify inequalities at the local level, so that the data may be used to precisely target and optimally allocate resources to interventions (Osgood-Zimmerman et al., 2018). Precision approaches that include social-ecological environments, as well as individual food choices, may therefore help to identify targets for intervention and to mitigate unintended consequences.

The objective of this paper is to present a case for precision analysis of food choices in the context of social and physical food environments in a South African secondary city. We compare the explanatory power of neighbourhood-level and household-level data for determining food insecurity and related outcomes. If household circumstances have a detectable effect on household food insecurity, over and above the effects of neighbourhoods, then spatially disaggregated data may be needed. If, on the other hand, neighbourhood characteristics are sufficient to explain variations in household food insecurity, then neighbourhood-level data can play an important role for ongoing monitoring of food insecurity in African cities.

Method

Case Study

Worcester (Figure 1) is a secondary city of 130 000 people located in the Breede Valley region of the Western Cape, South Africa. The Breede Valley has a long history of irrigated agricultural production and contributes substantially to South Africa's exports from agri-processing (Cape Winelands District Municipality, 2019; Cullis et al., 2018; Seeliger et al., 2018). However, food systems in the region are changing rapidly. Urban expansion threatens productive croplands around the city and competes with agriculture for energy and water. Food supply chains are globalised and consolidated, and most of the food produced in the Breede Valley region goes to export (Muller, 2014; Rumble, 2013). Nutrition challenges include high levels of stunting and increasing diet-related non-communicable disease (Balogun et al., 2015; Du Plessis et al., 2016). Patterns of socio-economic segregation and the apartheid spatial legacy further complicate the process of planning for development and lead to unequal impacts on the food system. These characteristics are typical of rapidly growing secondary cities in South Africa.

-- FIGURE 1 ABOUT HERE --

Figure 1. Study location Worcester with high-income and low-income residential neighborhoods. Grey/NA indicates non-residential (industrial) areas. Source: Breede Valley Municipality (income data), ESRI (basemaps).

Data Collection

Primary data collection included two components: a household survey on food consumption and a mapping exercise to locate food retail businesses. These methods and instruments were approved by the Social and Societal Ethics Committee of the KU Leuven (G-2019 06 1664) and the Humanities and Social Science Research Ethics Committee of the University of the Western Cape (HS19/6/15).

Household Survey Participants. Participants were adults knowledgeable about the household food supply. Fieldworkers approached participants at home and requested an interview. Surveys were conducted face-to-face in either English, Afrikaans, or isiXhosa languages. Survey answers were recorded in digital form using open-source data collection software (ODK) on tablet computers.

Household Survey Sampling. The target sample size was set to detect food insecurity, conditional on household wealth. The sampling and power calculations were stratified according to household wealth, and the sample was additionally geographically stratified using the Statistics South Africa small area units.

To calculate the target sample size, we used Cochran's formula for estimating prevalence:

$$N = \frac{Z^{2} P(1-P)}{d^{2}}$$

where Z = confidence level, P = expected prevalence, and d = precision.

We set $Z = 1.96$ and $d = 0.05$ based on convention, and can estimate P based on national-level prevalence estimates from Statistics South Africa's 2017 General Household Survey (GHS): $P(\text{food insecurity} \mid \text{low wealth}) = 0.21$, $P(\text{food insecurity} \mid \text{high wealth}) = 0.11$. A baseline sample size to accurately estimate food insecurity would therefore be N = 256 low-wealth households, and N = 231 high-wealth households. To allow for additional variation in other parameters in the food security model, and for the fact that prevalence estimates came from a national-level survey rather than a Worcester-specific or Western Cape-specific survey, the target sample size was set higher than this baseline, at approximately $N = 1000$ households.

Households were randomly sampled within the spatially defined Enumeration Areas (EAs) of South Africa's 2011 Census. One satellite map was produced per EA in Worcester and Zweletemba and used to guide the fieldwork. Fieldworkers selected a random starting point within the EA and then targeted every *n*th house for a survey, with *n* a random number based on days of the week. All residential EAs in Worcester and Zweletemba were included in the survey (126 residential EAs: 111 formal residential, 7 informal residential, 8 collective living).

Household Survey Instrument. A survey design workshop was held in Worcester on 16 August 2019. The workshop included Food4Cities South Africa team members and an advisory group consisting of a nutritionist and complex systems expert. The household survey was piloted in the field on 29 September 2019 by the field team and subsequent small changes were made, primarily to shorten the length of the survey and remove redundant items. The household survey ran in Worcester from 9 to 30 October 2019.

Household Survey Attrition. Between 9 and 30 October 2019, a total of 1784 household surveys were attempted. Of these, 154 found no-one home, 72 were not able to access the property, 21 found no knowledgeable adult at home, 82 made an appointment to return for a survey, 467 refused to participate, there were 2 child-headed households, and 3 surveys had other visit outcomes.

Food Retail Locations. The location and type of food retailers around Worcester was recorded in two waves. Student data collectors drove around the town in October 2019 and recorded store locations and locations of informal traders using GPS. However, the students could not access all areas of the town due to safety issues. In January 2020, a second research team of local residents visited the previously un-accessed areas and recorded store locations and types.

Outcome and Predictor Variables

Outcomes. All outcomes are measured at the household level. Food insecurity was measured using a shortened version of the Food Insecurity Experience Scale (FIES, Hardoy et al., 2019; Satterthwaite et al., 2010). These questions (Table 1) referred to the dimensions of food insecurity previously found to be common in multiple cultures: anxiety and uncertainty about food supply, insufficient quality, insufficient food intake, and its physical consequences (Marais et al., 2016).

-- TABLE 1 ABOUT HERE --

Table 1. Questions on food adequacy extracted from the Food Insecurity Experience Scale.

Dietary diversity was measured according to the FAO guidelines on measuring individual dietary diversity (Kennedy et al., 2011). Respondents were asked about the foods they had consumed in the past 24 hours, inside and outside the home. The individual dietary diversity is the number of target food groups consumed in the past 24 hours and reflects the probability of micronutrient adequacy of the diet (Kennedy et al., 2011). Food groups included in the dietary diversity score (WDDS), as recommended by its authors, were: cereals; white roots and tubers; vitamin A-rich vegetables and tubers; dark green leafy vegetables; other vegetables; vitamin A-rich fruit; other fruits; organ meat; flesh meats; eggs; fish and seafood; legumes, nuts, and seeds; milk and milk products; oils and fats; sweets; and spices, condiments, and beverages (Kennedy et al., 2011, p. 8).

Target foods were included as an outcome. In addition to the food groups used for the FAO dietary diversity score, our advisory group identified certain food groups that may be important to health outcomes in South Africa. These included fruits and vegetables, including vitamin A-rich vegetables, green leafy vegetables, other vegetables, vitamin A-rich fruit, and other fruit; animal-source foods, including organ meat, chicken, red meat, other meat, eggs, fish, and dairy; highly processed foods, including instant noodles, highly processed meat, ultra-processed dairy, and breakfast cereal; and fats and sugars, including fried potatoes, oils and fats, sugar, confectionery, cakes, vetkoek, soft drink, and salty snacks.

Reliance on informal food retailers was also included as an outcome. Participants were asked to nominate, for each food eaten in the last 24 hours, where this was purchased. The list of food retailers was divided into formal and informal categories. Retailers included in the "formal" category were supermarkets, convenience stores, specialty food shops (e.g., bakeries, biltong stores), and formal butcheries. Retailers included in the "informal" category were spaza shops, bakkie traders, roadside stalls, and households selling food to neighbours. For each participant, the proportion of food purchased from informal retailers was calculated and rescaled to produce a final "informal retail index" that ranged from 0 (all food purchased from formal retailers) to 1 (all food purchased from informal retailers).

Neighbourhood Predictors. Neighbourhood-level variation in food insecurity was controlled in two ways. First, a neighbourhood-level covariate, neighbourhood income, was calculated based on the reported annual household income per ward provided by the Breede Valley Municipality (based on the 2011 South African Census). Neighbourhood income information is available at ward level as the number of households in each income bracket reported in the Census. The average income per ward was calculated by multiplying the centre of each income bracket by the number of households reported in that bracket, and dividing by the total population of the ward. This average income in Rand was then mean-centred and scaled to allow its inclusion in the statistical models with other covariates that had been measured at different scales.

Second, neighbourhood was collected as part of the household survey and a fixed effect of neighbourhood was included in the analyses. Neighbourhood was included as 24 categorical "dummy" variables representing wards, the local government administrative areas most likely to be used as neighbourhood proxies for food insecurity. The reference category was the most populous ward, Bergsig (2011 South African Census).

Geographic Predictors. Based on the food retail locations, each respondent was assigned two numbers that reflected their average travel time to formal and informal food retail outlets in minutes (driving time). During the household survey, we captured the street address and GPS location of each household. Similarly, during the food retail survey, we captured the street address and GPS location of each retail outlet. Map distances between respondents' home addresses and formal and informal food retail outlets were calculated using the R package *ggmap* (Kahle & Wickham, 2013).

"Access to formal food retail" calculated respondents' average driving time to supermarkets, convenience stores, specialty food shops (e.g., biltong stores), and formal butcheries and bakeries. "Access to informal food retail" calculated respondents' average driving time to spaza shops, bakkie traders, roadside stalls, and house-based informal stores households selling food to neighbours.

Household Predictors. Two indicators measured poverty: income below the South African food poverty line and an adapted version of the South African Multidimensional Poverty Index (SAMPI) (Statistics South Africa, 2014). The food poverty line is the amount of money that an individual would need to afford the minimum required daily energy intake and we used the amount calculated for South Africa in the year of data collection (Statistics South Africa, 2019). The SAMPI was constructed using four dimensions of poverty: health (nutrition), education (years of schooling), living standards (fuel for cooking, sanitation, water, type of dwelling, and assets), and economic activity (employment), as shown in Table 2.

-- TABLE 2 ABOUT HERE --

Table 2. Dimensions of the case study adaptation of the South African Multidimensional Poverty Index. As with the SAMPI, all dimensions are weighted equally and the indicators within each dimension are weighted equally.

In addition to poverty measurements, the household survey asked whether households produced any foods at home, including crops and/or livestock. We also asked about sources of food assistance, such as school feeding programs, government nutrition programs, and soup kitchens. We asked whether respondents had access to food storage and preparation technologies: fridge, freezer, microwave, oven, and stove.

Statistical Methods

Food Insecurity. The FIES treats food insecurity as a latent trait ranging from mild to severe. Based on the item responses, a probabilistic assignment procedure was used to assign participants to classes of severity along the latent "food insecurity" trait. We used the recommended analysis methods by the creators of the FIES, implemented in their R package *RM.weights* (Cafiero et al., 2018). The distribution of the raw score was assumed to be a mixture of three Gaussian densities, corresponding to food insecurity classes mild, moderate, and severe. Each density was centred on the raw score parameters and scaled with country-specific measurement errors. Each participant thus received an estimated food insecurity class: Food Secure (no or mild food insecurity), Moderate Food Insecurity, or Severe Food Insecurity.

Dietary Diversity. As recommended by the FAO, the individual dietary diversity score was calculated as the number of target food groups consumed in the past 24 hours (Kennedy et al., 2011). The higher the WDDS, the greater the dietary diversity (ranging from 0 to 9).

Statistical Analysis. A series of generalised linear models (GLM) estimated the effects of household size, household children and infants, poverty index (SAMPI), food poverty line, home food production, distance to formal and informal retailers, gender, population group, cooking energy source, and food preparation technologies, neighbourhood income, and a fixed effect of neighbourhood as predictors on a set of outcome variables including: moderate and severe food insecurity (FIES), dietary diversity (WDDS), intake of target foods (fruits and vegetables, animal-source foods, highly processed foods, fats and sugars), and choice of formal or informal food retailers. Neighbourhood income and fixed effects of neighbourhood were investigated in alternate models (Models 1 and 2, respectively).

Due to the large number of statistical tests given by all combinations of predictors and outcomes, a high threshold for statistical significance was applied ($p < .01$). GLMs for binary outcome variables (e.g., food insecurity) used a logit link and may be interpreted as a logistic regression. GLMs for continuous outcome variables (e.g., dietary diversity) used an identity link and may be interpreted as a standard linear (Gaussian) regression. Sensitivity analyses, using alternative model formulations, are reported in the Supplementary Material, including an alternative formulation of the dietary diversity model, using a Poisson family GLM with log link, as the data were collected as counts (Table S5); and an alternative formulation of the informal food purchases model, using a fractional logit, to account for the censoring at zero and the proportional nature of the variable (Table S6).

Effect Sizes. Predicted rates for outcome variables were calculated based on coefficients of generalized linear models with logit link (logistic regression coefficients). For logit link GLMs, the coefficient (*B*) is a log odds ratio, and therefore the exponent of the coefficient, *exp*(*B*), is given in the interpretation. The coefficient is interpreted relative to the base rate (P_C) for each outcome. Compared to the base rate, the predicted rate in the treatment group (P_T) is calculated using the following formula:

$$P_T = \left(\frac{exp(B) \times P_C}{(1 + exp(B) \times P_C - P_C)}\right)$$

The effect size is therefore the predicted percentage difference in an outcome variable (e.g., food insecurity) for each unit increase in the predictor variable, calculated as the predicted rate in the treatment group and the base rate, $P_T - P_C$. Effect sizes are reported for results in Model 2 (including neighbourhood fixed effects).

Results

The final sample size was $N = 983$ completed surveys. Of the sample, 484 households reported some form of multidimensional poverty, representing 50.57% of the sample. This was not significantly different to the target sample proportion of 52.57% low-wealth households ($z = 1.20$, $p = .247$), so we consider both high-wealth and low-wealth areas to be adequately sampled. Respondents included 681 women and 298 men. 328 respondents were aged 18-40, 437 respondents were aged 41-60, and 215 respondents were aged 61+. The sample over-represents women, and we deal with this by presenting descriptive results separately for women and men and by including gender as a moderator in all analyses.

Gender-disaggregated results are summarised in Table 3. There was a significant gender difference in moderate food insecurity, with women more likely than men to report food insecurity. Dietary diversity was similar between women and men. The proportion of respondents who had consumed fruits and vegetables, animal-sourced foods, highly processed foods, or fats and sugars in the past 24 hours was similar between women and men. Men were marginally more likely than women were to rely on informal sources for food retail.

Correlations between outcomes are reported in Table S1 in the Supplementary Material. Moderate and severe food insecurity were highly and positively correlated, as expected, and were each negatively correlated with dietary diversity and intake of fruits and vegetables, animal-sourced foods, and highly-processed foods. Reliance on informal retail was positively correlated with moderate and severe food insecurity and negatively correlated with dietary diversity and intake of animal-sourced foods.

-- TABLE 3 ABOUT HERE --

Table 3. Descriptive statistics for study outcome variables. Standard deviations are in brackets. *t*-tests are Welch two-sample *t*-tests for gender differences.

Consistent with national data, the average household size was 4 members, with women reporting significantly larger households than men. Women were more likely to report children or infants in the household than men were. Women were additionally more likely to rely on food assistance than men were, and were less likely to be employed than men were. Women were more likely to report a household income below the poverty line, but men were more likely to report multidimensional poverty, such as informal housing or no in-home water or sanitation.. Women and men reported similar rates of home food production, similar access to formal and informal retail, and similar rates of ownership of consumer technologies for food transport, storage, and preparation (see Table S2 in the Supplementary Material for full results).

Households producing their own food were also likely to receive some kind of food assistance. Household size was positively correlated with food poverty, such that larger households were more likely to be below the food poverty line. Households with children or infants were more likely to produce their own food and to rely on food assistance. Households without electricity for cooking were additionally likely to produce their own food and to rely on food assistance. Households with high access to consumer technologies were more likely to have electricity for cooking and had higher access to formal retail. Multidimensional poverty was correlated with informal retail access, such that driving time to informal retail was lower for poor households than for rich ones (see Table S3 in the Supplementary Material for full results).

Food Insecurity

The estimated prevalence of moderate food insecurity in Worcester was 40% of the population and the estimated prevalence of severe food insecurity was 15%. There was significant variation in food insecurity and its predictors within rich and poor neighborhoods.

Moderate or severe food insecurity. A generalized linear model with moderate or severe food insecurity as the dependent variable and neighbourhood, geographic, and household variables as the predictors (see Table 4), with a logit link, revealed significant associations between food assistance, access to food-related technologies, and food insecurity.

There was a significant association between food insecurity and food assistance, such that the predicted rate of food insecurity in individuals relying on some form of food assistance was 9% higher than for the general population. White respondents were significantly less likely to report food insecurity than Black African respondents (the reference group).

Access to consumer food technology was significantly associated with food insecurity. The predicted rate of food insecurity was 18% lower for respondents with access to a fridge, and 16% lower for respondents with access to a freezer, than for respondents without access to any food refrigeration technologies.

A follow-up analysis explored the interaction between poverty and food storage technologies (refrigerator and freezer). The generalized linear model was repeated with all control variables, plus an additional interaction term between poverty (income below the food poverty line) and ownership of food storage technologies (see Table S4 in the Supplementary Material). The follow-up analysis revealed a significant interaction between poverty and access to food storage technologies. For respondents with no access to food storage technologies, the predicted probability of food insecurity was similarly high, whether respondents' income was above or below the food poverty line. However, for respondents with access to food storage technologies, the predicted probability of food insecurity was lower for those above the food poverty line (see Figure S1 in the Supplementary Material).

As shown in Figure 2, neighborhoods showed high heterogeneity in their geographic patterns of food insecurity, and in their relationship to geographic patterns of socio-economic status. Although poor neighborhoods were more likely than rich neighborhoods to report food insecurity, there were areas within poor neighborhoods that appeared food secure.

-- FIGURE 2 ABOUT HERE --

Figure 2. Severe food insecurity (above) and economic status (below) per small area in Worcester. FIES = Food Insecurity Experience Scale. Rate of Multidimensional Poverty indicates the rate of households with indicators of multidimensional poverty.

-- TABLE 4 ABOUT HERE --

Table 4. Moderate + severe food insecurity GLM (coefficients and standard errors).

Dietary Diversity

Dietary diversity items were summed to create a total individual dietary diversity score (range 0-9). The mean of individual dietary diversity for the case study sample was 3.46 (*SD* = 1.55). Men and women did not have significantly different dietary diversity, $t(584.22) = -0.552$, $p = .581$. Table 5 summarizes the gender-disaggregated rates of consuming different food groups.

-- TABLE 5 ABOUT HERE --

Table 5. Proportion of case study sample that consumed each food group in the past 24 hours.

A linear model with dietary diversity as the dependent variable and neighbourhood, geographic, and household variables as the predictors, with an identity link (see Table 6) predicted a significant 12.34% of the variance in dietary diversity, $R^2 = 0.12$, $F(42,910) = 3.05$, $p < .001$.

Neighbourhoods varied significantly in dietary diversity. Several neighbourhoods had significantly lower average dietary diversity than the reference neighbourhood, including Avian Park, Fairy Glen, Langerug, Roodewal, Worcester West, and Zweletemba.

There was a significant association between dietary diversity and food poverty, such that the predicted dietary diversity in individuals with income below the food poverty line was 25% lower than for the general population.

Access to consumer food technology was significantly associated with dietary diversity. The predicted dietary diversity was 37% higher for respondents with access to an oven, and there were marginally significant associations between dietary diversity and access to a microwave or stove.

-- TABLE 6 ABOUT HERE --

Table 6. Dietary diversity LM (coefficients and standard errors).

Target Foods

Table 7 presents the full GLM results for all target foods.

Fruits and Vegetables. The proportion of respondents who indicated that they had eaten any fruits or vegetables in the past 24 hours was 63% (*SD* = 48%). There was a significant association between neighbourhood income and fruit and vegetable consumption, such that neighbourhoods with lower income reported lower consumption of fruits and vegetables. Neighbourhoods varied significantly in fruit and vegetable consumption. Several neighbourhoods had significantly lower average consumption of fruits and vegetables than the reference neighbourhood, including Avian Park, Ou Dorp, Parkersdam, and Worcester West.

There was a significant association between fruit and vegetable consumption and food poverty, such that the predicted fruit and vegetable consumption in individuals with income below the food poverty line was 14% lower than for the general population.

Access to consumer food technology was significantly associated with consumption of fruits and vegetables. The predicted fruit and vegetable consumption was 12% higher for respondents with access to an oven.

Animal-Source Foods. The proportion of respondents who indicated that they had eaten any animal-source foods (ASF) in the past 24 hours was 84% (*SD* = 36%).

Access to consumer food technology was significantly associated with consumption of animal-source foods. The predicted animal-source food consumption was 7% higher for respondents with access to an oven and 8% higher for respondents with access to a stove.

Highly Processed Foods. The proportion of respondents who indicated that they had eaten any highly-processed foods in the past 24 hours was 50% (*SD* = 50%).

Neighbourhoods varied significantly in consumption of highly processed foods. Several neighbourhoods had significantly lower average consumption of highly processed foods than the reference neighbourhood, including Hospital Park, Parkersdam, and Van Riebeeck Park.

Households with children had marginally higher consumption of highly processed foods than households without children. Having children in the household raised the predicted rate of consumption of highly processed foods by 8%.

There was a significant association between highly processed food consumption and food poverty, such that the predicted highly processed food consumption in individuals with income below the food poverty line was 9% lower than for the general population.

Access to consumer food technology was significantly associated with consumption of highly processed foods. The predicted highly processed food consumption was 14% higher for respondents with access to an oven.

Fats and Sugars. The proportion of respondents who indicated that they had eaten any foods high in fats and sugars in the past 24 hours was 82% (*SD* = 38%).

There was a significant association between neighbourhood income and consumption of fats and sugars, such that neighbourhoods with lower income reported lower consumption of fats and sugars. Neighbourhoods varied significantly in consumption of fats and sugars.

Food assistance was associated with significantly higher consumption of fats and sugars, such that the predicted fat and sugar consumption in individuals relying on food assistance was 6% higher than for the general population.

Access to consumer food technology was significantly associated with consumption of fats and sugars. The predicted fats and sugars consumption was 9% higher for respondents with access to a stove, and there were significant associations between consumption of fats and sugars and access to an oven or a microwave.

-- TABLE 7 ABOUT HERE --

Table 7. GLM coefficients for target foods. Standard errors in brackets. All GLMs use logit link functions.

Formal and Informal Retail

Formal, informal, and street-based retailers were distributed across different parts of the city, as shown in Figure 3. Formal retailers, such as supermarkets, were clustered in the higher-income and upper-middle income neighborhoods of the city. Informal retailers, such as spaza shops, were clustered in the low-income neighborhoods of the city. Street-based retailers, such as roadside vendors, were sparsely located throughout the middle-income and low-income areas.

-- FIGURE 3 ABOUT HERE --

Figure 3. Location of formal (red), informal (green), and street-based (blue) food retailers in Worcester. Avian Park and Zweletemba are low-income neighborhoods, while Worcester Central is a high-middle income neighborhood.

Survey respondents purchased, on average, 14% of their food items consumed in the last 24 hours from informal sources (*SD* = 24%). However, respondents clustered into two groups: a majority never purchased from informal sources (61%), but those who did shop at spaza shops or street retailers purchased an average of 37% of their food from these sources (*SD* = 25%).

For the GLM, since the majority of respondents had zero food purchases from informal sources in the recall period, reliance on informal sources was re-coded to binary (1 = purchased any food from informal sources in the past 24 hours). A binomial GLM with reliance on informal food sources as the outcome and neighbourhood, geographic, and household variables as predictors, with a logit link found significant effects of food assistance and access to consumer food technology on reliance on informal food sources (see Table 8).

Food assistance was associated with significantly higher reliance on informal food retail, such that the predicted informal purchase rate in individuals relying on food assistance was 14% higher than for the general population.

Reliance on informal food retail was significantly associated with gender, such that the rate of predicted reliance on informal food retail was 8% higher for men than for women.

Access to consumer food technology was significantly associated with consumption of fats and sugars. The predicted fats and sugars consumption was 27% higher for respondents with access to a stove, and 10% higher for respondents with access to an oven.

Reliance on informal retail was unequally distributed across different parts of the city, as shown in Figure 4. Residents in poorer neighborhoods were more likely to rely on spaza shops and street vendors than residents in wealthier neighborhoods. However, there was significant variation, such that a non-zero rate of purchase from spaza shops was observed even in wealthy neighborhoods, and residents in some areas of middle-upper income neighborhoods were very likely to purchase food from spaza shops. In poorer neighborhoods, purchases from spaza shops and street retailers were also clustered in certain areas within the neighborhood.

-- FIGURE 4 ABOUT HERE --

Figure 4. Rate of purchases from informal food retailers, including street retailers and spaza shops, in Worcester.

Formal retailers, such as supermarkets, were the primary source of most foods. A few foods were more likely to be purchased from spaza shops or street retailers than from supermarkets: highly-processed dairy and dairy replacements, such as condensed and powdered milk, and instant noodles. Foods that were almost as likely to be purchased at a spaza as at a supermarket (less than 10% difference) included: vetkoek (a fried dough bread); salty snack foods such as potato crisps; organ meat; fish; cakes or donuts; confectionery items such as candy and chocolate; nuts; dark green leafy vegetables; and fruits. The largest differences were seen for rice, cooking oil, and sugar; all of these were nearly 50% more likely to be purchased from a supermarket than from an informal retailer (see Table S7 in the Supplementary Material for full results).

-- TABLE 8 ABOUT HERE --

Table 8. Informal food purchases GLM (coefficients and standard errors).

Discussion

Rapidly growing African cities face specific challenges in the food system, but also represent areas of high potential for transformative change. A city is a critical focus of social, economic, governance, and infrastructure networks in the surrounding landscape (Agergaard & Ortenbjerg, 2017; Andreasen et al., 2017; Marais & Cloete, 2017). The concentration of people, resources, knowledge, decision-making power, and infrastructure makes cities a crucial nexus point for transformative change. This transformative potential, however, can only be harnessed once the urban food environment is understood as an integrated system. Spatial linkage of urban food system data helps to understand its processes, actors, and flows (Kasper et al., 2017).

Worcester was a typical example of a South African secondary city in terms of hunger and food access. Food insecurity prevalence in Worcester (40%) was lower than has been reported for megacities in South Africa, including Cape Town (80%), but comparable to Johannesburg (42%) (Crush et al., 2012). There were considerable geographic variations in food insecurity within the city: neighborhoods with high socioeconomic status, more white residents, and more supermarkets had higher levels of dietary diversity. This finding parallels previous research in Johannesburg, where residents in areas with informal housing had low dietary diversity compared to formal settlements (Drimie et al., 2013).

However, there was additional variation within city regions: even within poor neighborhoods, we did not find a uniform high level of food insecurity. There are therefore additional factors at play that affect food access at the household level. This finding supports research in African megacities that found a combination of local food environments and endogenous household drivers were important to food security and associated obesogenic diets (Kroll et al., 2019). Lack of food access typically resulted from household and social-ecological environment variables, rather than an absolute shortage of food in the city, as reported for Cape Town and Johannesburg (Crush et al., 2012). Neighborhoods, townships, or informal settlements were large and diverse, and included sections or areas where the middle class lived, while wealthy areas were not uniformly food secure.

As in other studies, income - specifically, income below the food poverty line - was an important factor. Independent of employment status or standard of living, it predicted dietary diversity and intake of fruits and vegetables. Low-income households consumed fewer fruits and vegetables than households with incomes above the food poverty line. Interestingly, our findings indicated that income *per se* was more important than employment status, contrary to urban surveys in other African countries finding that informal employment was a key predictor of food consumption and the purchase of higher calorie food from informal sources (Blekking et al., 2020). Although income did not significantly predict food insecurity in our study, the results were in the expected direction, supporting a potential link between income and hunger.

Informal food assistance, in the form of community kitchens run by neighbours and family members, was a key source of food for the poorest and most food insecure citizens. Independent of income or asset ownership, city residents who relied on food assistance were more likely to report food insecurity than others. Food assistance was also associated with a higher likelihood of purchasing food from informal sources such as spaza shops. Thus, informal food assistance was an important part of the food system for vulnerable city residents, although the direction of causality is not clear from our data. In contrast, urban agriculture was not yet an important part of the Worcester food system for the majority of residents. Urban agriculture was not commonly practiced (7% of households), matching results from previous studies in South African cities (Cape Town 4%, Johannesburg 8%) (Crush et al., 2012) and was not related to any outcomes.

Informal food retail was an important part of the urban food system, matching previous research (Battersby, 2011; Spires et al., 2020). Reliance on informal food retail was 39% in Worcester, much lower than early reports on Cape Town (66%) and Johannesburg (85%) (Crush et al., 2012), but similar to a recent study of neighbourhood food provision in Khayelitsha, Cape Town, where informal food outlets were more common than supermarkets but supermarkets were key sources of household food (Kroll et al., 2019). Households that relied on informal retail were more likely to be food insecure and had lower intakes of fruits, vegetables, and animal-sourced foods than other households, confirming a previous survey of retailers in Worcester's Avian Park (Roos et al., 2013).

Staples such as bread and milk, as well as fresh fruits and vegetables, were relatively likely to be purchased from informal sources. However, many of the foods frequently purchased from spaza shops were ultra-processed. Previous research in Worcester's Avian Park additionally found that staple items tended to be cheaper in spaza shops than they were in supermarkets, or similarly priced (Roos et al., 2013), but that spaza shops carried a limited variety because they lacked the storage space, cold storage facilities, and transport arrangements to stock fresh food. Household purchases of ultra-processed food may therefore also relate to available technology; absent technologies for food transport, storage, and preparation, households may need to rely on smaller and more frequent food purchases, and may turn to ultra-processed food that is easily transported and stored.

Consumer technologies, independent of their utility as markers of household wealth, were important to household food security in general, including consumption of highly processed convenience foods. This result makes sense; convenience foods are ready-packaged and therefore easy to take on public transport, or when travelling by foot. They do not expire as quickly as fresh foods when stored without refrigeration. Thus, they are a practical, if unhealthy, alternative for residents who lack these technologies (Monteiro, 2009; Monteiro et al., 2018; Spires et al., 2016).

Critically, however, our research suggested that even in wealthy neighborhoods and high-income households, people who did not own a fridge or freezer were more likely to suffer food insecurity. The model results indicated that income above the food poverty line was protective against food insecurity, but only when combined with access to a fridge or freezer. The food poverty line is a relatively conservative measure of poverty, and many households that do not meet the threshold for food poverty may still struggle to afford a fridge, as the item itself is a significant investment. Additionally, refrigeration is expensive to run; many poor households in the city rely on prepaid electricity and often run out of funds to purchase electricity. There may be an opportunity, however, to supply refrigeration to spaza shops, and future research could investigate the role of supply-side constraints to storing and preparing fresh foods. Complex social-ecological interactions like these are part of the reason why a precision approach, tailored to individual factors as well as neighborhood-level ones, is key to successfully tackling hunger and poor quality diets.

Neighbourhood-level poverty was predictive of diet quality at the household level, with richer neighbourhoods reporting higher consumption of fruits and vegetables and higher dietary diversity. Food assistance and consumer technology remained significantly associated with food security and diet quality, even after controlling for neighbourhood and household poverty. This combination of results suggests that household covariates, over and above area effects, are related to food insecurity. Thus, when studying poverty, area-level estimates may be sufficient and the additional effort of geographically precise data may not be needed. However, as compared to overall poverty, food insecurity has the additional variations of food preparation and storage technologies available to households even within small geographic areas. For the study of food insecurity, it may be beneficial to collect data at a more precise spatial level than neighbourhoods.

The potential benefits of precision analysis must be weighed against the increased costs of collecting spatially disaggregated data. Our study collected data using in-person surveys, which can be costly and slow. However, the costs were reduced by using handheld electronic data capture systems that automatically stored and uploaded data. Future research could explore the use of alternative data sources, such as satellite imagery or existing government data, to further reduce the costs of data collection for spatially disaggregated analysis. Additionally, due to the correlational nature of survey data, any statistical associations in the present study must be interpreted with caution. Establishing causal links will require more focused research.

The human-related economic, social, and cultural elements of food choices are key drivers of individual dietary behaviours and may also be relevant to food access. For example, gender is an important driver that affects food insecurity directly and indirectly, through differing dietary needs for women of reproductive age (Labadarios et al., 2011). Children and infants also have differing dietary needs to adults (Haysom et al., 2017; May, Witten, & Lake, 2020; Rose & Charlton, 2002). Thus, women or caregivers of young children may be differently affected by changes in their economic and physical access to food.

Our study focused on demand for food and the immediate social-ecological food environment determining accessibility to food, but the total urban food system is much greater. Hunger and diets of urban residents are additionally affected by food available from local primary production, which is further affected by agricultural policy and investment, energy and water availability, variable and extreme weather, and changes in global crop and petrochemical markets (Battersby & Watson, 2018; Greenberg, 2017). Land use is increasingly discussed as researchers and policymakers consider the potential for urban land to expand into agricultural production areas, and for food cultivation areas to expand into previously pristine land (Ramankutty et al., 2018; Von Bormann & Gulati, 2014). Our results add to this larger picture by demonstrating the important variety of individual and social-ecological factors at play, including the key role of formal and informal retailers in the urban food system (Vitiello & Brinkley, 2013).

Our study found that consumer technologies for food storage and preparation were important to household food security. Since food insecurity and gender equality are mutually enriching goals, a discussion of these technologies should also consider the implications for gender equality. Food preparation and storage technologies can reduce the amount of labour required for caregiving and domestic tasks, which are disproportionately performed by women (Gebre et al., 2021). An anthropological study in Morocco found that consumer technologies may have the effect of increasing women's time and encouraging other household members to perform domestic tasks (Dike, 2021). However, these technologies may also affect women's position within the household, perhaps negatively if they devalue the importance and difficulty of caregiving and domestic labour (Dike, 2021). Future research could investigate the impacts - positive and negative - of food storage and preparation technology on women in African cities.

A systems approach may be helpful in understanding the linkages between city food security and emerging topics of concern, such as city resilience. As an example, the lockdowns implemented by the South African government from March 2020 in response to the COVID-19 pandemic highlighted the complex vulnerabilities of local food systems. The prevention of informal food trading, curfews, and disruptions to value chains increased food insecurity, especially for women. Evidence is emerging of heightened domestic violence, as well as food protests, as a result of unstable local access to food (May, Witten, & Lake, 2020). These multiple consequences highlight the complex synergies and trade-offs between food insecurity and other outcomes. Managing the synergies and trade-offs between food insecurity and city-wide resilience, and avoiding unintended consequences, will require future research that takes a systems approach.

Future research may also investigate the different levels at which food security impacts local and regionalised conflict. In our study, food insecurity had very distinct predictors at individual, household, and neighbourhood levels. Emerging research suggests that food insecurity may predict conflict at similarly discrete levels. At the individual or household level, food insecurity may create incentives for anti-social behaviour (Martin-Shields & Stojetz, 2019). At the neighbourhood level, conflict can arise in response to limitations on food access, in the form of higher prices Martin-Shields & Stojetz, 2019), restrictions on travel (May, Witten, & Lake, 2020), or lowered food production (Martin-Shields & Stojetz, 2019). Future research on the connection between food insecurity and conflict might usefully consider the linkages between individual, household, and neighbourhood variables.

In conclusion, our results suggest that meaningful variations exist at smaller geographic units than the city-level or neighborhood-level statistics typically reported in food security research. Average socioeconomic status of neighborhoods may not be a good proxy for their food insecurity, as households within poor areas vary substantially in their food access options and food choices. Precision estimates of hunger and poor diets are needed to complement neighborhood-level data to better design and target interventions and policies to those households with the greatest need, and to tailor interventions for the specific individual needs of urban residents and the characteristics of the food system in the specific local food environment.

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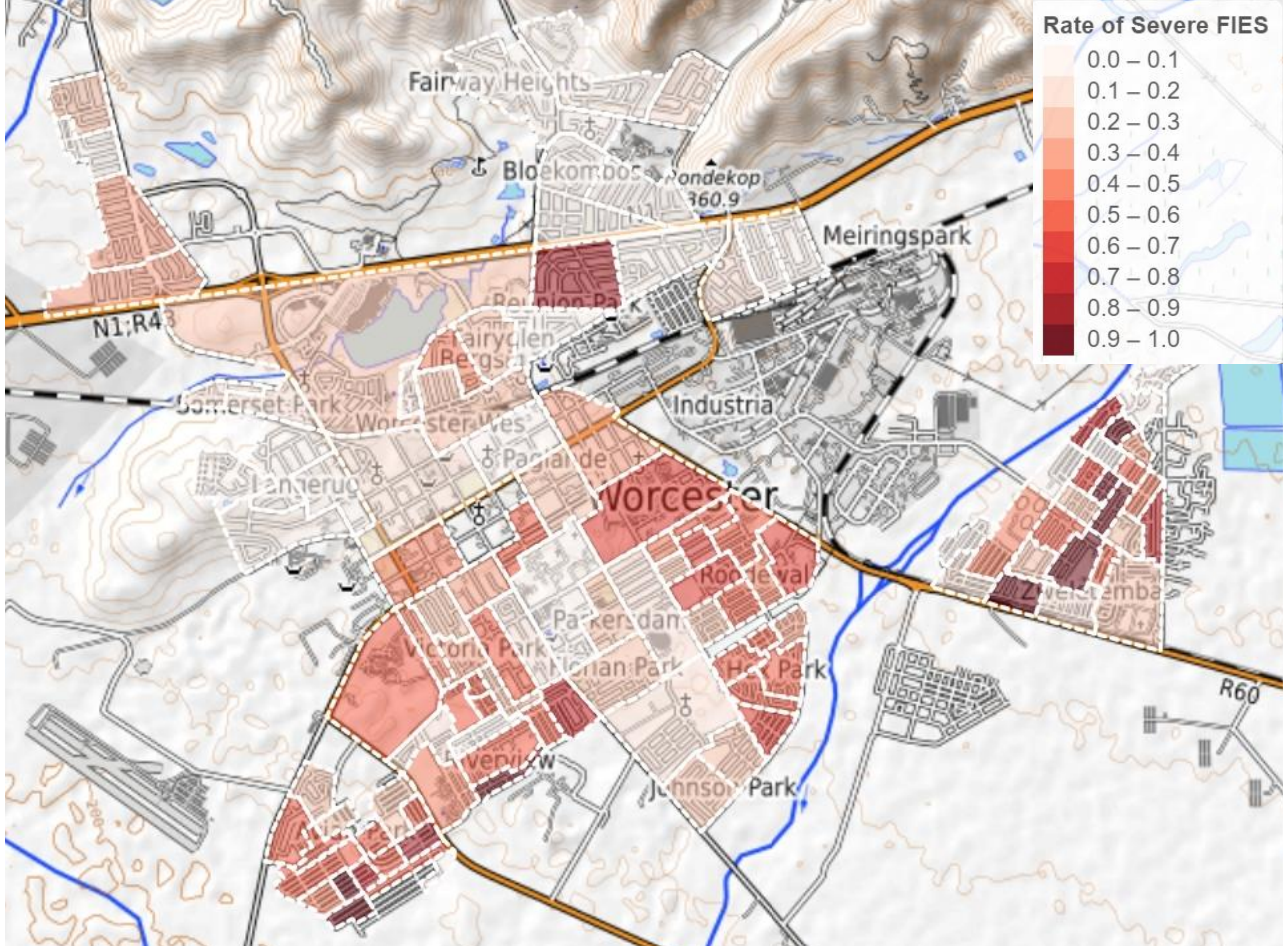
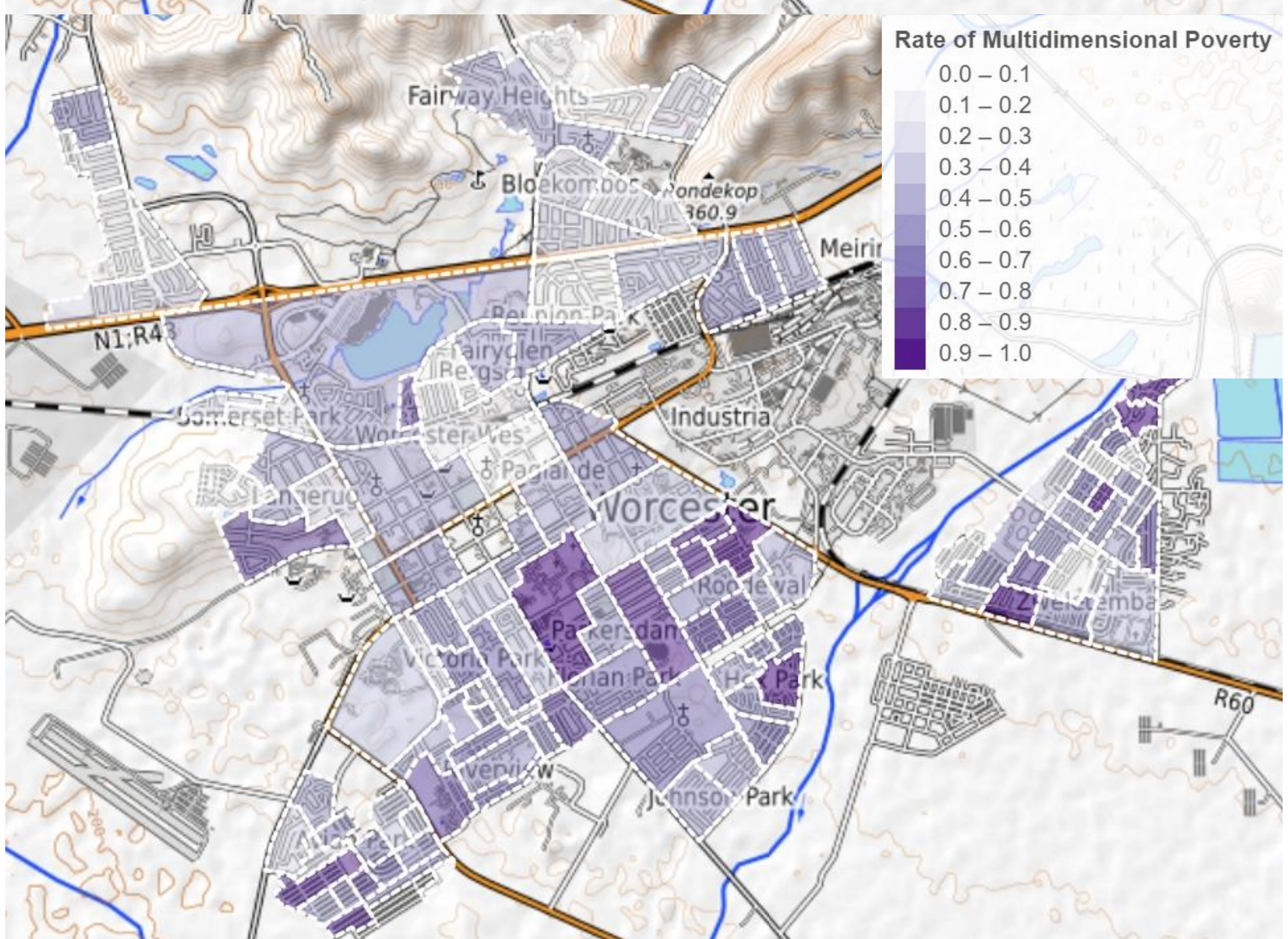
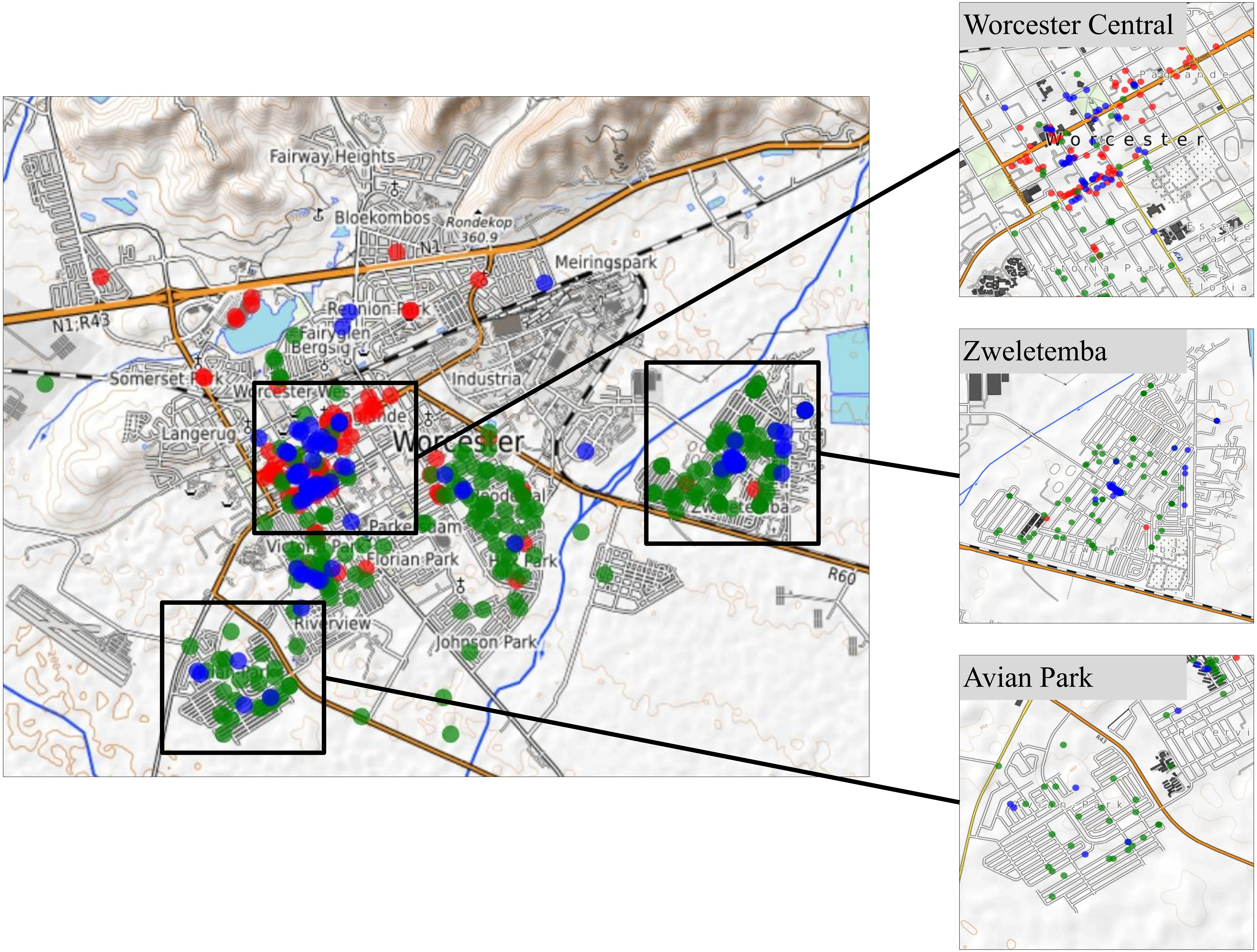
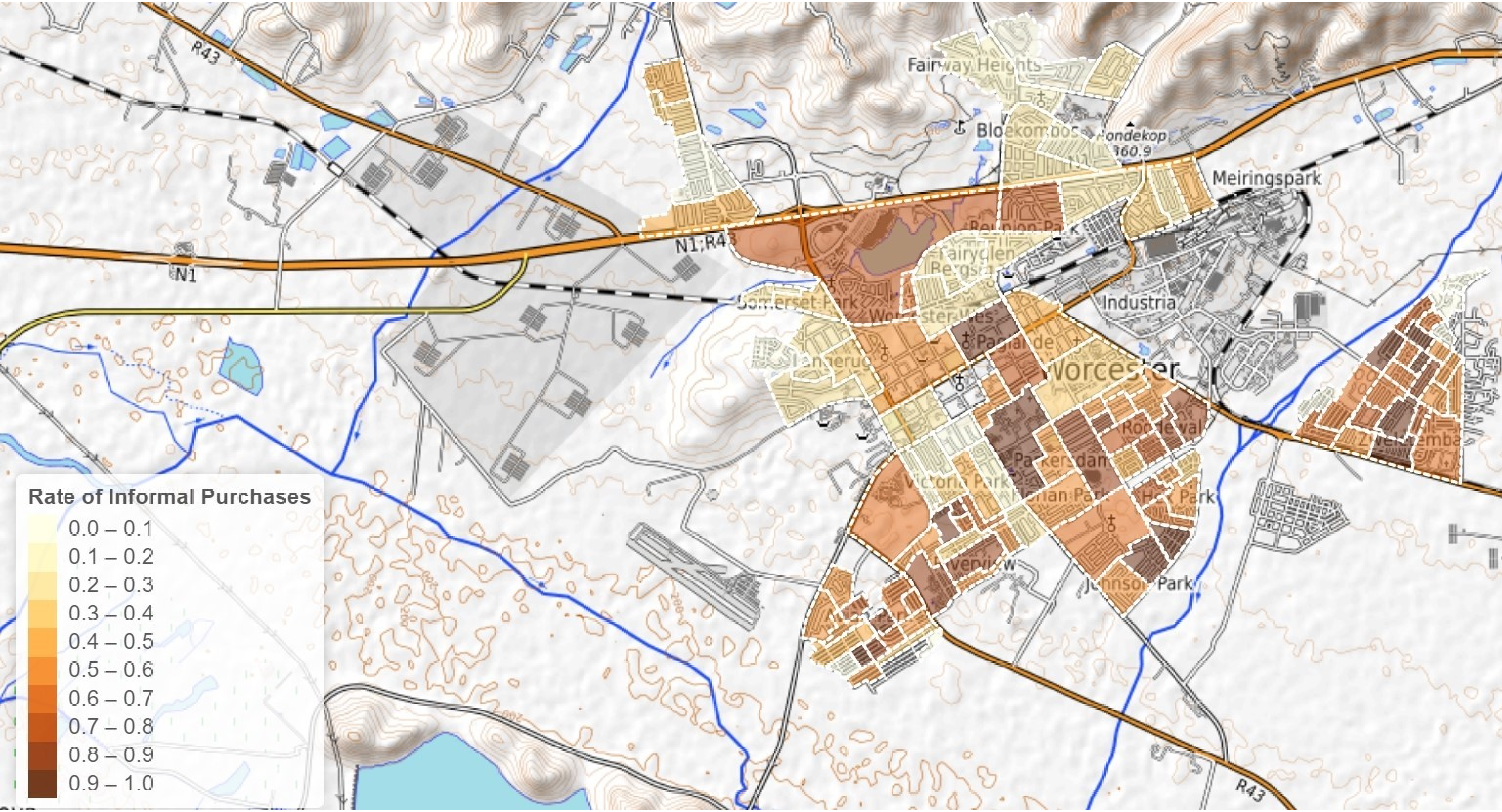
Average Income
High
High/Medium
Medium/Low
Low/Medium
Low
NA
Worcester West
Meiring Park
Worcester Industrial Zone
Worcester
Zweletemba
Hexpark
Johnsons Park
Avian Park
Worcester
South Africa
Western Cape
Eastern Cape
North West
Cape Town
Port Elizabeth


Rate of Severe FIES
0.0 – 0.1
0.1 – 0.2
0.2 – 0.3
0.3 – 0.4
0.4 – 0.5
0.5 – 0.6
0.6 – 0.7
0.7 – 0.8
0.8 – 0.9
0.9 – 1.0
Fairway Heights
Meiringspark
N1;R43
Industria
Worcester
Roodeval
Zwelethemba
Parkersdam
Victoria Park
Hex Park
Johnson Park
R60


Rate of Multidimensional Poverty
0.0 – 0.1
0.1 – 0.2
0.2 – 0.3
0.3 – 0.4
0.4 – 0.5
0.5 – 0.6
0.6 – 0.7
0.7 – 0.8
0.8 – 0.9
0.9 – 1.0
Fairway Heights
N1;R43
Industria
Worcester
Roodeval
Parkersdam
Victoria Park
Hex Park
Johnson Park
R60



Fairway Heights
Bloekombos
Rondekop
360.9
N1
Meiringspark
N1;R43
Fairyglen
Bergsig
Somerset Park
Industria
Langerug
Worcester
Florian Park
Riverview
Johnson Park
R60
Worcester Central
Zweletemba
Avian Park



Rate of Informal Purchases
0.0 – 0.1
0.1 – 0.2
0.2 – 0.3
0.3 – 0.4
0.4 – 0.5
0.5 – 0.6
0.6 – 0.7
0.7 – 0.8
0.8 – 0.9
0.9 – 1.0
Fairway Heights
Bloekombos
Rondekop
360.9
Meiringspark
N1;R43
N1
R43
Reunion Park
Fairyglen
Industria
Worcester
Roodewal
Zwelethemba
Parkersdam
Victoria Park
Hex Park
Riverview
Johnson Park

Table 1. Questions on food adequacy extracted from the Food Insecurity Experience Scale.

Question	**Response options**
During the last 12 MONTHS, was there a time when you were worried you would not have enough food to eat because of a lack of money or other resources?	Yes / No
Still thinking about the last 12 MONTHS, was there a time when you were unable to eat healthy and nutritious food because of a lack of money or other resources?	Yes / No
Was there a time when you ate only a few kinds of foods because of a lack of money or other resources?	Yes / No
Was there a time when you had to skip a meal because there was not enough money or other resources to get food?	Yes / No
Was there a time when you were hungry but did not eat because there was not enough money or other resources for food?	Yes / No
Still thinking about the last 12 MONTHS, was there a time when you ate less than you thought you should because of a lack of money or other resources?	Yes / No
Was there a time when your household ran out of food because of a lack of money or other resources?	Yes / No
During the last 12 MONTHS, was there a time when you went without eating for a whole day because of a lack of money or other resources?	Yes / No

Table 2. Dimensions of the case study adaptation of the South African Multidimensional Poverty Index. As with the SAMPI, all dimensions are weighted equally and the indicators within each dimension are weighted equally.

Dimension	**Indicator**	**Deprivation cut-off**
Health	None	None
Education	Years of schooling	If respondent has not completed 5 years of schooling
Standard of living	Fuel for lighting and heating	If household is using paraffin/wood/coal/dung/other/candles/none
	Fuel for cooking	If household is using charcoal/wood/coal/dung/other/none
	Water access	If no piped water in dwelling or on stand
	Sanitation type	If not a flush toilet
	Dwelling type	If an informal shack / traditional dwelling / caravan/tent/other
	Asset ownership	If household does not own more than one of radio, television, telephone, or refrigerator and does not own a car
Economic activity	Unemployment	If respondent is unemployed

Table 3. Descriptive statistics for study outcome variables. Standard deviations are in brackets. *t*-tests are Welch two-sample *t*-tests for gender differences.

Outcome Variable	**Women** (N = 683)	**Men** (N = 299)	**All** (N = 983)	
Food insecurity (moderate + severe) (range: 0-1)	0.44 (0.45)	0.31 (0.44)	0.40 (0.45)	t = 4.22, p < .001
Food insecurity (severe) (range: 0-1)	0.16 (0.27)	0.14 (0.26)	0.15 (0.27)	t = 1.50, p = .135
Dietary diversity (range: 0-9)	3.44 (1.56)	3.51 (1.51)	3.46 (1.55)	t = -0.59, p = .558
Fruit and vegetable consumption (range: 0-1)	0.64 (0.48)	0.61 (0.49)	0.63 (0.48)	t = 0.98, p = .326
Animal-source foods consumption (range: 0-1)	0.83 (0.37)	0.87 (0.34)	0.84 (0.36)	t = -1.35, p = .177
Highly processed foods consumption (range: 0-1)	0.51 (0.50)	0.48 (0.50)	0.50 (0.50)	t = 0.56, p = .576
Fats and sugars consumption (range: 0-1)	0.81 (0.37)	0.84 (0.37)	0.83 (0.38)	t = -0.83, p = .404
Reliance on informal food retail (range: 0-1)	0.13 (0.22)	0.17 (0.27)	0.14 (0.24)	t = -1.96, p = .050

Table 4. Moderate + severe food insecurity GLM (coefficients and standard errors).

	Model 1	**Model 2**
(Intercept)	-0.67	0.04
	(0.64)	(1.06)
Neighbourhood predictors		
Neighbourhood income	-0.06	
	(0.10)	
Neighbourhood fixed effects		
Avian Park		0.25
		(0.72)
Esselen Park		-1.55
		(0.86)
Fairway Heights		-14.95
		(1568.16)
Fairy Glen		-0.10
		(1.05)
Florian Park		-1.11
		(1.30)
Hex Park		0.05
		(0.78)
Hospitaalheuwel		-15.63
		(1597.43)
Hospital Park		-0.59
		(1.09)
Johnson Park		-1.41
		(0.91)
Langerug		-15.73
		(751.80)
Meirings Park		-0.99

		(1.28)
Other		-0.79
		(1.63)
Ou Dorp		-16.94
		(1077.84)
Paglande		-15.41
		(1294.29)
Panorama		0.24
		(1.37)
Parkersdam		-0.69
		(0.85)
Riverview		-0.36
		(0.73)
Roodewal		0.30
		(0.75)
Roux Park		0.29
		(0.88)
Somerset Park		-0.93
		(1.15)
Van Riebeeck Park		-15.76
		(710.99)
Victoria Park		-0.88
		(0.83)
Worcester West		0.99
		(0.83)
Zweletemba		-0.83
		(0.84)
Geographic predictors		
Distance to formal food retail	0.06	0.08
	(0.05)	(0.05)

Distance to informal food retail	-0.09	-0.10
	(0.06)	(0.06)
Household predictors		
Household size	0.06	0.06
	(0.05)	(0.05)
Household includes children	-0.23	-0.24
	(0.20)	(0.20)
Multidimensional poverty index	-0.26	-0.19
	(0.37)	(0.38)
Food poverty line	0.53**	0.38
	(0.20)	(0.20)
Home food production	-0.41	-0.37
	(0.33)	(0.33)
Food assistance	1.58***	1.57***
	(0.17)	(0.18)
Gender	-0.37*	-0.24
	(0.19)	(0.20)
Race (Colored)	-0.35	-0.24
	(0.20)	(0.51)
Race (White)	-1.28**	-1.90**
	(0.74)	(0.74)
Energy source for cooking	0.93	0.85
	(0.64)	(0.67)
Employment	0.51	0.59
	(0.37)	(0.38)
Technology predictors		
Refrigerator	-0.81**	-0.86**
	(0.31)	(0.32)
Freezer	-0.75***	-0.77***
	(0.18)	(0.19)

Oven	-0.12	-0.08
	(0.23)	(0.24)
Microwave	-0.24	-0.20
	(0.25)	(0.25)
Stove	-0.41	-0.34
	(0.32)	(0.33)
AIC	991.18	980.62
N	950	964

* *p* < .05, ** *p* < .01, *** *p* < .001

Table 5. Proportion of case study sample that consumed each food group in the past 24 hours.

Food group	**Women** (N = 683)	**Men** (N = 299)	**All** (N = 983)
Starchy staples	97.51	94.31	96.54
Dark green leafy vegetables	10.69	10.03	10.48
Vitamin A-rich fruits and vegetables	30.60	35.79	32.15
Other fruits and vegetables	45.24	40.13	43.64
Organ meat	6.59	9.03	7.32
Meat and fish	71.74	77.59	73.45
Eggs	22.69	27.09	24.01
Legumes, nuts, and seeds	11.42	9.36	10.78
Dairy	48.17	47.15	47.81

Table 6. Dietary diversity LM (coefficients and standard errors).

	Model 1	Model 2
(Intercept)	-0.59	0.35
	(0.27)	(0.41)
Neighbourhood predictors		
Neighbourhood income	-0.04	
	(0.04)	
Neighbourhood fixed effects		
Avian Park		-0.85
		(0.27)
Esselen Park		-0.36**
		(0.31)
Fairway Heights		-0.21
		(0.46)
Fairy Glen		-0.97**
		(0.35)
Florian Park		-0.45
		(0.43)
Hex Park		-0.48
		(0.30)
Hospitaalheuwel		-0.96
		(0.50)
Hospital Park		-1.10**
		(0.41)
Johnson Park		-0.65*
		(0.33)
Langerug		-1.02**
		(0.32)
Meirings Park		-0.65*

		(0.33)
Other		-1.21*
		(0.49)
Ou Dorp		-0.88*
		(0.39)
Paglande		-0.76
		(0.42)
Panorama		0.32
		(0.38)
Parkersdam		-0.89**
		(0.32)
Riverview		-0.60*
		(0.28)
Roodewal		0.75**
		(0.29)
Roux Park		0.36
		(0.34)
Somerset Park		-0.72
		(0.38)
Van Riebeeck Park		-0.70*
		(0.32)
Victoria Park		-0.65*
		(0.31)
Worcester West		-0.99***
		(0.30)
Zweletemba		-0.86**
		(0.33)
Geographic predictors		
Distance to formal food retail	-0.01	-0.01
	(0.02)	(0.02)

Distance to informal food retail	<0.01	0.01
	(0.02)	(0.02)
Household predictors		
Household size	0.01	0.01
	(0.02)	(0.02)
Household includes children	-0.01	-0.01
	(0.02)	(0.08)
Multidimensional poverty index	0.05	-0.03
	(0.15)	(0.15)
Food poverty line	-0.11**	-0.25**
	(0.13)	(0.08)
Home food production	-0.11	-0.10
	(0.13)	(0.13)
Food assistance	0.07	0.06
	(0.07)	(0.07)
Gender	0.04	0.03
	(0.07)	(0.07)
Race (Colored)	-0.05	-0.21
	(0.08)	(0.20)
Race (White)	0.11	-0.07
	(0.14)	(0.25)
Energy source for cooking	-0.39	-0.36
	(0.26)	(0.26)
Employment	0.01	0.02
	(0.15)	(0.15)
Technology predictors		
Refrigerator	0.21	0.18
	(0.12)	(0.12)
Freezer	0.02	<0.01
	(0.07)	(0.08)

Oven	-0.40***	0.37***
	(0.10)	(0.10)
Microwave	-0.21	0.20
	(0.11)	(0.10)
Stove	-0.28	0.24
	(0.13)	(0.13)
Multiple R-squared	0.09	0.12
N	950	953

* *p* < .05, ** *p* < .01, *** *p* < .001

Note: Dietary diversity was mean centred and scaled to allow for statistical analysis.

Table 7. GLM coefficients for target foods. Standard errors in brackets. All GLMs use logit link functions.

	Fruits and vegetables		**Animal sourced foods**		**Highly processed foods**		**Fats and sugars**	
	Model 1	**Model 2**	**Model 1**	**Model 2**	**Model 1**	**Model 2**	**Model 1**	**Model 2**
(Intercept)	0.12	1.95	0.76	1.06	-0.78	0.16	-0.36	1.45
	(0.57)	(1.27)	(0.70)	(1.18)	(0.61)	(1.00)	(0.67)	(1.38)
Neighbourhood predictors								
Neighbourhood income	-0.13		-0.20		-0.12		-0.37***	
	(0.09)		(0.12)		(0.09)		(0.11)	
Neighbourhood fixed effects								
Avian Park		-2.24*		-0.12		-1.31		-0.70
		(1.07)		(0.84)		(0.70)		(1.10)
Esselen Park		-1.30		-0.96		-0.65		-0.08
		(1.15)		(1.10)		(0.78)		(1.30)
Fairway Heights		-0.94		-0.64		-1.57		-1.21
		(1.52)		(1.36)		(1.07)		(1.53)
Fairy Glen		-1.29		-0.15		-1.48		-1.87
		(1.23)		(1.10)		(0.85)		(1.20)
Florian Park		-1.53		15.48		-0.04		-0.77

	(1.35)	(1391.88)	(1.08)	(1.53)
Hex Park	-2.23*	1.20	-1.13	0.10
	(1.10)	(1.02)	(0.74)	(1.24)
Hospitaalheuwel	-2.54	15.48	-1.23	-1.16
	(1.41)	(1761.00)	(1.15)	(1.56)
Hospital Park	-3.01*	0.56	-3.38**	-0.47
	(1.28)	(1.35)	(1.27)	(1.52)
Johnson Park	-2.32*	-0.03	-1.13*	-1.24
	(1.13)	(0.97)	(0.78)	(1.18)
Langerug	-2.27*	-1.54	-1.08*	-2.11
	(1.13)	(0.89)	(0.79)	(1.13)
Meirings Park	-1.60	-0.24	-1.40	-1.24
	(1.17)	(1.02)	(0.81)	(1.20)
Other	-3.03*	-0.50	-0.94*	-2.41
	(1.39)	(1.40)	(1.16)	(1.40)
Ou Dorp	-3.11*	15.60	-1.18*	-0.51
	(1.22)	(1189.65)	(0.91)	(1.50)
Paglande	-2.31	-1.10	-1.61	-0.76
	(1.28)	(1.13)	(0.98)	(1.50)

Panorama	-1.39	15.28	-1.16	-1.88
	(1.31)	(1189.91)	(0.93)	(1.26)
Parkersdam	-2.87*	0.31	-1.71*	-1.38
	(1.13)	(1.02)	(0.79)	(1.19)
Riverview	-1.23	0.83	-0.67	-0.21
	(1.09)	(0.90)	(0.72)	(1.16)
Roodewal	-2.17*	0.23	-1.02*	-0.55
	(1.09)	(0.88)	(0.73)	(1.15)
Roux Park	-1.66	0.31	-0.77	-1.49
	(1.18)	(1.10)	(0.85)	(1.21)
Somerset Park	-1.96	-0.86	-0.29	-1.65
	(1.22)	(1.05)	(0.96)	(1.27)
Van Riebeeck Park	-2.02	-0.31	-1.93*	-2.62*
	(1.14)	(0.98)	(0.80)	(1.13)
Victoria Park	-1.87	-0.24	-0.59	-1.27
	(1.12)	(0.93)	(0.77)	(1.16)
Worcester West	-2.49*	-0.71	-1.56*	-2.19*
	(1.10)	(0.89)	(0.76)	(1.11)
Zweletemba	-1.77	-0.02	-0.74	-1.44

		(1.14)		(0.97)		(0.81)		(1.22)
Geographic predictors								
Distance to formal food retail	-0.01	-0.05	<-0.01	0.01	-0.02	-0.06	-0.04	-0.05
	(0.04)	(0.04)	(0.05)	(0.06)	(0.04)	(0.04)	(0.05)	(0.05)
Distance to informal food retail	0.01	0.07	0.02	-0.01	0.02	0.07	0.04	0.05
	(0.05)	(0.05)	(0.08)	(0.07)	(0.05)	(0.05)	(0.06)	(0.06)
Household predictors								
Household size	0.01	0.02	0.03	0.04	-0.02	-0.02	0.10	0.09
	(0.04)	(0.04)	(0.06)	(0.06)	(0.04)	(0.04)	(0.06)	(0.06)
Household includes children	-0.06	-0.07	-0.21	-0.21	0.28	0.33	-0.21	-0.23
	(0.17)	(0.17)	(0.23)	(0.23)	(0.17)	(0.17)	(0.22)	(0.23)
Multidimensional poverty index	0.38	0.33	0.60	0.58	-0.49	-0.50	0.51	0.54
	(0.34)	(0.34)	(0.46)	(0.47)	(0.34)	(0.34)	(0.46)	(0.47)
Food poverty line	-0.55**	-0.56**	-0.29	-0.30	-0.37*	-0.36*	-0.27	-0.27
	(0.18)	(0.18)	(0.23)	(0.24)	(0.18)	(0.18)	(0.24)	(0.24)
Home food production	<0.01	0.06	-0.40	-0.35	-0.12	-0.16	-0.57	-0.49
	(0.28)	(0.28)	(0.33)	(0.34)	(0.27)	(0.28)	(0.32)	(0.33)
Food assistance	<0.01	-0.08	-0.16	-0.22	0.06	0.03	0.55**	0.44*
	(0.15)	(0.16)	(0.21)	(0.22)	(0.15)	(0.16)	(0.21)	(0.22)

Gender	-0.21	-0.27	0.26	0.23	-0.07	-0.06	0.30	0.32
	(0.15)	(0.16)	(0.22)	(0.22)	(0.15)	(0.16)	(0.21)	(0.21)
Race (Colored)	-0.27	-0.08	-0.02	-0.34	0.37*	0.61	0.67**	-0.17
	(0.18)	(0.44)	(0.24)	(0.55)	(0.18)	(0.47)	(0.23)	(0.59)
Race (White)	0.07	-0.04	-0.20	-0.12	0.67*	1.05	0.06	-0.28
	(0.30)	(0.58)	(0.39)	(0.70)	(0.29)	(0.58)	(0.35)	(0.71)
Energy source for cooking	-0.11	-0.09	-0.96	-0.90	-0.63	-0.51	-0.47	-0.41
	(0.56)	(0.57)	(0.66)	(0.66)	(0.61)	(0.62)	(0.64)	(0.64)
Employment	-0.35	-0.29	-0.55	-0.57	0.31	0.31	-0.71	-0.79
	(0.33)	(0.34)	(0.45)	(0.45)	(0.34)	(0.34)	(0.44)	(0.45)
Technology predictors								
Refrigerator	0.10	0.10	0.56	0.47	0.43	0.41	0.18	0.02
	(0.26)	(0.27)	(0.31)	(0.32)	(0.27)	(0.28)	(0.33)	(0.33)
Freezer	0.10	0.10	-0.04	-0.07	-0.18	-0.18	-0.11	-0.19
	(0.16)	(0.17)	(0.22)	(0.23)	(0.16)	(0.16)	(0.22)	(0.23)
Oven	0.58**	0.57**	0.68**	0.61*	0.60**	0.56**	0.56*	0.53*
	(0.20)	(0.21)	(0.26)	(0.26)	(0.21)	(0.21)	(0.26)	(0.26)
Microwave	0.09	-0.02	0.18	0.19	0.26	0.20	0.48	0.59*
	(0.23)	(0.23)	(0.28)	(0.29)	(0.23)	(0.23)	(0.28)	(0.29)

Stove	0.44	0.38	0.93**	0.85**	0.27	0.14	0.75*	0.75*
	(0.28)	(0.28)	(0.31)	(0.32)	(0.29)	(0.29)	(0.32)	(0.32)
AIC	1247.30	1256.40	814.45	836.50	1299.00	1319.80	851.39	880.92
N	950	953	950	953	950	953	950	953

* *p* < .05, ** *p* < .01, *** *p* < .001

+ For alternative model including neighbourhood fixed effects, please see Table S7 in the Supplementary Material.

Table 8. Informal food purchases GLM (coefficients and standard errors)

	Model 1	**Model 2**
(Intercept)	-0.71	-1.12
	(0.59)	(0.93)
Neighbourhood predictors		
Neighbourhood income	-0.11	
	(0.09)	
Neighbourhood fixed effects		
Avian Park		0.21
		(0.59)
Esselen Park		0.18
		(0.68)
Fairway Heights		-0.53
		(1.02)
Fairy Glen		-1.84*
		(0.93)
Florian Park		-0.28
		(0.92)
Hex Park		0.59
		(0.65)
Hospitaalheuwel		1.73
		(1.26)
Hospital Park		0.14
		(0.89)
Johnson Park		0.41
		(0.68)
Langerug		-0.86
		(0.71)
Meirings Park		-0.43

		(0.72)
Other		-1.61
		(1.26)
Ou Dorp		0.09
		(0.83)
Paglande		-15.43
		(508.97)
Panorama		-1.26
		(0.96)
Parkersdam		-1.74*
		(0.76)
Riverview		0.05
		(0.61)
Roodewal		0.34
		(0.62)
Roux Park		0.27
		(0.74)
Somerset Park		-1.07
		(0.87)
Van Riebeeck Park		-1.35
		(0.78)
Victoria Park		-0.63
		(0.67)
Worcester West		-0.46
		(0.65)
Zweletemba		0.50
		(0.73)
Geographic predictors		
Distance to formal food retail	0.02	0.03
	(0.04)	(0.04)

Distance to informal food retail	-0.03	-0.05
	(0.05)	(0.05)
Household predictors		
Household size	0.04	0.02
	(0.04)	(0.05)
Household includes children	0.12	0.17
	(0.17)	(0.18)
Multidimensional poverty index	0.16	0.15
	(0.34)	(0.35)
Food poverty line	-0.15	-0.19
	(0.18)	(0.19)
Home food production	0.61*	0.58
	(0.30)	(0.31)
Food assistance	0.58***	0.56***
	(0.15)	(0.16)
Gender	0.24	0.33*
	(0.16)	(0.17)
Race (Colored)	-0.27	0.05
	(0.18)	(0.47)
Race (White)	-1.25***	-1.41
	(0.30)	(0.61)
Energy source for cooking	-0.35	-0.29
	(0.59)	(0.60)
Employment	-0.05	-0.07
	(0.33)	(0.34)
Technology predictors		
Refrigerator	-0.11	-0.23
	(0.28)	(0.29)
Freezer	-0.03	-0.03
	(0.17)	(0.17)

Oven	0.38	0.42
	(0.21)	(0.22)
Microwave	-0.19	-0.10
	(0.24)	(0.24)
Stove	1.02***	1.10***
	(0.30)	(0.30)
AIC	991.18	1235.40
N	950	953

* $p < .05$, ** $p < .01$, *** $p < .001$