Insights from the Guatemalan food system: an application of exploratory spatial data analysis techniques for food security analysis

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Abstract

The achievement of food security for all remains one of the main development objectives worldwide. Most commonly, non-spatial models are developed for either explaining the underlying determinants of food insecurity and undernourishment or for predicting their changes, so as for identifying vulnerable groups for targeting support. Such approach ignores geographic determinants and the spatial dependency of food security and nutrition outcomes. This paper seeks to address this issue. We use nationally representative data from Guatemala, which faces high and rising rates of undernourishment and child stunting in spite of the efforts engaged on their reduction. Through exploratory spatial data analysis and overlay techniques, some elements embedded in the food system are explored and integrated with the aim of providing complementary information for the analysis of food security. The preliminary results show that these elements are spatially related and that they display geographic trends and spatial dependency. The consideration of these patterns in research and modelling applications can improve the understanding of the related information and its use for the development of food security enhancing strategies. We conclude with recommendations on methodology so as to include spatially explicit analysis in causal or predictive models of food security.

Keywords: food-system, spatial, Guatemala

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Introduction

The achievement of food security for all remains one of the main development objectives for both developed and developing countries. With the exception of Guatemala, El Salvador, and Venezuela most of the Latin American countries registered a reduction on the prevalence of undernourishment during the 1990's. It has been forecasted that if the current conditions remain, Guatemala will not reach the objectives of halving the prevalence of undernourishment and child stunting (MDG 1[1]) by 2015 (León et al, 2004).

Due to its location and topography Guatemala has a wide array of ecological zones, ranging from coastal to highland areas with about 4200 meters above the sea level. Earthquakes, hurricanes, tropical storms, droughts, and volcanic activity are occasional (FAO, 2003). In 2002 there were 11,237,196 inhabitants in the country, from which 54% were living in the rural areas (INE[2], 2002). By the year 2000, 56% of the population was living in poverty (World Bank, 2003). The country is also socially and culturally diverse. About 41% of the population has indigenous origins, from which approximately 32% speak only their native language (FAO, 2003).

According to León et al (2004) food insecurity and poverty are closely related in the Latin American context, but food insecurity also occurs irrespective of poverty and constitutes a phenomenon that should be explored on its own. The objective of this paper is to make a preliminary exploration of the spatial distribution and properties of some elements embedded in the Guatemalan food system, with the aim of gaining contextual and integrative information relevant for the analysis and modelling of food insecurity.

Literature review

Food security "*exists when all people, at all times, have physical, economic, and social access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life*" (FAO, 1996/2001). The FAO (2006) identifies 4 dimensions of household food security, namely food availability, access, utilization, and stability.

While food availability refers to food supply at regional and national level, food access and utilization refer to the ability of households to obtain and use food for meeting the food preferences and nutritional needs of its members (Webb and Rogers, 2003; Guardiola et al, 2006). Stability in the three dimensions leads to a long term condition of food security (FAO, 2006). The first three dimensions have a hierarchical relationship. Food availability is necessary, but does not guarantee households' food access, which in turn is necessary, but does not ensure adequate utilization (Webb and Rogers, 2003).

Several factors operating at different scales influence the households and individuals' food security and nutritional status in a given setting. While the dimensions of food security give a good sense of the relevant factors acting at each of these scales, most often they are analyzed separately and without consideration of their spatial behaviour. By doing so, the analysis and

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[1] Millennium Development Goal
[2] National Institute of Statistics

results produced are not only partly de-contextualized and face the risk of missing key elements that provide complementary information; but also fail to account for spatial effects. These facts can lead to misleading and/or incomplete conclusions about the specific issue being investigated and may compromise the validity and reliability of the related estimates.

Sobal et al (1998) define a food a nutrition system as „*the set of operations and processes involved in transforming raw materials into foods and transforming nutrients into health outcomes, all of which functions as a system within biophysical and sociocultural contexts*“ and propose an integrated conceptual model that captures the relationships between agriculture, food consumption, and health. The model is composed by 3 subsystems:

- Producer subsystem: focuses on the production, processing and distribution of food products.
- Consumer subsystem: refers to the population’s acquisition, preparation and consumption of food.
- Nutrition subsystem: involves absorption, and metabolism of food and nutrients. In interaction with other factors, a given nutritional status is achieved, which is a major outcome of the system.

The food system is embedded in specific physical, social, economic, and political environments that provide the context and resource base for its operation and influence its outcomes at each level. The exploration of the system allows to visualize the links between the subsystems and to describe their features and problems (Sobal et al, 1998). The existence of food and nutrition insecurity can be seen as a failure of the system. As León et al (2004) point out; knowledge on the food system supports the establishment of food policies and initiatives that are in line with the characteristics, behaviours, and interests of all who are involved on it.

<u>Spatial Data Analysis</u>

Geographic Information Systems (GIS) have become very powerful tools for visualizing and analyzing data with a spatial perspective. They can aid in the exploration of regional patterns in social behavior and processes; in the understanding of natural and human environments; and in the effective allocation of resources in accordance to defined criteria (Longley et al, 2005).

Exploratory spatial data analysis (ESDA) helps to describe the way of how measurements vary over space or relate to each other based on their location (Kitanidis, 1997). In addition to classic data exploration methods such as boxplots, scatterplots, or histograms; ESDA procedures facilitate the identification of the spatial distribution, patterns, and structures in the data (Anselin and Getis, 1992). Spatial dependency (value similarity among neighbors) can be assessed by the global Moran’s I statistic, which indicates of the overall pattern of autocorrelation observed (Anselin and Bao, in Fischer and Getis, 1997, Ch. 3).

Overlay analysis is a technique that is used to visualize the spatial relationship of different variables. On it, data from different sources can be integrated and analyzed (Chrisman, 2002). Based on the combined information, areas where certain criteria has, or not, been met can be identified. Spatial analysis can therefore, broaden the methodological toolkit for analyzing food security.

Data and methods

The data used for the analysis was obtained from the living conditions national survey 2006 (ENCOVI), the thematic atlas 2002, and the ministry of health's coverage report 2000. Table 1 presents the variables employed, with their corresponding level of aggregation.

Table 1. Variables included in the analysis

Producer subsystem	Consumer subsystem	Nutrition subsystem
Degree of deficit in basic grains production (M)	Proportion of the population in extreme poverty (M)	Proportion of chronic malnourished (stunted) first grade children (M)
Risk to drought (M)	Proportion of the population without access to health services (A)	
Road availability (M)	Proportion of food insecure households according to calorie availability vs. requirements (urban and rural, D)	
Land use intensity (NA)		

M = municipio, D = departamento, A = health area, NA = no aggregation

Considering theory, many variables should be included in the analysis of the food system; however, for simplification purposes, only a reduced set was incorporated. The variables selected aim to represent the most relevant aspects on each subsystem.

All variables were taken as published by the official data sources[3], with the exception of the proportion of food insecure households for which the variable was constructed using the food consumption information as collected by the survey (2 week recall). An important issue of this variable is its time frame. While the other information refers to the period 2000-2002 and provide a picture of the situation at that moment; this variable stems from 2006. Its levels might not be similar to those of 2000-2002. Nevertheless, since the aim of the study is to make a preliminary exploration the spatial behaviour and trend of the food system, the actual values were considered of secondary importance[4]. Upon availability of updated and previously non-available data, future analyses will incorporate more elements which are based on more recent conditions and that can provide a better insight into the system by the year 2006.

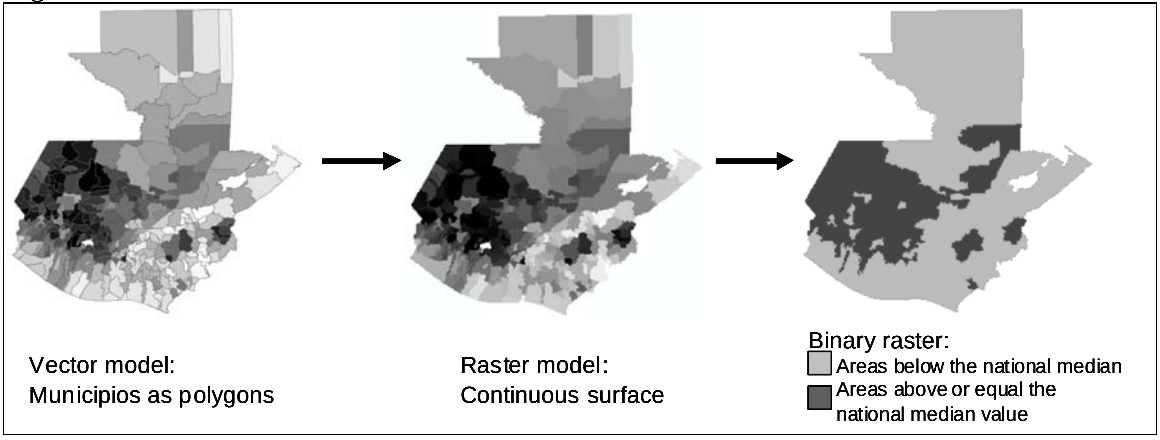
Data preparation was done using SPSS. For the combined analysis, all data was fed into the GIS software ArcGIS and aligned into a common geographic reference system.

At first, the information was available (or created) in vector format with polygons representing Municipios (331 units), Departamentos (22 units), or health areas (26 units). Afterwards, the information was converted to the raster (grid) format. In order to simplify the visualization, these new datasets were further transformed into binary grids using the following approach (Figure 1):

[3] Full documentation on these variables is provided in the original sources.
[4] In 2000 an ENCOVI survey was carried out in Guatemala. Its information on food consumption would be more consistent with the other sources; however, the survey provides representative results only for 8 major regions. The ENCOVI 2006 allows estimates at the departamento level (22), making it more adequate for the purposes at hand.

- Maps for the variables in the consumer and nutrition subsystems (all continuous variables) focused on areas where the values are equal or above the national median level
- Maps for the variables in the production subsystem (all grouped variables) focused on the negative levels of the variables (for example "high or very high grain deficiency[5]")

Figure 1. Variable creation within the GIS, chronic malnutrition.



The median values were selected as cut off points because they are considered as robust statistics in ESDA. The areas with values below the national median were excluded from the analysis since they portray better-off conditions relative to the national context. While this was done for simplifying the displays and visualizations, their exclusion does not imply that threats and problems to the food system are nonexistent, nor that the observed levels (i.e. poverty) are low in absolute terms.

Overlay analysis was executed using the binary grids. ESDA techniques were employed along the analysis in order to explore important elements of the food system (following Sobal et al, 1998). The global Moran's I statistic was calculated using the inverse (Euclidean) distance between the municipio geographic centroids, as neighbourhood parameter.

Results and discussion

Producer subsystem

The forms of production, processing, distribution, and commercialization of food in Guatemala are diverse. Subsistence and small farmers, modern agricultural enterprises, agro-industries, and traditional and modern commercialization venues operate simultaneously in the country (León et al, 2004).

Fifty-two percent of the population is engaged in agricultural production (INE, 2002) on which subsistence farming dominates (MFEWS, 2005). Small and family farmers account for ca. 96% of the total productive units and occupy about 40% of the cropped area. These units have a limited capacity for contributing to the aggregate food supply. In contrast, medium and big agricultural enterprises (4%) occupy a high proportion of the cropped area but are mainly export oriented (León et al, 2004).

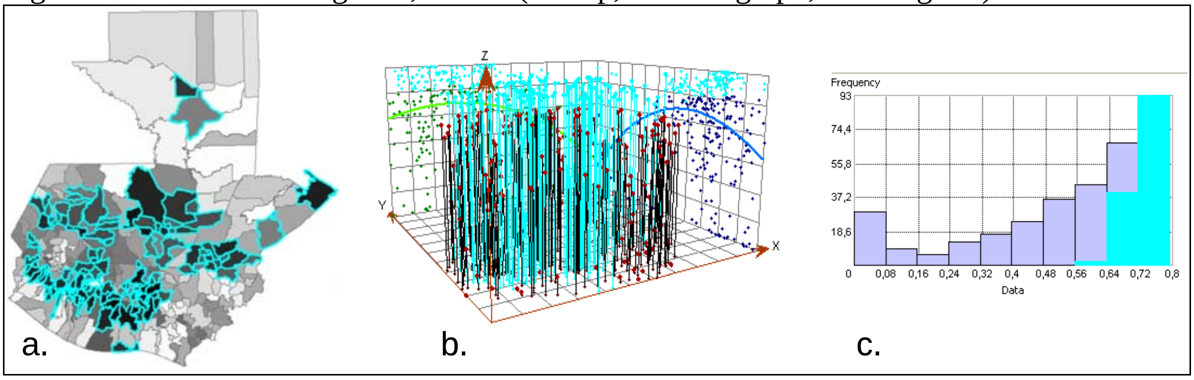
Subsistence and low scale agriculture is characterized by the achievement of low yields. Part of this can be explained by the difficulties that small holders face as regards access to credits, irrigation, implementation of technological innovations, and land tenure guarantees. Moreover,

[5]The variable on deficit of basic grains had also a continuous variable equivalent. See Figure 2.

58% of the land is not arable, further limiting the earning potential of the farmers (FAO, 2003).

The main crops produced are maize, beans, vegetables, banana, coffee, sugar cane, and cardamom. The first three are most often produced by subsistence farmers. Animal husbandry (mainly beef) and fishery are much less developed (MFEWS, 2005). Since the 1990's, an ongoing reduction in the area cropped of maize and beans, the main food items in the country ("basic grains"), has been observed. The inability of producers to compete with import prices, the conversion into other crops, and the negative effects of natural disasters and climatic adversities are among the main factors affecting their production (UN, 2003). The lower production volume and the reduction in the level of imports have created an ongoing undersupply of these items (León et al, 2004). Figure 2 presents the spatial distribution of the basic grains deficit across municipios.

Figure 2. Deficit of basic grains, ESDA (a. map, b. trend graph, c. histogram)



The figure is composed by 3 elements: a map, a trend graph and a histogram. The map shows a colour gradient from white to black on which darker colours represent higher deficit levels. The highlighted areas indicate places where the deficit is at highest. The position of these areas in the histogram and in the trend graph is also indicated. The trend graph shows the projection of the deficit values (z) on the (x,y) geographic coordinates. These coordinates have as initial point the most western and southern locations in the map area.

Along the (x) axis, the west-east direction, grain deficiency is high in the west, reaches a maximum in the central part, and decreases towards the east (green line). In the south-north direction (y), grain deficiency raises towards the center and decreases in the northern part of the country (blue line). The green and blue lines are curves fitted to the behaviour of the data when projected into the (x) or (y) axes.

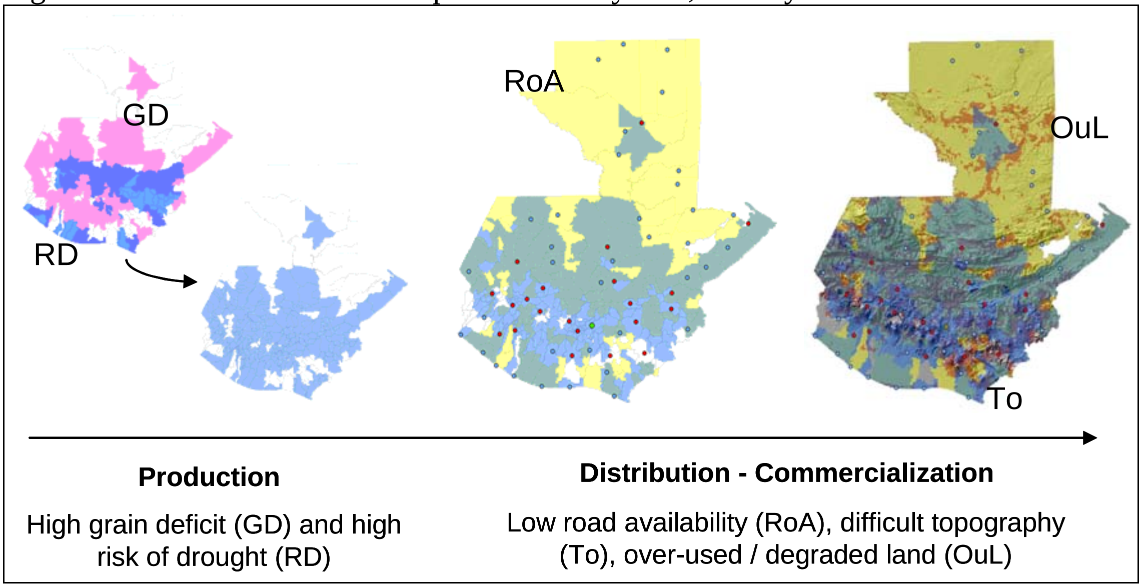
Clusters of similar deficit levels can be recognized. In order assess the presence of spatial autocorrelation, the Moran's I measure was calculated[6]. The resulting index was 0.09, with significance (Z score) of 18.3, meaning that the data presents some clustering, i.e. spatial autocorrelation.

The strong reliance on basic grains and the low involvement on other production alternatives already indicate the challenge faced by the system for supplying a sufficient and varied diet to the population. During the past decades, the aggregate average energy supply showed a deficiency around 200 kcal/capita/day (UN, 2003). Furthermore, the vulnerability to food

[6] The null hypothesis states that no spatial clustering of the values exists. Positive I values indicate clustering, and negative values indicate dispersion.

insecurity when risks to agricultural production arise becomes evident. Figure 3 presents other factors relevant for this subsystem.

Figure 3. Factors relevant for the producer subsystem, overlay



At the left, food production serves as starting point. Areas in pink indicate the municipios where grains' deficit (GD) is high. Blue shading appears on areas where the risk of drought (RD) is also high. In the overlay, areas in purple (combination of pink and blue) indicate that both GD and RD are present. A combined layer (light blue) displays the areas that present either high GD and/or high RD.

In the central map of the figure, information reflecting low road availability (RoA, in yellow) and the location of main cities (red dots) and towns (blue dots) is added to the view. Low RoA and high distance to major centers can represent difficulties for the physical access and distribution of food. As in the GD example, areas in yellow indicate that RoA is low, but neither GD nor RD are present. Areas in blue indicate that GD and RD are prevalent, but not low RoA. Areas in greyish-green show areas where GD/RD and RoA overlap.

At the right side, factors such as topography (To, roughed surface) and areas where land is over-used (OuL, red spots) are incorporated. A southern blue belt where the main problem is GD and difficult To appears. This area has good RoA given the presence of numerous cities (red dots). The areas where all information overlaps correspond to hilly and rather rough textured locations in the central part of the country. These areas present supply problems which are reinforced by the difficult access, land degradation, and distance to major population centers.

Consumer subsystem

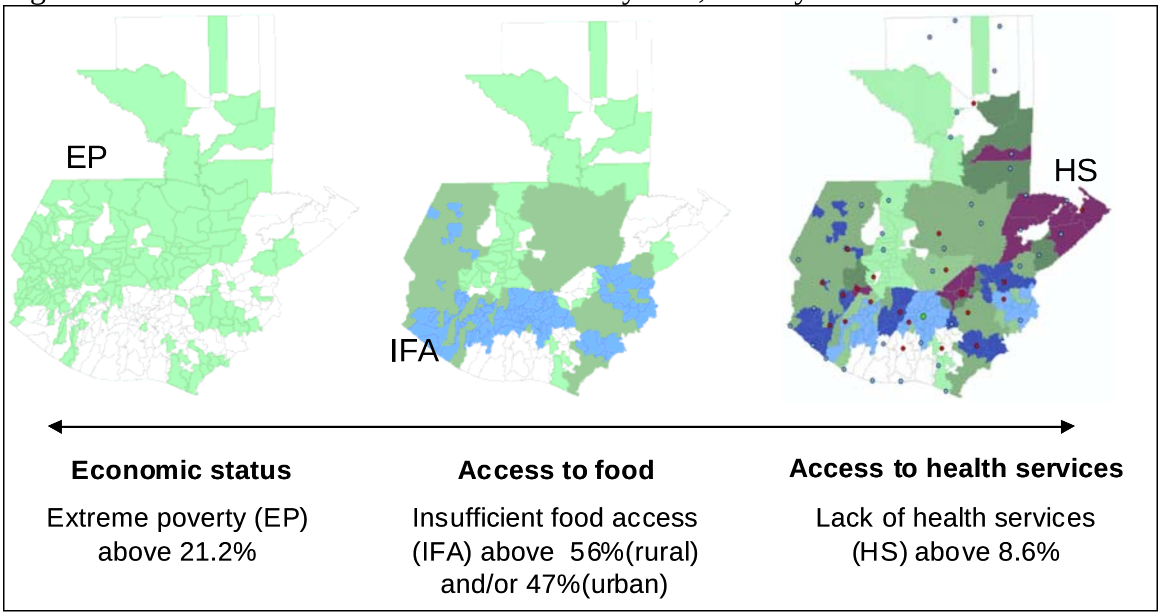
This subsystem relates to the households' capacity to access food and follows the sequence started in Figure 3. An income survey revealed that the average monthly per capita income in 1998 was 610 Quetzales[7] (Q. 977 urban vs. Q. 368 rural). Estimations indicated that the average household income could cover only 50% of the cost of the basic food basket (FAO, 2003). Nowadays, this proportion could be lower given the negative effects of the 2001 coffee crisis and recent natural disasters (droughts, hurricanes Mitch and Stan) on the population's economy. Figure 4 presents elements relevant for this subsystem.

[7] The average market exchange rate in 1998 was 6.6 Quetzales per 1USD (Banco de Guatemala, 2008)

The map on the left shows municipios where the incidence of extreme poverty (EP) is higher than the national median. High EP levels are observed in the west-central part of the country. In the central map, areas with high proportion of households presenting insufficient food access (IFA, in blue) are added. Areas of overlapping (greyish-green), with both EP and IFA, appear. Interestingly, areas where only IFA is present (blue) are similar to those areas in the south where only grain deficiency is observed and which are near main cities.

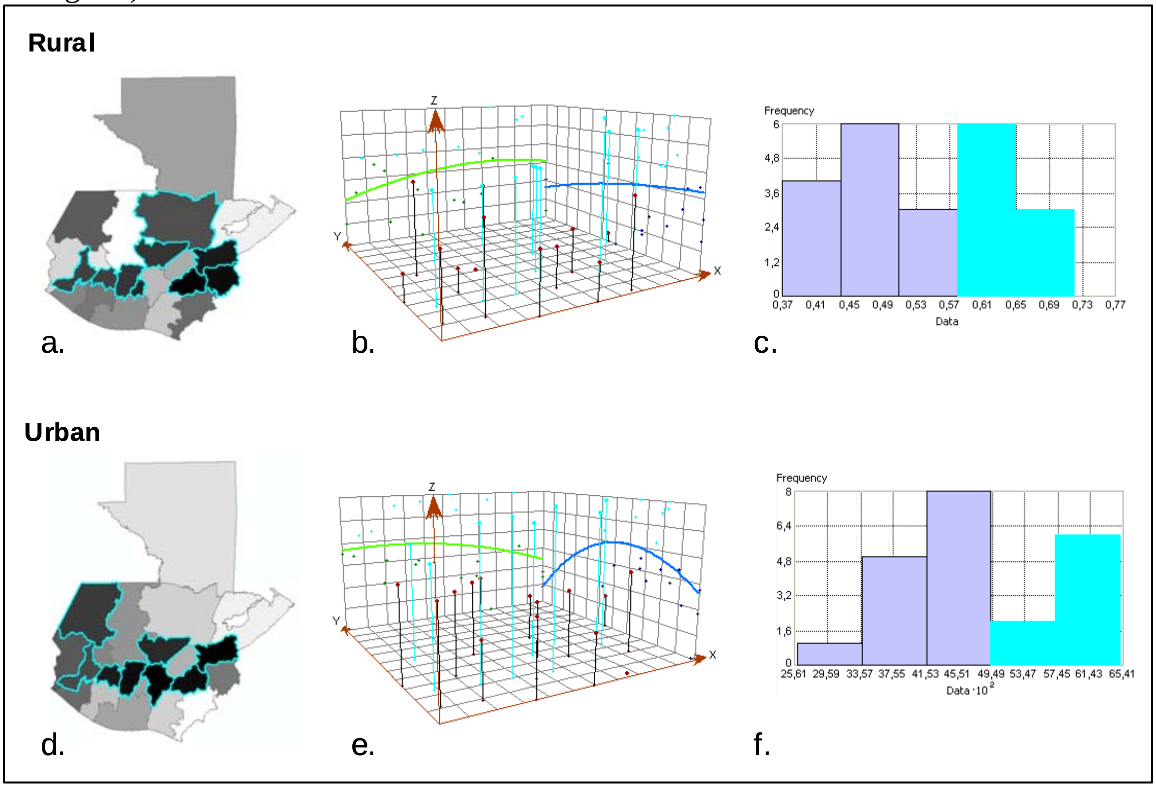
Given the importance of general health for a good nutritional status, information regarding the proportion of the population with no access to health services (HS, in purple) is included. The changes in the shadings from the IFA view are easily observed. Areas of EP/IFA overlap become greyer if HS is also a concern. IFA areas become dark-blue and EP areas dark-green. It appears that both the west and the east parts of the country face more difficulties to access health services.

Figure 4. Factors relevant for the consumer subsystem, overlay



The double heads in the arrow suggest that the 3 factors interact. Overall, the western and central-eastern side present the 3 conditions. While EP does not represent a major concern in the east, IFA and lack of HS do occur. Figure 5 presents the exploration of IFA for both urban and rural locations.

Figure 5. Insufficient food access rural and urban, ESDA (a/d. map, b/e. trend graph, c/e. histogram)



The aggregation of the IFA data allows exploration only at the departamento level. For both rural and urban locations, the highest proportions of households with IFA are in the central part. The trend graph for rural areas indicates that IFA levels increases towards the east. For the urban areas the tendency is to decrease in that direction. For both areas, IFA levels rise in the north-south direction. A slight drop in the south corner occurs in the urban areas.

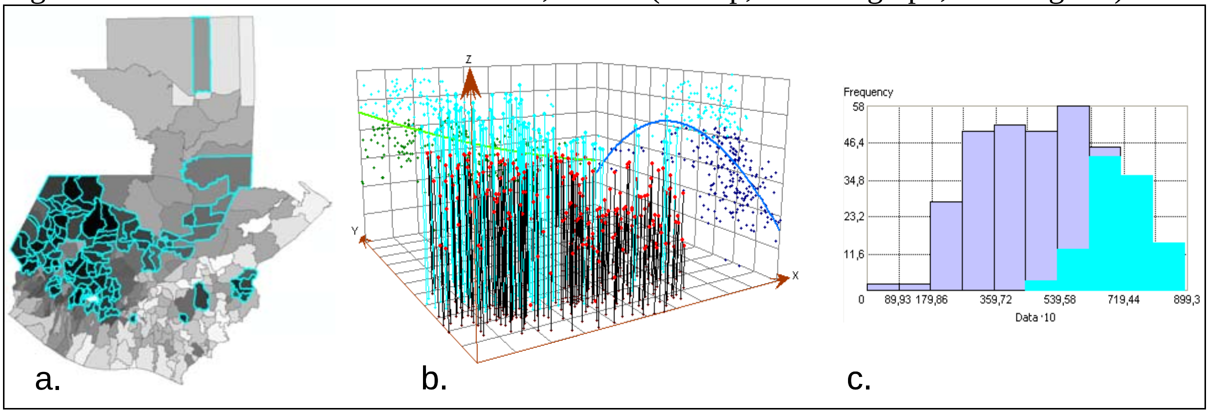
As regards spatial autocorrelation, both distributions are classified as random across space according to the Moran's I statistic. However, given the low number of units (22) and their properties (five big departamentos dominate the northern half of the country), the ability to assess the real patterns and variability in the data is reduced

Nutrition subsystem

This subsystem represents the end of the food system, for which the observed nutritional status is a major outcome. Approximately, a fifth of the population does not meet its minimum caloric requirements and about half of the children under 5 years of age are stunted. Micronutrient deficiencies prevail, especially in the rural areas (FAO, 2003).

In parallel, the prevalence of overweight and obesity have increased. Marini and Gragnolati (2003) found that obesity increased in children and adults, being higher in urban areas, among the non poor, and for the non-indigenous population. Diet related diseases by under or over-nutrition, co-exist and pose additional challenges to the Guatemalan health services. Issues regarding dietary quality and nutrition education become relevant at this point. Figure 6 presents the exploration of chronic malnutrition.

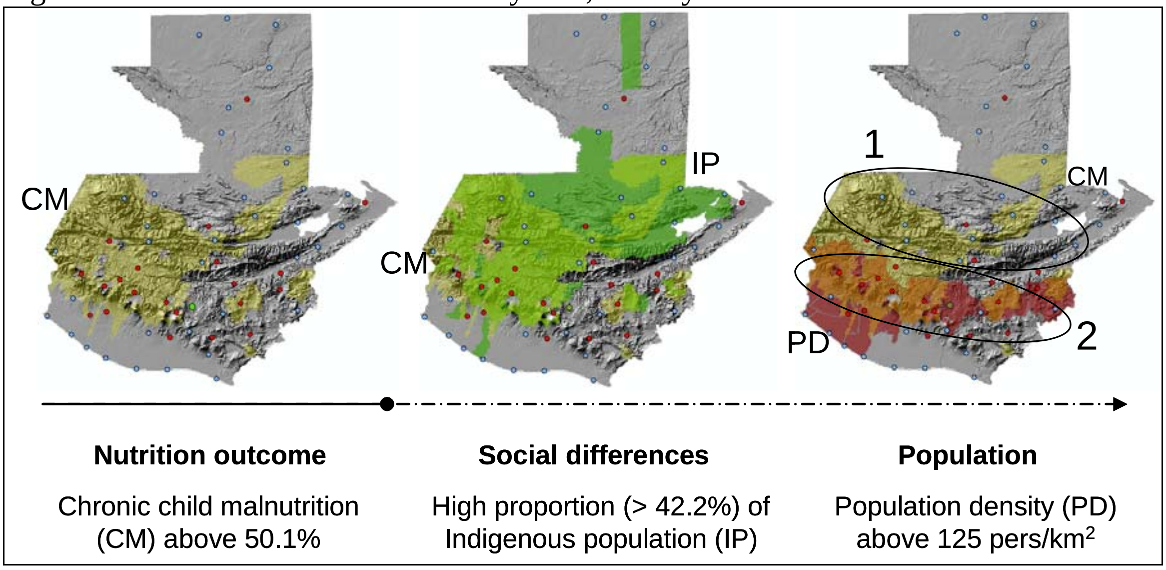
Figure 6. Chronic malnutrition in children, ESDA (a. map, b. trend graph, c. histogram)



High rates of malnutrition are concentrated in the central-west and decrease towards the east. In the north-south direction, the central part presents the highest levels. The Moran's I statistic for spatial autocorrelation (I = 0.22, Z score = 45.66) indicates that clusters of similar values are present.

Figure 7 presents the overlay of high prevalence of child malnutrition (CM) with variables reflecting a high proportion of indigenous population (IP) and high population density (PD). Areas with high CM closely overlap with areas where IP is high (light-green). Areas with high CM and PD (orange) occur at/near main cities. Their location is similar to that of the southern belt observed previously (high GD, difficult To, and high IFA).

Figure 7. Outcome of the nutrition subsystem, overlay

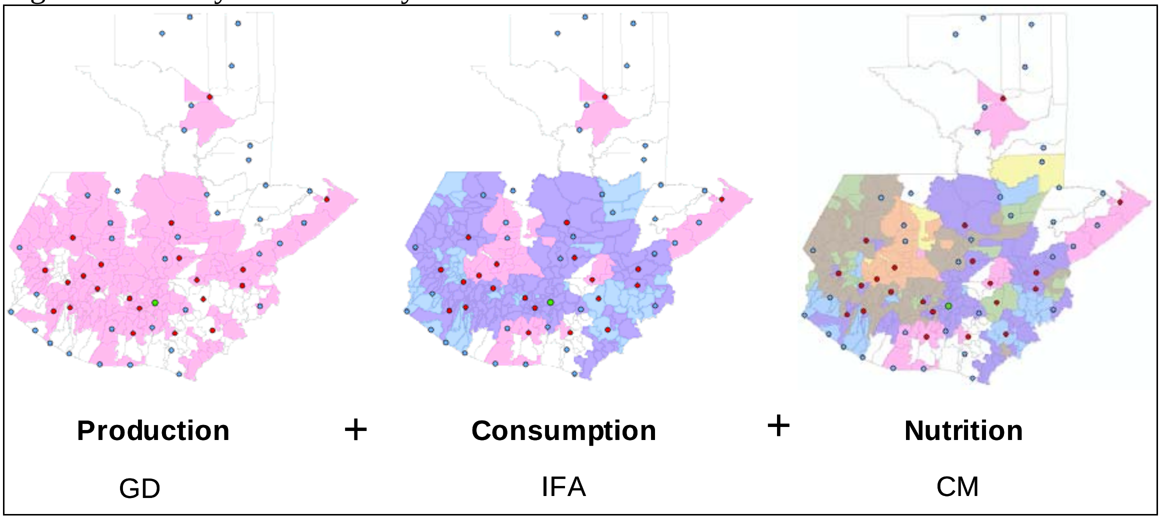


Two areas require special attention (right side map). Area 1 was pointed out by the 3 subsystems as facing conditions that threat food and nutrition security. This area appears to be underdeveloped and disadvantaged (low PD, low RoA, lack of HS, high EP); therefore it requires actions at many levels for strengthening the system.

Conversely, area 2 is more developed since many cities are located there. Factors like To, RoA and HS appear not to be major concerns. For this area, interventions may focus on improving food (basic grains) availability and food access at the household level.

Figure 8 presents a final overview of the main variables analyzed. Grain deficiency (pink) is presented as threat to food security in the production subsystem. Insufficient food access is added for the consumption subsystem. Purple areas indicate overlap from both subsystems. Lastly, the nutrition outcome given by children chronic malnutrition is overlaid. Dark orange areas indicate the overlap of the 3 layers. As already mentioned, these areas are mostly in the west-central part of the country.

Figure 8. Overlay of the 3 subsystems



Interestingly, the south-east area does not present generalized high CM prevalence, in spite of facing supply and consumption constraints. This fact brings us back to an earlier comment. The variables in Figure 8 are commonly used for measuring food insecurity either by food availability, access, or utilization. Each of them identifies the food insecure differently in terms of location, general characteristics, and total numbers. The focus on one element is valid for a specific research or intervention purpose; however the consideration of the broader system information could provide valuable information as regards underlying causes and potential impacts.

Conclusion

The general food context in Guatemala is characterized by insufficient availability of food, impaired access to it, and a compromised utilization; which derive in large proportions of the population suffering from undernourishment. Two regions with different behaviours along the system were identified. Their characteristics point the direction on which supporting measures could be undertaken for improving the performance of the system and the food security of the population.

The exploratory and overlay analyses revealed how key factors relevant for the operation of the food system are spatially related. The data presented clear geographic trends and spatial autocorrelation. These findings help in the understanding and contextualization of the nutrition outcomes and provide relevant information for model building in later stages of analysis.

In general, many factors related to the food system are genuinely geographic (i.e. soils suitable for food production, climatic and topographic conditions, distances to markets, sub-cultural/ethnic differences, etc.) and thus present a spatial behaviour. Consequently, it is pertinent to analyze the system or its components with a spatial perspective, in order to identify and account for spatial structures and patterns.

Many research applications related to food security (and at some extent practitioners' work) rely on non-spatial regression models (predictive or causal) of food security status, consumption estimates, or anthropometric measures. The incorporation of the spatial properties of the data via spatial models, represents a methodological advancement in model specification and can improve the performance and reliability of the estimates.

The analysis showed the importance of accessing geographic data. Information about the location of towns, markets, roads, etc., can be easily collected when surveying and is of great support for food security spatial analyses.

The enhanced understanding of the processes contributing to food insecurity will derive in improved strategies for its reduction.

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