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# TOWARDS A NEW FOOD SECURITY INDEX FOR URBAN HOUSEHOLD FOOD SECURITY

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## Abstract

The multidimensionality of food security can confound both statistical modelling and clear policy narratives. That complexity can become amplified in urban areas where food security is often a function of both local and global factors. Rather than focusing on one dimension of food security metrics, this investigation proposes a method for building an index of urban household food access, utilization and stability. The performance of this index is compared across three aggregation methods using household surveys collected from five cities around the world. The findings indicate that each aggregation method was internally consistent, although one of the aggregation methods, relying on geometric means, was likely to be more methodologically sound among the options. This method provides a means of capturing the multidimensional nature of food security in a way that is amenable to statistical modelling and clear policy narratives.

## Keywords

food security, urban, measurement, household

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# Introduction

Food security is a fundamentally important attribute in determining the well-being of people. Yet the concept of food security is inherently difficult to define (Barrett and Lentz,2010). In times past, food security was addressed through a food supply lens of producing more food to meet the needs of increasing populations and to overcome famine (Burchi and De Muro, 2012). This approach was founded on an initial definition of food security at the World Food Conference in 1974 which focused on food supply at the global scale (FAO, 2006). At that time, food security was defined as "availability at all times of adequate world supplies of basic foodstuffs to sustain a steady expansion of food consumption and to offset fluctuations in productions and pricing" (FAO, 2006: 1). However, there have been major paradigm shifts in food security thinking over the years that have led to diversified definitions. In particular, there have been shifts from global and national to household and individual scales, from food first to livelihood approaches, and from objective to subjective perspectives (Maxwell et al., 1996).

Central to these shifts was Amartya Sen's (1981) entitlement approach. Sen argued that people's entitlement to different commodities, including food, is based on their personal endowments or access to commodities through trade or exchange (Burchi and De Muro, 2012; Sen, 1981). Rather than supply and production, such an approach prioritized demand and consumption where disruptions to entitlement such as loss of employment and trade failures negatively impact food access (Barrett and Lentz,2010). As such, there was a shift in focus from food supply at the global and national level to household and individual food access (FAO, 2006). Sen's contribution on entitlement and access also created a broader platform for identifying constructs such as economic, social and political disruptions that influence food security (Devereux, 2001; Maxwell, 1996). For example, the food security crisis of 2007 which triggered political riots, resulted from lack of access to food for masses living in poverty (FAO, 2009). Currently, food security thinking connects linkages between food security, vulnerability to food prices, poverty and development (Cohen and Barrett, 2010; Napoli et al., 2011; UNDP 2012).

The most cited definition of food security in recent decades was first adopted at the 1996 World Food Summit, where food security was defined as a condition that exists "when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (FAO, 2006: 1). According to the FAO (2008a), food security is a multidimensional construct encompassing food availability, access, utilization, stability, and safety. The objective of food security for all will only be achieved by addressing these dimensions simultaneously (FAO, 2008a). Therefore, food insecurity refers to the absence or deficiency in one or more of these dimensions. The decision to use the term food security or food insecurity depends on how a given argument is framed and the scale of measurement being used (Jones et al., 2013). The FAO (2008b) definition of food insecurity can be understood as a representation of the evolution that has taken place in food security paradigms over the years, transitioning from a predominantly supply-driven understanding of food security to an appreciation of the importance of entitlements for food access (Sen, 1980). The importance of multidimensionality in food security paradigms has been further underscored by growing recognition of vulnerability and risk in assessing food security (Barrett, 2002; Barrett, 2010; Ecker and Breisinger, 2012).

Despite the diversified definition of food security, the influence of food supply and agricultural productivity has persisted with evidence of rural-centered interventions and support for agricultural livelihoods (Crush et al., 2018; Tuholske et al., 2018). This is problematic amidst increased urbanization and equally high levels of food insecurity in urban and rural areas within most low- to middle-income countries (UN DESA, 2019; Van Wesenbeek, 2018). Furthermore, urban poverty has been on the increase in urban areas where almost all food is purchased, resulting in vulnerability to food price increases (Cohen and Barrett, 2010; Frayne et al., 2014). Food access in urban areas is also affected by access to social infrastructure and physical infrastructure (Frayne and McCordic, 2015). A persistent focus on food supply reflects a misinterpretation of the food insecurity problem and will affect its measurement.

Although it is important to focus on all dimensions of food security under varying scales and situations, this makes measurement complicated (Vaitla et al., 2017). For instance, food insecurity can be described as transitory and temporary or chronic and permanent based on how long it occurs (FAO, 2008a). At the same time, food insecurity has other indicators including hunger, malnutrition, and uncertain food access resulting in moderate to severe food insecurity and poor health outcomes (FAO et al., 2019). Burchi and De Muro (2012) further suggest that the root causes of food security should be explored and identified within the broader topic of well-being. Such complexities have increased calls for appropriate measurement of food insecurity because of serious implications for health, development programs, nutrition evaluations, vulnerable group identification, and informing various government policies ( Jones et al., 2013; Maxwell et al., 1999). Evidently, food security requires a consistent measurement scale in tandem with urbanization trends due to its varying definitions, operationalization, and multidimensional nature.

As household food security measurements are multidimensional, previous studies indicate that household food access is only one dimension of urban food insecurity (as demonstrated in the scale produced by Ryan and Leibbrandt, 2015). Coates et al. (2007) state that the Household Food Insecurity Access Scale (HFIAS) and Household Food Insecurity Access Prevalence (HFIAP) classification continue to be effective measures of household food access. The HFIAS and HFIAP) has been used in previous studies to measure household food insecurity and the prevalence of African food deserts in addition to access to public resources (McCordic and Abrahamo, 2019; Wagner et al., 2019; McCordic, 2016; McCordic, 2017; Frayne and McCordic, 2015). Frayne and McCordic (2015) also assess the relationship between the HFIAS/HFIAP and other food security scales, such as the Months of Adequate Household Food Provisioning (MAHFP).

This paper presents an additional tool for use in urban food security research and policy by building and assessing an index of food access, utilization and stability of urban households. The focus is on providing a robust methodological framework to measure and compare the status of household food security along these three dimensions. The proposed index would support predictive analytics to uncover the drivers of urban household food security without sacrificing its multidimensional nature.

## Measuring Urban Food Security

One of the greatest obstacles in food security research is deciphering clear narratives around the drivers of food insecurity while recognizing the complexity of this development challenge (Carletto et al., 2013; Pérez-Escamilla et al., 2017; Renzaho and Mellor, 2010). Research on the drivers underpinning inconsistent food access in cities has gathered momentum in recent years (Crush and Frayne, 2011b; Frayne et al., 2022). Several authors have noted the crippling effects of household poverty on food security in cities of the Global South (Maxwell, 1999; Tawodzera and Crush, 2016;) particularly during food price shocks (Cohen and Garrett, 2010). Research has also indicated that poor households in cities can face disrupted food security under the strain of both communicable and non-communicable diseases (Crush et al., 2011; Demmler et al., 2017; Smit et al., 2016).). Inconsistent access to infrastructure can also predispose poor urban households to food insecurity (Frayne and McCordic, 2015).

Stable food access in cities depends upon a functioning urban food system that connects food producers to consumers. The supply of food can occur through both formal markets and supermarkets (Crush and Frayne, 2011a) or informal markets and urban food production (Battersby and Marshak, 2017; Frayne et al., 2014; Orsini et al., 2013; Skinner, 2008). The complexity of modern urban food systems can create significant governance challenges, particularly in developing countries (Smit, 2015). The multitude of actors engaged in the urban food system creates a disaggregated network that is difficult to manage through centralized governance (Haysom, 2015). Maxwell (1999) further notes that the lack of formal safety nets can offload the responsibility for food security onto the household. Localized food systems have emerged as a prominent policy solution to bolster urban food security as well as becoming a common theme in urban food studies (Sonnino, 2016). Localization is also a response to social justice concerns about equitable household access to food.

To inform urban food security policy, Haysom and Tawodzera (2018) have urged a renewed focus on building food security metrics that are applicable to the unique characteristics of urban food systems. Representative survey-based methods have provided a foundational platform to guide policy interventions (Pérez-Escamilla, 2012). Freedman and Bell (2009) further note that self-reported measures of food accessibility can be an accurate and valid basis for designing food security interventions.

The multidimensional nature of food security impacts obstructs the development of precise social research methods and analytical approaches. The multiscaler and collateral impacts of climate change have exacerbated both national food supply and household incomes, rendering opaque the images of food security vulnerabilities and obstructing effective mitigation measures (Wheeler and von Braun, 2013). The interdisciplinary analysis by Foran et al. (2014) of food security frameworks identifies several conceptual paradigms, often in tension with one another and confounding effective food security interventions. As a result, there is a pressing need to develop innovative decision-support mechanisms to support food security policy and research (Mock et al., 2013).

Haysom (2015) notes the need for clear urban food research narratives to help coordinate urban policy action by multiple actors in municipal government. However, the complexity of urban food security challenges can hamper the effective translation of research into policy, often because of miscommunication of urban food research findings (Romero-Lankao et al., 2017). The nature of these challenges is amplified in urban environments where food access, utilization, and stability are often subservient to global economic and climate pressures translated through the local dynamics of market access and household entitlements (Brown and Funk, 2008; Cohen and Garrett, 2010; Crush et al., 2012). Without the appropriate diagnostic tools, policymakers are left with the unenviable task of clarifying the nuanced narratives of social research. As a result, there is an urgent need for research tools that can effectively capture the complexity of urban food security to support statistical modelling and public policy formation. Previous approaches to overcoming this challenge have distilled satellite imagery into relevant and timely famine early warning systems (Enunkel et al., 2014). Scenario-based simulations have provided helpful visualizations to support policy decisions on food security impacts (He et al., 2013). Other researchers have developed novel metrics to account of the combined influence of multidimensional factors underlying sustainable food and nutrition security (Gustafson et al., 2016). Each approach attempts to capture the dynamic and complex nature of food security by simplifying that complexity into a metric that is valid and reliable (Prosperi et al., 2016)

Three of the most widely used self-reported cross-cultural food security scales were developed by the Food and Nutrition Technical Assistance (FANTA) programme: the Household Dietary Diversity Score (HDDS) (Swindale and Bilinsky, 2005), the Household Food Insecurity Access Scale (HFIAS) (Coates et al., 2007), and the Months of Adequate Food Provisioning (MAHFP) (Bilinsky and Swindale, 2010). In this discussion paper, each of these scales is discussed and assessed as measures of food utilization, food access, and food stability.

# Methodology

## Household Dietary Diversity Score

The Household Dietary Diversity Score (HDDS) is designed to measure nutritional diversity in household food consumption by calculating the number of food groups consumed by any member of a household in the previous 24 hours (Swindale and Bilinsky, 2005):

*HDDS* = ∑ *Food Groups Consumed in the Last 24 Hours*

The score is based on the report of the household member in charge of food preparation and/or the person who can reliably describe the consumption patterns of the household. The scale can be adapted to local foods and consumption patterns using the following food groups as a guide (Table 1).

If the household has consumed food in any of these food groups in the past 24 hours, a score of one is inputted for that food group. Otherwise, a zero is inputted. The HDDS is then calculated by adding the number of food groups consumed by the household in the previous 24 hours:

The HDDS score for each household ranges from 0 to 12 where the higher the score, the greater the dietary diversity. The same methodology can be used to calculate a score for individuals rather than households; the Individual Dietary Diversity Score (IDDS) (Kennedy et al., 2011). Dietary diversity is a key component of effective food use (Renzaho and Mellor, 2010) has been used as a proxy measure of food use by other studies (Codjoe et al., 2016; Labadarios et al., 2011). As a result, HDDS can provide information on effective household food use in social survey research. The HDDS is also supported by a growing body of evidence for its external validity. Cordeiro et al. (2012) found a strong correlation between HDDS and energy intake in a survey of Tanzanian adolescents. HDDS also demonstrated a strong correlation with the Food Consumption Score in several surveys (Jones et al., 2013). Faber et al. (2009) found a strong correlation between the HDDS and the HFIAS in a survey of Limpopo in South Africa. However, this finding was not replicated in a study by Maxwell et al. (2014). As they suggest, this finding may have arisen because the two scales measure different dimensions of food security. In sum, the HDDS provides important information on a key aspect of effective food utilization and nutritional diversity.

## Household Food Insecurity Access Scale

The Household Food Insecurity Access Scale (HFIAS) is a survey instrument designed to measure the frequency and intensity of food access challenges experienced by a household (Coates et al., 2007). The scale comprises nine Likert

**TABLE 1: Household Dietary Diversity Score Food Groups**

| |
|---|
| 1. Bread, rice, noodles, biscuits, or any other foods made from millet, sorghum, maize, rice, wheat, or any other locally available grain |
| 2. Potatoes, yams, manioc, cassava, or any other foods made from roots or tubers |
| 3. Other vegetables |
| 4. Fruit |
| 5. Beef, pork, lamb, goat, rabbit, wild game, chicken, duck, other birds, liver, kidney, heart or other organ meats |
| 6. Eggs |
| 7. Fresh or dried fish or shellfish |
| 8. Foods made from beans, peas, lentils, or nuts |
| 9. Cheese, yoghurt, milk, or other milk products |
| 10. Foods made with oil, fat, or butter |
| 11. Sugar or honey |
| 12. Other foods such as condiments, coffee, tea |
| Source: Swindale and Bilinsky (2005: 4) |

questions designed to measure the physical, economic, and social dimensions of challenges related to food access. The questions range from minor to more severe experiences of these challenges in food access. The Likert scale accompanying each question ranges from never in the last month to more than 10 times in the last month. The questions in the scale include the following items (Table 2).

If the household experienced any of these food access challenges, respondents are asked to rank the frequency with which this occurred the following scale: One = Rarely (once or twice in the past four weeks), Two = Sometimes (three to ten times in the past four weeks), or Three = Often (more than ten times in the past four weeks). The scores are then summed to provide an overall HFIAS score of from zero to 27, where higher scores represent a higher frequency of experiencing food access challenges.

*HFIAS* = $\sum$ *Frequency of Food Access Challenges in the Past 4 Weeks*

The HFIAS is probably the most implemented of the three scales reviewed here and has assembled a strong body of evidence to support its use. Knueppel et al. (2009), for example, confirmed that the HFIAS scores were supported by key informants in a study of rural Tanzania. Similarly, HFIAS was also associated with an increased probability of undernutrition among children in surveys carried out in Bangladesh, Vietnam and Ethiopia (Ali et al., 2013). Charamba et al. (2019) also found that the scale was internally and externally valid in a survey of households in Windhoek, Namibia. However, some studies have questioned the effectiveness of the scale. Dietchler et al. (2010), for example, found that the HFIAS was less accurate in its classification of food security status than the Household Hunger Scale (citing potential challenges in translating the concepts of the HFIAS). As with other measures of food security, the overriding recommendation has been to use multiple food security measures rather than attempting to rely solely on one food security scale and disregard other dimensions of food security (Maxwell et al., 2014). Among the multiple food security scales available for measuring different dimensions of food security, the HFIAS is still considered to be the reliable measure of household food access. The HFIAS can also be expressed as a categorical measure by applying a scoring algorithm to the scale responses in order to categorize households into different levels of food insecurity (the Household Food Insecurity Access Prevalence indicator or HFIAP (Coates et al., 2007).

**TABLE 2: Household Food Insecurity Access Scale (HFIAS) Questions**

| In the past four weeks: |
|---|
| 1. Did you worry that your household would not have enough food? |
| 2. Were you or any household member not able to eat the kinds of foods you preferred because of a lack of resources? |
| 3. Did you or any household member have to eat a limited variety of foods due to a lack of resources? |
| 4. Did you or any household member have to eat some foods that you really did not want to eat because of a lack of resources to obtain other types of food? |
| 5. Did you or any household member have to eat a smaller meal than you felt you needed because there was not enough food? |
| 6. Did you or any household member have to eat fewer meals in a day because there was not enough food? |
| 7. Was there ever no food to eat of any kind in your household because of lack of resources to get food? |
| 8. Did you or any household member go to sleep at night hungry because there was not enough food? |
| 9. Did you or any household member go a whole day and night without eating anything because there was not enough food? |
| Source: Coates et al. (2007: 5) |

## Months of Adequate Household Food Provisioning

The Months of Adequate Household Food Provisioning (MAHFP) provides a measure of the stability with which households have maintained adequate food provisioning over the previous year (Bilinsky and Swindale, 2010). The scale is administered using the following questions:

> *Were there months, in the past 12 months, in which you did not have enough food to meet your family's needs?*
>
> *If yes, which were the months in the past 12 months during which you did not have enough food to meet your family's needs?" (Bilinsky and Swindale, 2010:4).*

If a given month is identified by the respondent, 1 is inputted for that month. Otherwise, 0 is inputted for any months not identified by the respondent. The scale is calculated by subtracting the sum of the inputted numbers from 12 (thus, higher scores on the scale are associated with greater household food stability).

*MAHFP* = 12 – $\sum$ *Months of Inadequate Food Provisioning in the Last Year*

Unlike the HDDS and the HFIAS, there have been fewer studies assessing the validity or reliability of this measure in spite of its widespread use in studies of urban food security (Battersby, 2011; Frayne and McCordic, 2015; Frayne et al., 2010). One study has identified common predictors of the MAHFP and other food security scales (Harris-Fry et al., 2015). In sum, the MAHFP is s an empirically supported measure of food stability, but without the same degree of external validation as the other measures reviewed above.

Each of the reviewed food security scales provides a measure of different dimensions of food security. To combine the measures into one overarching index, there are several considerations to take into account. First, the relative weighting of each food security scale's contribution to the overall index score needs to be decided (Munda and Nardo, 2005a). Although this is usually a decision made on theoretical grounds, the index can either give equal weight to each scale's contribution or give disproportionately weight to each scale's contribution based on these grounds. Second, given that HDDS, HFIAS, and MAHFP are measured on different scales of varying magnitude, the scales need to be normalized to ensure that they are comparable (Nardo et al., 2005). Third, the means by which the scores are aggregated (averaged) can significantly impact the stability of the overall index. These predominantly revolve around the theoretical implications of compensability (or the extent to which performance on each scale can be traded off) (Munda and Nardo, 2005b). Some means of aggregation (like arithmetic mean or Bordo ranking procedures) are perfectly compensable, in that poor performance on one scale can be traded off for improved performance on another scale. Alternatively, Condorcet classification procedures ensure that performance on each scale cannot be traded off for performance on another scale.

To support clear policy narratives and statistical modeling, an index of urban food access, utilization, and stability will thus need to address the issues of compensability and weighting. Such an index needs to provide (a) a means of normalization that is not relative; (b) a weighting scheme that ensures equal priority to all included measures, and (c) a means of aggregation that is consistent with the theory underlying food security measurement. The remainder of this paper compares three methods for building a single index of urban household food access, utilization, and stability using the HDDS, HFIAS, and MAHFP measures. The aim is to provide an internally consistent and externally valid means of scoring household food security across these three dimensions.

To create a single index from the HDDS, HFIAS and MAHFP scales, all three need to be normalized so that they can be expressed on the same numeric scale. Given the focus on building an index to support comparisons of household food security across geographical regions and time, relative normalization techniques (such as standardization and ranking) were not viable approaches. Instead, we implemented min-max normalization to transform each food security score on a scale of zero to one. All transformed scales are denoted with the superscript ′ notation (e.g., HDDS′). The HDDS and MAHFP scores were transformed using the following equations:

$$HDDS' = \frac{HDDS - 0}{12 - 0}$$

$$MAHFP' = \frac{MAHFP - 0}{12 - 0}$$

While this approach easily converts the magnitude of each scale, the Min-Max transformation does not account for the reversed direction of the HFIAS (where, unlike HDDS and MAHFP, higher scores denote more severe food insecurity). In this case, the Min-Max Normalization Equation was modified in order to reverse the direction of the HFIAS scale in addition to its magnitude:

$$HFIAS' = \frac{HFIAS - 27}{0 - 27}$$

### FSGM Index Aggregation

We used three methods for aggregating the normalized food security scales: arithmetic means, geometric means, and harmonic means. Each of these methods of aggregation provides its own properties and benefits. As a result, testing the differences between each of the means provides an opportunity to assess the utility of each approach. The approaches are all predicated on the notion that each food security scale should equally contribute toward the overall food security index.

The Food Security Arithmetic Mean (FSAM) index provides the unweighted arithmetic mean of the three normalized food security scores. This approach allows for trade-offs in performance across these indices (perfect compensability). In other words, poor household performance on one scale can be traded off for better household performance on another scale. This aggregation approach is also sensitive to outliers, which can skew the overall mean. Furthermore, the arithmetic mean assumes that the scales included in the index can be aggregated linearly. As with other aggregation methods, the arithmetic mean also assumes that each of the scales included in the index are independent of one another. The FSAM was calculated using the following equation:

Step 1. Sum the normalized HDDS, HFIAS, and HDDS scores and divide by 3:

$$FSAM = \frac{HFIAS' + HDDS' + MAHFP'}{3}$$

The Food Security Geometric Mean (FSGM) index provides an alternative approach to aggregating the food security scales in an unweighted fashion. In this case, the mean is calculated as the nth root of a product of n scales. The geometric mean has a few advantages over the arithmetic mean. First, the geometric mean is less sensitive to outliers (displaying imperfect compensability) than the arithmetic mean. Second, the geometric mean is a unitless measure and can aggregate scales with varied degrees of magnitude. Finally, geometric means are the preferred method of aggregation for ratios. That said, there is one important caveat to the use of geometric means when aggregating multiple scales. The inclusion of a score of 0 for any of the scales included in the index will result in a geometric mean of 0 (regardless of the scores for the other scales). In order to overcome this challenge, the scale for each of the food security scales was shifted by one before calculating the geometric mean of the food security scales (providing FSGM’). Once the geometric mean was calculated, one was subtracted from the geometric mean to provide the FSGM:

Step 1. Add 1 to each normalized HFIAS, MAHFP, and HDDS score, multiply the sums together and find the cubed root of the product:

$$FSGM' = \sqrt[3]{(HFIAS' + 1) \star (HDDS' + 1) \star (MAHFP' + 1)}$$

Step 2. Subtract 1 from the resulting cubed root:

FSGM = FSGM′ – 1

The Food Security Harmonic Mean (FSHM) provides an alternative approach to the scale aggregation challenge. Harmonic means express the quotient of n divided by n reciprocal scales. Expressed differently, the harmonic mean is also the reciprocal of the arithmetic mean of the reciprocals for each scale. Harmonic means are helpful when averaging across different rates. Like the geometric mean, however, including a score of 0 for any of the underlying scales creates challenges for the calculation. In this case, the harmonic mean would be undefined if any of the underlying scales included 0 as a score. As a result, similar to the FSGM calculation, one was added to each of the underlying food security scales. Once the FSHM was calculated, one was subtracted from the overall mean to bring the FSHM back to its original normalized scale.

Step 1. Add 1 to each normalized HFIAS, MAHFP, and HDDS score, sum the inverse of these totals, and calculate 3 divided by the resulting sum:

$$FSHM' = \frac{3}{\frac{1}{(HFIAS' + 1)} + \frac{1}{(HDDS' + 1)} + \frac{1}{(MAHFP' + 1)}}$$

Step 2. Subtract 1 from the resulting quotient:

FSHM = FSHM′ – 1

Each of these scales represent unweighted approaches to aggregating the food security scales. It should be noted that, given the properties of each approach, there is a ranked order to a given household's FSAM, FSGM and FSHM scores. More specifically, the following order (FSHM≤FSGM≤FSAM) will be consistent for all households.

### Index Internal Consistency

The indices constructed represent aggregated measures of urban household food access, utilization, and stability. Given the multidimensional nature of these scales, it is not necessary for the scales to consistently measure one domain (as would be indicated by tests of internal consistency). In order to preserve the linear aggregation of the scales, it is important to determine whether there is a positive linear relationship between the scales that would support the aggregation of the scales. A negative linear relationship between any of the scales would indicate that increasing scores on one food security scale was associated with decreasing scores on another food security scale in the index (creating internal inconsistency in the index). As a result, one or more of the sub-scales may not be positively correlated with the overall index score. In order to assess whether this is the case, we calculated descriptive statistics of the index scores for the different aggregation methods. Pearson's R correlation analysis was used to determine the linear strength and direction of the correlation between each of the underlying scales and the overall index score using each aggregation method.

## Application

To illustrate the utility of the New Food Security Index, this section of the paper draws on data from household food security surveys conducted by the Hungry Cities Partnership in five cities: Maputo, Mozambique; Kingston, Jamaica; Nairobi, Kenya; Mexico City, Mexico; and Nanjing, China. These surveys all administered the same household survey instrument and administered the survey in the same manner to adult household respondents in each randomly selected household. However, the language in which the survey and scales were administered did vary. The survey scales were administered in English (in Kingston and Nairobi), Portuguese (in Maputo), Spanish (in Mexico City), and Mandarin (in Nanjing).

Each survey sampled households from across the city using a combination of random systematic sampling with sample sizes distributed across city subdistricts using approximate proportionate allocation (based on the most recently available census data for the city). The sample sizes varied between the cities but for this analysis 500 households were randomly selected from each city data set to provide an equal contribution of each to the effects observed. Among the final 2,500 household samples, the response rates for the food security scales varied from 96% to 99%.

The three indices (the FSAM, FSGM and FSHM) demonstrated a similar distribution. However, there were city-specific differences in both the magnitude and spread of the scores for the different indices (Figure 2). The households in Nanjing recorded the highest scores on the FSAM, FSGM and FSHM as well as the smallest spread. The households in Maputo indicated the lowest scores across the three indices as well as the greatest spread.

FIGURE 1: Histograms of FSAM, FSGM and FSHM

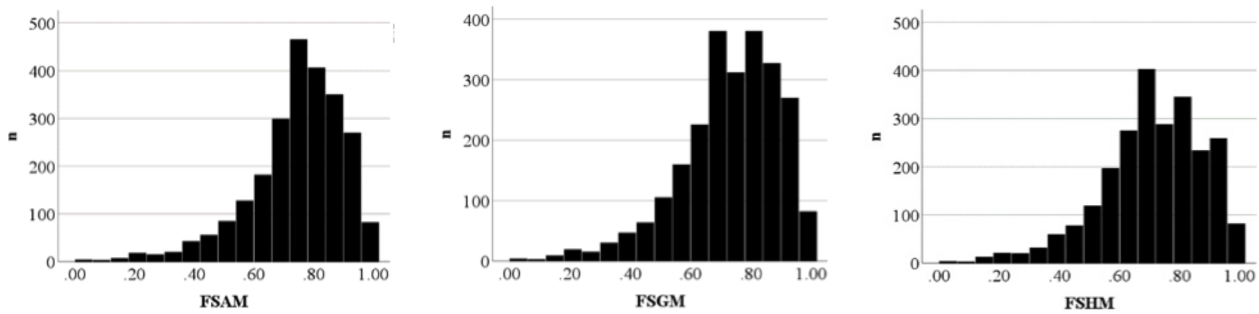
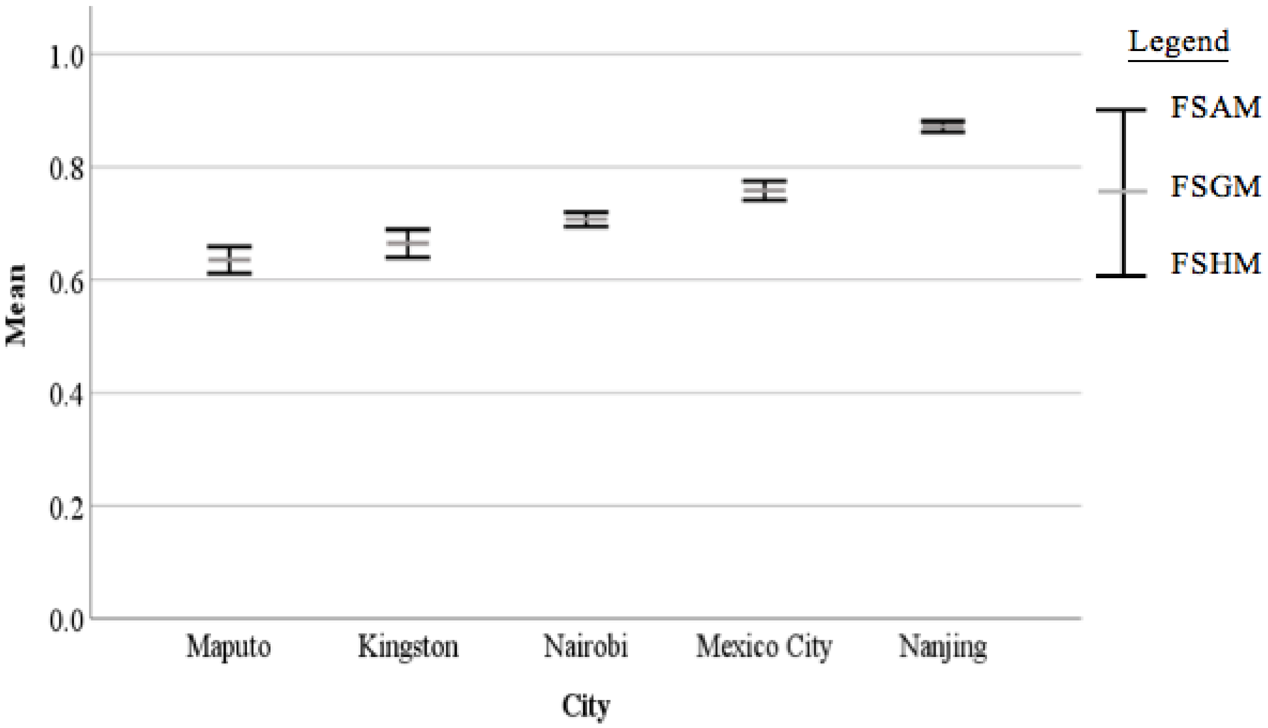



FIGURE 2: Distribution of Mean FSAM, FSGM and FSHM Scores Across Cities



The descriptive statistics behind Figure 3 are presented in Table 3. The differences observed in the variation of these three indices across the cities may be the result of a combination of factors: for example, the predominant clustering of high scores in a given city (as observed in Nanjing) or the reduced range of scores (as observed in Nanjing and Nairobi). The association between the clustering of scores within and between the three index scores in each city gives an indication of the spread inherent in the underlying food security scales in these cities.

**TABLE 3: Descriptive Statistics of the FSAM, FSGM and FSHM Scores Across Cities**

| City | Statistics | FSAM | FSGM | FSHM |
|---|---|---|---|---|
| Maputo (n=484) | Mean | 0.66 | 0.64 | 0.61 |
| | Median | 0.7 | 0.67 | 0.64 |
| | Std. Dev. | 0.18 | 0.18 | 0.18 |
| | Min | 0.06 | 0.05 | 0.05 |
| | Max | 0.97 | 0.97 | 0.97 |
| Kingston (n=474) | Mean | 0.69 | 0.66 | 0.64 |
| | Median | 0.72 | 0.68 | 0.65 |
| | Std. Dev. | 0.15 | 0.16 | 0.16 |
| | Min | 0.03 | 0.03 | 0.03 |
| | Max | 1 | 1 | 1 |
| Nanjing (n=488) | Mean | 0.88 | 0.87 | 0.86 |
| | Median | 0.89 | 0.88 | 0.88 |
| | Std. Dev. | 0.07 | 0.08 | 0.09 |
| | Min | 0.59 | 0.55 | 0.51 |
| | Max | 1 | 1 | 1 |
| Nairobi (n=493) | Mean | 0.72 | 0.71 | 0.69 |
| | Median | 0.74 | 0.73 | 0.71 |
| | Std. Dev. | 0.15 | 0.15 | 0.15 |
| | Min | 0.22 | 0.2 | 0.18 |
| | Max | 1 | 1 | 1 |
| Mexico City (n=494) | Mean | 0.77 | 0.76 | 0.74 |
| | Median | 0.78 | 0.77 | 0.75 |
| | Std. Dev. | 0.12 | 0.13 | 0.14 |
| | Min | 0.06 | 0.05 | 0.05 |
| | Max | 1 | 1 | 1 |
| Total (n=2433) | Mean | 0.75 | 0.73 | 0.71 |
| | Median | 0.77 | 0.75 | 0.72 |
| | Std. Dev. | 0.16 | 0.16 | 0.17 |
| | Min | 0.03 | 0.03 | 0.03 |
| | Max | 1 | 1 | 1 |

The Pearson's R correlations of the indices and sub-scales revealed significant and high positive linear correlations across the three indices (Table 4). In addition, each of the underlying food security scales also demonstrated significant and positive correlations with the three indices. However, while the relative strength of the relationship between these sub-scales and the three indices did not vary substantially across indices, the relative strength of these relationships did vary by city. For example, Maputo, Nairobi, Mexico City and Kingston all indicated very strong linear correlations between the food security scales and the three indices. In Nanjing, however, the MAHFP and HFIAS indicated weak to moderate positive relationships with the overall food security scale. This observation likely resulted from the fact that few households received less than a perfect food security score on these scales in the Nanjing household sample.

**TABLE 4: Correlation of HFIAS, MAHFP, and HDDS Scores with FSAM, FSGM, and FSHM Across Cities**

| Maputo (n=484) | FSAM | FSGM | FSHM |
|---|---|---|---|
| FSAM | 1 | .997** | .987** |
| FSGM | .997** | 1 | .996** |
| FSHM | .987** | .996** | 1 |
| HDDS' | .632** | .683** | .733** |
| HFIAS' | .875** | .857** | .829** |
| MAHFP' | .815** | .790** | .760** |
| **Kingston (n=474)** | **FSAM** | **FSGM** | **FSHM** |
| FSAM | 1 | .995** | .981** |
| FSGM | .995** | 1 | .995** |
| FSHM | .981** | .995** | 1 |
| HDDS' | .622** | .684** | .740** |
| HFIAS' | .848** | .818** | .776** |
| MAHFP' | .685** | .645** | .602** |
| **Nanjing (n=488)** | **FSAM** | **FSGM** | **FSHM** |
| FSAM | 1 | .998** | .992** |
| FSGM | .998** | 1 | .998** |
| FSHM | .992** | .998** | 1 |
| HDDS' | .954** | .966** | .974** |
| HFIAS' | .457** | .415** | .377** |
| MAHFP' | .273** | .244** | .219** |

| Nairobi (n=493) | FSAM | FSGM | FSHM |
|---|---|---|---|
| FSAM | 1 | .998** | .992** |
| FSGM | .998** | 1 | .998** |
| FSHM | .992** | .998** | 1 |
| HDDS' | .705** | .738** | .769** |
| HFIAS' | .871** | .859** | .842** |
| MAHFP' | .740** | .715** | .688** |
| Mexico City (n=494) | FSAM | FSGM | FSHM |
| FSAM | 1 | .996** | .983** |
| FSGM | .996** | 1 | .996** |
| FSHM | .983** | .996** | 1 |
| HDDS' | .620** | .677** | .727** |
| HFIAS' | .770** | .729** | .681** |
| MAHFP' | .673** | .631** | .586** |
| *p<.05; **p<.01 | | | |

## Conclusion

This paper proposed a new index of urban household food access, stability, and utilization by combining three common food insecurity metrics (the HFIAS, HDDS and MAHFP) via min-max normalization and geometric means for index aggregation. Geometric means are less sensitive to outliers (demonstrating partial non-compensability) and the preferred method of aggregation for ratios and skewed data (as is the case in normalized data and food security data, which can be highly skewed). The issue of compensability is also an important theoretical consideration among these index aggregation techniques. Perfect compensability (as allowed by an arithmetic mean) would allow households to trade off their performance across their food access, utilization, and stability. These pillars of food security are likely meant to be interpreted as fundamental necessities in order for food security to exist (rather than compensable entities). As a result, from a theoretical perspective, it is unlikely that arithmetic means would work as a means of measuring across urban household food access, utilization and stability. While perfect non-compensability is not likely to be helpful (given that available methods, like Condorcet methods, would only support household ranking rather than scoring). Geometric means may provide a more reasonable conceptual grounds for the index, given that the approach supports imperfect compensability.

The proposed index should not be interpreted as a comprehensive measurement of household food access, utilization and stability, but rather as an indication of these food security characteristics. For example, the definition of food utilization covers a broader set of features than that measured by the HDDS and the scale by which food stability is measured can vary from the 12-month recall period covered by the MAHFP. As a result, this index provides one proxy for the measurement of these food security concepts. With the development of more refined food security scales, it may be possible to develop more sophisticated indices of food security to better account for the characteristics not covered by the current proposed index.

This paper provides a means of calculating an index of urban household food access, utilization and stability that is methodologically sound, reliable and externally valid. Given the data normalization technique implemented, this index also provides a means of comparing performance on these pillars of food security across geographies and points in time. Furthermore, the index provides a means of simplifying multiple dimensions of urban household food security into one metric that is amenable to both statistical modelling and clear policy narratives. Given the complexity of both the characteristics and the drivers of urban food security, the utility of the index methodology proposed here could support further research into sustainable food insecurity mitigation measures under the twin pressures of climate change and rapid urbanization. Future research could investigate the utility of this index as a means of measuring household food security status in cities not included in this paper.

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