Food Security Assessment Based on GIS Spatial Analysis in the Rural Area of East Azerbaijan Province, Iran

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Abstract

GIS is an exploration tool into the use of spatial reasoning methods, to identify regions at risk, due to inadequate food and water resources, which are a result of inherent environmental scarcity. The purpose of this study is to lay an evidentiary foundation to assess food security in rural area of East Azerbaijan Province. We estimate vulnerability of food availability by approximating local food supply. Food availability was estimated by determining local supply through agricultural and industrial activities. For this to happen, relevant criteria were considered for food security assessment, and GIS multi-criteria analysis was employed for producing food security maps. Based on the obtained food security map, very high and highly secure zones include 544 villages (22.15% of rural area), while 1,905 villages (57% of rural area) were classified as being in insecure zones. The results of this research are of great importance to decision makers, and, in particular, to government departments such as the Ministry of Agriculture, the Ministry of Water Resource Management, and the Ministry of Natural Resources for the East Azerbaijan Province of Iran.

1 Introduction

Healthy reproduction, physical growth, cognitive and educational performance, immunity, work capacity, life expectancy, and quality of life are key factors for achieving national human development in each society. These factors are closely related to food and nutrition security. Food security has been considered as a basic human need, and, along with primary health care, as a prerequisite for human development (MCLNTYRE 2003). Food security was defined as a situation where all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life (FAO 2002). In other words, it is considered as a household's availability to healthy food that is consistently accessible to sustain an active and healthy lifestyle (KANE 2014). The three determinants of food security are availability, access, stability, and utilization. Food availability is associated with geographical and agricultural determinants of each area, such as domestic production, import capacity, food stocks, water availability, agriculture land, population density and distribution (CHRISTIANSEN 1995). This security is threatened on a community and global level by three important

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factors: (1) access and availability of food in local environments, (2) effects of the changing climate on agriculture and natural resources, and (3) active participation in planning, developing and managing effective strategies to optimize and sustain food production with the available existing land (KANE 2014). In many countries food security has been measured and evaluated with various techniques and methods (MOHAMMADZADEH 2010). GIS and related spatial analytical techniques is one of these methods that provide a set of tools for evaluating and understanding food security. Several strategies have been developed using GIS and remote sensing techniques, which contribute knowledge and understanding to food security. These strategies include techniques, which examine local food environments, assess changes in land use and land cover, and identify areas of importance in specific regions to determine the relationships between biophysical and socioeconomic attributes. GIS plays a significant role in securing the future of our food production and our population. The importance of food security is directly linked to increases in population density, limitations on agriculture yields, and the spread of food deserts (KANE 2014). In rural areas of the world, such as East Azerbaijan Province (EAP), and other developing countries, there is limited accessibility to outside food sources. These regions depend highly on their own agriculture production to sustain their populations. With increasing populations, urbanization leads to agriculture land fragmentation and weakening productivity of agriculture lands. When food security is minimal, residents migrate to more secure regions. To optimize food production and create a sustainable region that has so much possibility for productivity, it is vital that proper planning, development, and management strategies be put into place for small farm holders in these rural regions to support their own populations (KANE 2014). Within this research we aim to model the situation of food security in East Azerbaijan Province, which is an important area in terms of agricultural activities and housing in the Northwest of Iran.

2 Study Area and Dataset

The East Azerbaijan Province (EAP) is located in the Northwest of IraT .nhis area, with 57 cities and 3,094 villages, totalling in 3.7 million inhabitants, is important in terms of housing, industrial, and agricultural activities for Iran. The rural area, with a population of about 1,144,813, covers 31% of the EAP. Agricultural activities are considered as a main income of the rural area, which is greatly affected by the topographical and climatological situation. Within the EAP, the elevation increases from 1,260 meters at Urmia Lake to 3,710 meters above sea level in the Sahand Mountains. The climate of this area is semi-arid, and the annual precipitation amounts to approximately 300 mm. Generally speaking, the EAP enjoys a cool, dry, climate, being in the main a mountainous region. But the gentle breezes off the Caspian Sea have some influence on the climate of the low-lying areas. The area's geology is responsible for volcanic hazards, earthquakes and landslides. This setting makes the slopes of the area potentially susceptible to natural hazards (FEIZIZADEH & BLASCHKE 2011, 2012).

3 Methods

3.1 Selection of Evaluation Criteria

Evaluation criteria objectives and attributes need to be identified with respect to the particular situation under consideration. The set of criteria selected should adequately represent the decision-making environment, and contribute towards the final goal (FEIZIZADEH & BLASCHKE 2014). There are no universal guidelines for selecting parameters for Food Security Assessment (FSA). In addition, each geographical area has its specific condition which needs to be taken into account. In this study, topography, as well as agricultural and economical properties of the rural areas, climate, vegetation and anthropogenic factors were selected based on the expert knowledge, on the basis of field studies related to the food availability. In doing so, we employed 21 factors as effective criteria for food security assessment in the rural area of EAP (see Table 1).

The first step in our study was to establish a spatial database for the spatially explicit analysis of the FSA. Accordingly, data processing was performed to create each criterion as the indented GIS layer. For this to happen, agricultural crop areas were derived from the agricultural database of the EAP, prepared by the Ministry of Agricultural and Natural Resource (MANR). This database was also used as the basis of our food availability indices. Road networks and ground water maps were extracted from topographical maps of the area in a scale of 1:25,000. Pasture lands were extracted from satellite images of the study area, and data on drinkable water was obtained from a database of the Ministry of Water Resources (MWR). Meteorological data, including precipitation data for a 30-year period, were used to create a precipitation map. In the preparation phase, all necessary geometric thematic editing was done on the original datasets, and a topology was created. In the next step, all vector layers were converted into raster format with 20 m resolution, and the spatial datasets were processed in ArcGIS. In doing so, all criteria were standardized. It has to be mentioned that “Standardization is a process that transforms and rescales the original criteria into comparable units” (GORSEVSKI et al. 2012, p 288). This technique is an extension of the classic binary logic, which enables the definition of sets without sharp boundaries, and allows elements to be partially assigned to a particular set. A fuzzy set is essentially a set whose members have degrees of membership ranging between 0 and 1, as opposed to a classic binary set in which each element must have a membership degree of either 0 or 1 (MALCZEWSKI 2004, FEIZIZADEH et al. 2013). In this particular FSA for the rural area, the criteria used relate to topography, climate, agricultural factors, vegetation, and anthropogenic factors, all of which were represented by separate data layers with memberships of different potential classes, were subsequently standardized using the maximum eigenvectors approach on a 0 to 1 scale.

3.2 Assisting Criteria Weights

In order to obtain the importance of each criterion for the model of aggregation, we employed the Analytic Hierarchy Process (AHP) to extract standard weights. The AHP method is typically used for rating and standardizing ordinal values (MALCZEWSKI 2004). The AHP method (SAATY 1977) is a well-known means of the multi-criteria technique, which has been incorporated into GIS-based multi-criteria analysis (MARINONI 2004, JANKOWSKI and RICHARD 1994). Quantitative and qualitative information about decision making problems can be organized using the AHP method (MALCZEWSKI 1999). The AHP method reduces the complexity of a decision problem to a sequence of pairwise comparisons, which are synthesized in a ratio matrix that provides a clear rationale for ordering the decision alternatives from the most to the least desirable. Specifically, the process builds a hierarchy of decision criteria. Through the pairwise comparison of each possible criterion pair, a relative weight for each decision criterion within the hierarchy is produced. The development of the AHP pairwise comparison is based on the rating of relative preferences for two criteria at a time. Each comparison is a two-part question, determining which criterion is more important and to what extent, using a scale with values from the set: {1/9, 1/8, 1/7, 1/6, 1/5, 1/4, 1/3, 1/2, 1, 2, 3, 4, 5, 6, 7, 8, 9}. The values range from 1/9, representing the least important (than), to 1 for equal importance, and to 9 for the most important (than), covering all the values in the set.

In this study we utilized the AHP's ability to incorporate different types of input data, and the pairwise comparison method for comparing two parameters at the same time. However, both the comparison of the parameters relative to each other and the determination of the decision alternatives, namely the effect values of the sub-criteria of the parameters (see Table 1); (weight), were based on the comparison of FSA factors. Respectively to the implementation of the pairwise comparison matrix, experts' opinions were asked to calculate the relative importance of the factors and criteria involved. Consequently, the weight values were determined accurately for the datasets used.

In the next step, the Consistency Ratio (CR) (SAATY 1977) was calculated. One of the strengths of the AHP method is that it allows for inconsistent relationships, while at the same time, providing a CR as an indicator of the degree of consistency or inconsistency. Therefore, we implemented the AHP method with the option to let the user define an acceptable CR threshold value in this study. If the CR > 0.10, it is important to be careful in accepting the resulting weights without changing the inputs of the pairwise comparison matrix, and also to ensure that the matrix really reflects the user's beliefs and does not contain errors (BODIN & GASS 2003, FEIZIZADEH & BLASCHKE 2012, 2013). In our study the resulting CR for the pairwise comparison matrix for nine dataset layers was 0.033, indicating that the comparisons of characteristics were perfectly consistent, and that the relative weights were appropriate to FSA model.

Table 1: Evaluation criteria of FSA and AHP weights

Main criteria	Sub Criteria	Weights
Cereal	Wheat	8
	Barley	5
Legum	Beans	3
	Pea	2
	Corn	5
Fruits Nuts	Apple	2
	Grape	2
	Apricot	1
	Onion	2
	Walnut	2
	Almond	1
Oilseeds	Canola	3
	Sunflower	7
Agricultural	Crop area	8
	Pasture lands	5
Sugar	Sugar	2
Meat	Meat	8
Water	Precipitation	5
	Groundwater	12
Road network	Road type	5
Population	Population density	12
Sum		100

3.3 Producing FSA Map Based on Ordered Weighted Averaging

The Ordered Weighted Averaging (OWA) method was employed to develop the FSA map. The OWA operators were introduced by Yager in 1988. OWA is a class of multicriteria operators, which was given quantifier-guided aggregation in 1996 (YAGER 1988). OWA is a method involving two sets of weights, including criterion importance weights and order weights (MALCZEWSKI 2006, FEIZIZADEH & BLASCHKE 2012, FEIZIZADEH et al. 2013). An importance weight is assigned to a given criterion (attribute) for all locations in a study area to indicate its relative importance (according to the decision-maker's preferences) in the set of criteria. The order weights are associated with the criterion values on a location-by-location (object-by-object) basis. They are assigned to a location's attribute values in decreasing order without considering which attribute the value comes from. The order weights are central to the OWA combination procedures. YAGER (1988) proposed OWA as a parameterized family of combination operators. For a given set of n criterion, an OWA operator can be defined as the following function $\mathrm{OWA}: \mathrm{I}^{\mathrm{n}} \rightarrow \mathrm{I}$, where I= [0, 1] that is associated with a set of order weights V= $[v_{1,} v_{2\,,} \dots , v_n]$ so that $v_j \in [0,1]$ for j=1, 2,…, n and $\sum_{j=1}^{n} = 1v^j = 1$ given a set of standardized criterion value $A_i = [a_{i1}, a_{i2}, \dots, a_{in}]$ for i=1,2,…m, where $a_{ij} \in [0,1]$ is associated with the location (e.g., cell, polygon, line, point), the OWA operator is defined as follows (BOROUSHAKI & MALCZEWSKI 2010):

$$\mathrm{OWA_i} = [a_{i1}, a_{i2}, \ldots, a_{in}] = \sum_{j=1}^{n} v_j \, z_{ij} \tag{1}$$

Where $za_{i1} \geq z_{i2} \geq \cdots \geq z_{in}$ is the sequence obtained by reordering the criterion values $a_{i1}, a_{i2}, \ldots, a_{in}$. With different sets of order weights V, one can generate a wide range of OWA operators including the three cases used in this article: WLC, Boolean overlay combination ("AND") and ("OR") by changing the set of order weights V (YAGER 1988, BOROUSHAKI & MALCZEWSKI 2010).

The OWA combination operator in Eq. (1) ignores the fact that most of the GIS-based decision-making problems require a set of different weights to be assigned to criterion map layers. In order to extend the conventional OWA approach, it is necessary to fuse the 'criterion weights' (importances), W, into the OWA procedure. YAGER (1997) proposed a criterion weight modification approach for the inclusion of criterion weights into the OWA operator as follows (BOROUSHAKI & MALCZEWSKI 2010):

$$V_j = Q\left(\frac{\sum_{I=1}^{i} u_I}{\sum_{I=1}^{n} u_I}\right) - Q\left(\frac{\sum_{I=1}^{j-1} u_I}{\sum_{I=1}^{n} u_I}\right) \tag{2}$$

Where u_j is the reordered jth criterion weight, w_j, according to the reordered z_{ij}. Considering $Q(p) = p^x$ for x > 0, E_q. (2) can be simplified to:

$$V_j = \left(\frac{\sum_{I=1}^{i} u_I}{\sum_{I=1}^{n} u_I}\right)^x - \left(\frac{\sum_{I=1}^{j-1} u_I}{\sum_{I=1}^{n} u_I}\right)^x \tag{3}$$

Accordingly, given the sets of criterion weights, W, and order weights, V, the OWA operator can be defined as:

$$\mathrm{OWA_i} \sum_{j=1}^{n} = \left(\left(\frac{\sum_{I=1}^{i} u_I}{\sum_{I=1}^{n} u_I}\right)^x - \left(\frac{\sum_{I=1}^{j-1} u_I}{\sum_{I=1}^{n} u_I}\right)^x\right) z_{ij} \tag{4}$$

OWA provides a tool for generating a wide range of decision strategies in a decision strategy space, by applying a set of order weights to criteria that are ranked in ascending order on a pixel-by-pixel basis. The number of order weights is equal to the number of criteria and must sum to one. The position of a set of order weights can be identified in a decision strategy space, based on the concepts of trade-off and risk (YAGER 1988, JIANG & EASTMAN 2000). Trade-off indicates the degree to which a low standardized value on one layer can be compensated for by a high standardized value on other considered criteria. Risk refers to how much each criterion affects the final solution (JIANG & EASTMAN 2000, MALCZEWSKI 2006, ROBINSON et al. 2010, FEIZIZADEH & BLASCHKE 2013, FEIZIZADEH et al. 2012, 2013, 2014).

4 Results

The FSA map was produced based on GIS-OWA technique (see Figure 1). Based on the FSA map, very high and highly secure zones include 544 villages with a population of about 253589 (22.15% of the rural population). According to the results, 1,905 villages with a population of about 528,496 (57% of the rural population) were classified to be in insecure zones. While only 628 villages with a population of about 239,055 (21.85% of the rural population) were assigned within the moderately secure zones.

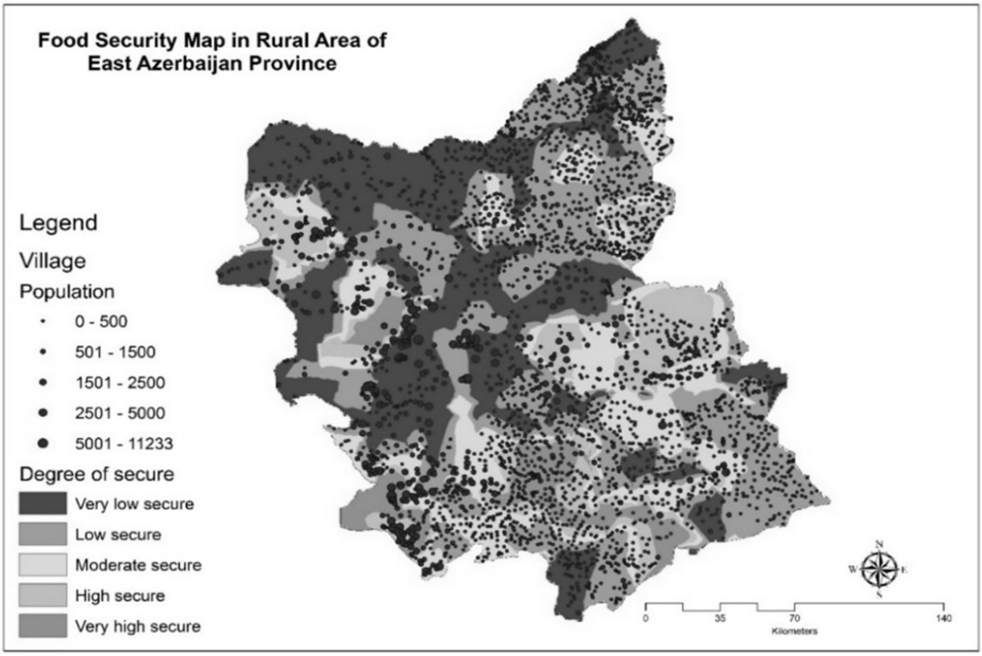

Fig. 1: FSA map of the rural areas in the East Azerbaijan Province

Table 2: FSA situation in rural areas of the East Azerbaijan Province

Food secure category	Observed village	Population
Very high secure	177	67264
High secure	367	186325
Moderate secure	628	239055
Low secure	1204	362728
Very low secure	701	289441
Sum	3082	1144813

5 Conclusion and Outlook

This research began with the assumption that GIS spatial analysis provides a powerful methodology for FSA. The results demonstrated that GIS indeed provides essential techniques that can be used to better understand the changing relationships between food availability, the accessibility of landmass, and the effects of climate change on agriculture production. We have described a method to assess the risk and likelihood of food insecurity based on an assessment of food vulnerability. The FSA model was based on a geospatial analysis of factors ranging from topography, land use, climate, and agricultural activates. The study resulted in the ability to illustrate regions at risk within the EAP. The results indicate a significant promise for extending the GIS spatial analysis. Based on the achieved results, future work will benefit from fuzzy logic for the integration of AHP when applying sensitivity and uncertainty analyses. By better understanding the results of the FSA, proper planning can be applied to prevent disasters related to food insecurity, and we can strengthen sustainable practices, thus securing food supply for future generations. This information is of great importance to decision makers, and, in particular, to government departments such as the Ministry of Agriculture, the Ministry of Water Resource Management, and the Ministry of Natural Resources for the East Azerbaijan Province of Iran.

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