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A framework for a regional integrated food security early warning system: a case study of the Dongting Lake area in China

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Abstract Understanding the regional food security situation is of great importance to maintaining China's food security. To provide targeted information to help regional policymakers monitor food security status, based on the differentiated foci during the phased development of food security, this paper was conceived from the perspective of the need for early warnings and proposes a framework for regional integrated food security that incorporates food quantity security, food quality security, and sustainable food security. In this framework, an indicator system is proposed, and the calculation of these indicators, as well as their warning thresholds and warning ranges, is discussed. To test this approach, a case study was conducted in one of China's major grain-producing areas, the Dongting Lake area. The results showed that the overall integrated food security situation in this area was generally in the low-alarm range between 1986 and 2011; the primary causes of this status were food quality security, generally in the low- or medium-alarm range, and sustainable food security, which in 14 of the 26 years was in the low-alarm range. The government should establish a more robust system for monitoring the quality of agricultural products, controlling waste discharge, and guaranteeing poor individuals access to sufficient, safe, and nutritious food to meet their dietary needs. Policies on pesticide and fertilizer application should shift from actively encouraging more use to controlling excess application.

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Introduction

The widely accepted concept of food security has been defined by the FAO as follows: ''Food security exists when all people, at all times, have access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life'' (FAO 2003). As the most populous country where the per capita presence of most natural resources is far below the world average, China never fails to attract attention from researchers and policymakers with regard to its food security.

In recent decades, most studies on China's food security have focused on food quantity and have aimed at helping the government achieve a national food self-sufficiency rate of 95 % and 400 kg/capita/year of annual available grain per capita (Felloni et al. 2003; Ma and Wang 2010); food quality and environmental issues arising in the process have been neglected (Qi et al. 2013). While in recent years, China's food self-sufficiency and annual available grain per capita have reached the above goals (NBSC 2014), this progress has accelerated the processes of resource degradation and environmental pollution, as well as the deterioration of food quality and safety, forcing policymakers and researchers to begin thinking about the quantity of food. Most relevant studies, however, have analyzed food security from the three aspects of food availability, access, and utilization (Gregory et al. 2005; Ericksen 2008; Barrett 2010; Ingram 2011), tending to include these scale-differentiated issues in studies with national/individual food insecurity as their major concern. The lack of comprehensive studies of fixed scales based on socioeconomic status, resources, and environmental conditions and carried out from the perspective of decision making made it difficult for regional policymakers to adopt and act upon important findings. Therefore, to construct a decision-oriented framework according to the social characteristics and development phases of food security, China's food security should be considered in an integrated manner: From the perspective of food quantity, governments must ensure the overall balance and stability of food supply and demand (Feng 2007; Felloni et al. 2003); from the aspect of food quality, food should be harmless and nutritionally balanced (Ensminger and Ensminger 1993; Zhong et al. 2010); and as for food sustainability, governments should ensure short-term capacity to produce the required amount of food, and food should not be obtained at the expense of the sustainability of the socio-ecological system in the long run (Azar et al. 1996; Qi et al. 2013). Many domestic researchers have asserted that China should revise its national food security strategy to promote the new concept of "integrated food security" with grain production as its central concern (Ding 2006; Xu et al. 2006). However, these ideas have remained in the conceptual or theoretical stage with no practicable method to analyze them, and a complete analytical framework of integrated food security is urgently needed.

To date, comprehensive studies on food security have typically been conducted at the national or global level. Although several studies were valuable and insightful (Carvalho 2006; Godfray et al. 2010; Foley et al. 2011; Krishnamurthy et al. 2014), their results were not made available to regional policymakers due to their coarse spatial resolution; the strategies used to manage and adapt to food security risks are highly contextual, and analyses at the national and global levels may hide regional trends. The most relevant studies conducted at the regional level generally focused on one or two issues that may cause food insecurity, such as natural disasters (Tadesse et al. 2008; Tirivarombo and Hughes 2011; Ashraf et al. 2013), adaptation capability (Groenewald and Bulte 2013; Chen et al. 2014), food requirements (Desjardins et al. 2010), food claims (Louden and MacRae 2010), food flows (Giombolini et al. 2010; Zhou et al. 2012), food sovereignty (Rocha and Liberato 2013; Quave and Pieroni 2014), food availability (Kiriti and Tisdell 2004; Acheampong et al. 2011; Li and Shangguan 2012), food supply chains (Ilbery and Maye 2005), and economic recession (Carney 2012). Because these studies tended to concentrate on a certain aspect, their results did not provide comprehensive and sufficient information to regional policymakers.

From the perspective of risk management, food security must be monitored at various levels of aggregation, such as household, local, regional, and national. The main objective of an early warning system is to monitor food security and nutritional status to inform policymakers of impending food shortages (Zhong et al. 2010). National early warning systems are generally implemented by governments with the help of external donors and implementing agencies, such as FAO, and focus on monitoring food availability and the food needs of vulnerable populations to prevent famine-related disasters (FAO 2000; Suresh and Ergeneman 2005). Although constructing such a system would be a useful tool for policymakers to monitor food security status, few studies on food security have been conducted from the perspective of early warning, and none to date has considered food security in an integrated manner (Genesio et al. 2011; Brickley 2012; Husak et al. 2013).

As noted above, there has long been a gap between scientific research and the concrete pursuit of integrated food security on a regional scale. Because food production is dominated by the major grain-producing areas in China, integrated food security conditions are of particular concern for these regions (Liu et al. 2010; Qi et al. 2013). Therefore, this paper is driven by the view that there is practical value in studying a food security early warning system in terms of integrated food security, focusing on the major grain-producing areas, at the regional level.

To provide targeted information for regional policymakers to monitor food security status, this paper aims to establish an early warning system that can be used to evaluate integrated food security status based on regional socioeconomic status, resources, and environmental conditions. The first step is to propose a system of indicators to identify the causes of food quantity insecurity, food quality insecurity, and sustainable food insecurity. Next, the calculation of these indicators, as well as their warning thresholds and warning ranges, will be elaborated. The approach is tested through a case study conducted in the Dongting Lake area, China.

Methods and procedures

Study area and data sources

This research has examined the Dongting Lake area (110°29′–114°15′E, 26°03′–30°08′N). This region is located in northern Hunan Province and has long been a major grain-producing area in China (Fig. 1). The raw data were taken from the 1987 to 2012 editions of the *Hunan statistical yearbook* and the *Hunan rural statistical yearbook*.

Framework of the indicator system

Early warning is a process of verifying alarms, detecting alarm sources, analyzing alarms, predicting the degrees of alarms, and removing alarms (Zhao et al. 2006). Each

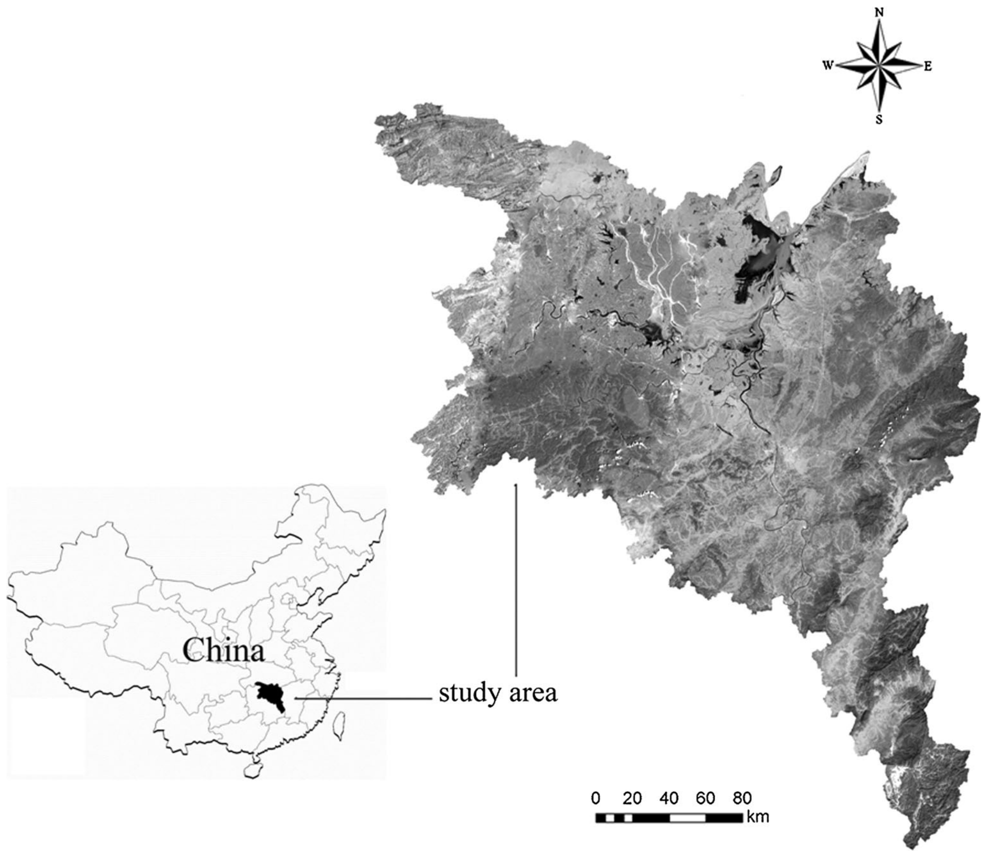

Fig. 1 Location of the Dongting Lake area

alarm has its source, which before being triggered, and without exception, produces a warning. Detecting the source is the foundation of early warning analysis as well as the premise of alarm removal. Because this paper aims to provide intuitive information on the current situation and the upcoming crisis of food insecurity for policymakers, with a focus on the socioeconomic and socio-ecological aspects that are easily affected by human behavior, we tended to choose the intuitive indicators that could better reflect the short-term food security situation. The construction process of the early warning indicator system is as follows:

As stated in the introduction, the early warning indicators of regional integrated food security can be divided into three main types: food quantity security indices, food quality security indices, and sustainable food security indices. Regarding food quantity security, the Chinese government mandated provincial leaders to take responsibility for maintaining an overall balance of food supply and demand within their provinces as early as 1995 (OECD 1999); thus, the balance and stability of regional food supply and demand are issues of greatest concern. Data on undernourishment, an indicator of hunger and food insecurity, are collected at global and national levels but provide little useful information to regional policymakers. While there are no statistics on the prevalence of undernourishment in the Dongting Lake area, food price volatility, diet quantity, nutritional balance, and income in poor areas—which are included in the food quantity security indices, food quality security indices, and sustainable food security indices in this paper, respectively (Fig. 2)—provide more comprehensive and detailed information (Krishnamurthy et al. 2014).

Frequent food hazards and accelerating changes in dietary structure make food safety and nutritional security the issues of greatest domestic concern in terms of food quality security (Bai et al. 2007; Ortega et al. 2011). For the Chinese-style dietary structure, nutritional security can be broadly measured by three aspects: high-quality protein, fat, and calories (CNS 2008). Although numerous indicators can be used to monitor food safety (e.g., additive residues, toxin residues, child stunting), few data were available in this area; as a result, only three indicators were developed for this framework (Fig. 2).

For sustainable food security, there are a wide variety of evaluation indicators. As discussed in the introduction, this paper primarily focused on the short-term sustainability of food production while taking into account the sustainability of the socio-ecological system in the long run. Although the interactions and trade-offs between agricultural production and environmental security are complex (Foley et al. 2011), long-term environmental sustainability has

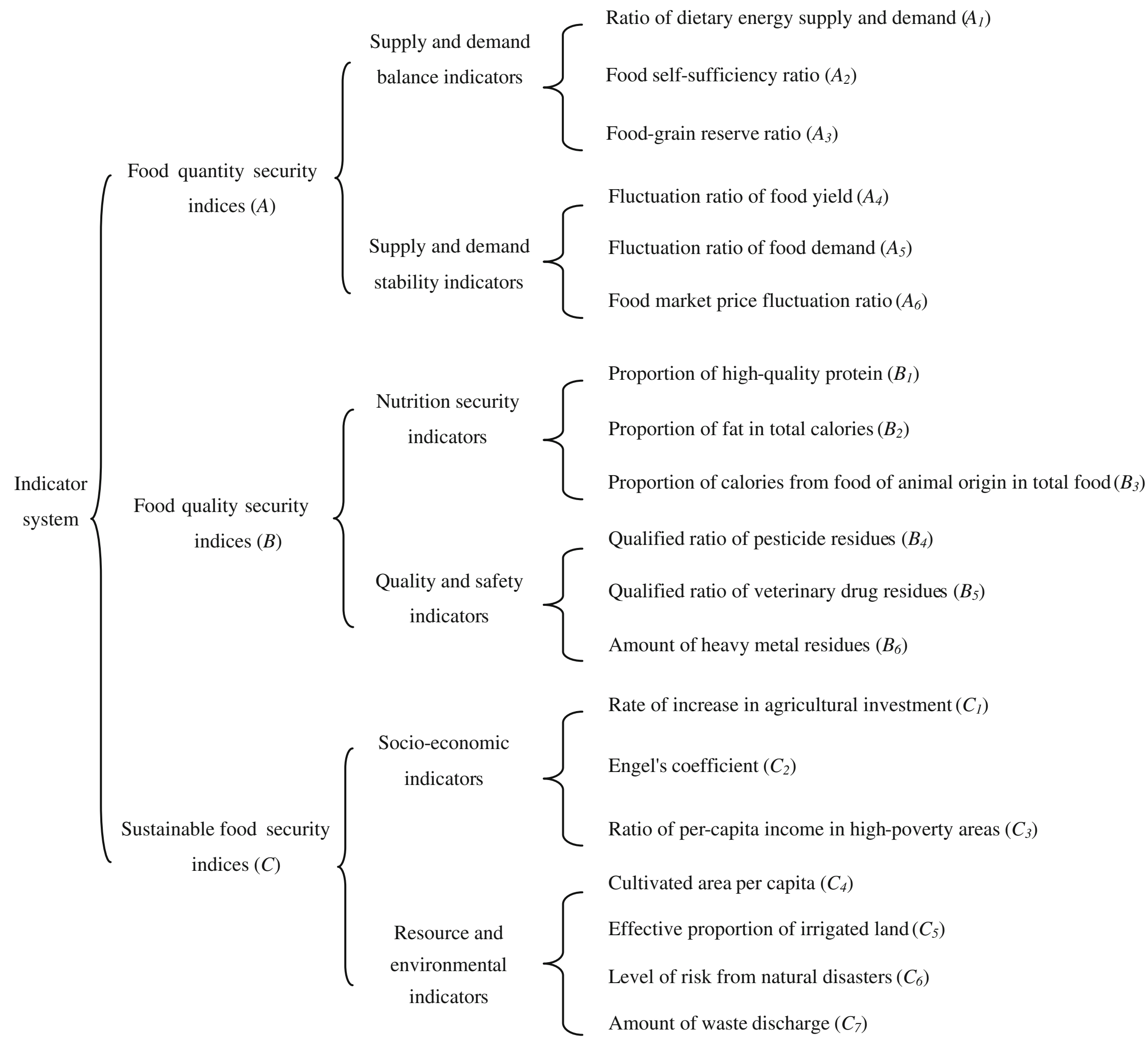

Fig. 2 Early warning indicator system for regional integrated food security risk

been ignored when the two conflict because China is a populous developing country where ensuring continued growth of food production is the most critical priority. For example, while increases in the cultivated area per capita has both positive and negative influences on sustainable food security (the positive being that more cultivated land allows for more food production, while the negative is increased ecological degradation, which may harm future production), only the positive influence was considered in this paper (as with irrigation and agricultural investment). Additionally, the composite indicators (those that are not intuitive, such as ecosystem services value, ecological footprint, and water footprint), the strict ecological indicators (those whose impacts are more significant in the long-term, such as biodiversity, ecological degradation, and ecological functioning), and the highly elusive indicators (those that are difficult to quantify and compare, such as education level and road density) were excluded from the sustainable food security indices.

Based on the above discussion and the available data, 19 indicators were singled out, and a framework for an early warning system for regional integrated food security was constructed as shown in Fig. 2.

Meaning of each indicator and its calculation

Food quantity security indices

Food quantity security can be reflected through balance indicators and stability indicators, with the balance between food supply and demand as the basic goal and the stability of food supply and demand as the key indicators.

Ratio of dietary energy supply and demand This indicator reflects the ratio of regional food energy supply to demand and can be calculated as follows:

$$\Delta D = \frac{DES - DED}{DED} \times 100\,\% \quad (1)$$

where DES is the dietary energy supply per capita, DED is the dietary energy demand per capita, and ΔD is the ratio of dietary energy surplus or deficiency to demand.

Food self-sufficiency ratio This indicator reflects the capability of the regional food supply to meet demand:

$$Z = \frac{S}{D} \times 100\,\% \tag{2}$$

where Z is the food self-sufficiency ratio, S is the total food yield, and D is the total food demand.

Food-grain reserve ratio This indicator reflects the ability to counteract the risk of imbalance between supply and demand:

$$K = \frac{R}{D} \times 100\,\% \tag{3}$$

where K is the food-grain reserve ratio, R is the food-grain reserves for a given year, and D is the grain consumption for that year.

Fluctuation ratio of food yield This indicator reflects the stability of the regional food supply:

$$V_y = \frac{Y_t - Y_{t-1}}{Y_{t-1}} \times 100\,\% \tag{4}$$

where V_y is the fluctuation ratio of food yield, Y_t is the food yield for a given year, and Y_{t-1} is the food yield for the previous year.

Fluctuation ratio of food demand This indicator reflects the stability of regional food demand:

$$V_d = \frac{D_t - D_{t-1}}{D_{t-1}} \times 100\,\% \tag{5}$$

where V_d is the fluctuation ratio of food demand, D_t is the food demand for a given year, and D_{t-1} is the food demand for the previous year.

Food market price fluctuation ratio This indicator reflects the stability of the regional food market:

$$V_P = \frac{P_t - P_{t-1}}{P_{t-1}} \times 100\,\% \tag{6}$$

where V_p is the food price fluctuation ratio, P_t is the food price for a given year, and P_{t-1} is the food price for the previous year.

Food quality security indices

Food quality security includes food nutrition security, food quality and food safety. Food nutrition security indicators reflect the degree of nutritional imbalance; food quality and safety indicators reflect the effects of harmful substances in food on human health.

Proportion of high-quality protein High-quality protein refers to the protein contained in beans and food of animal origin. The proportion of high-quality protein gives an accurate reflection of the nutritional balance status of the diet:

$$P_h = \frac{H_h}{T_p} \times 100\,\% \tag{7}$$

where P_h is the proportion of high-quality protein, H_h is the content of high-quality protein, and T_p is the total protein content.

Proportion of fat in total calories Fat is a major source of essential energy for the human body. An excessively low or high proportion of fat consumption is harmful to human health. Therefore, the proportion of fat in total calories is considered an important indicator of food nutrition security:

$$P_f = \frac{F_f}{T_c} \times 100\,\% \tag{8}$$

where P_f is the proportion of fat in total calories, F_f is the caloric content of fat, and T_c is the total calorie content of food.

Proportion of calories from food of animal origin in total food Food of animal origin is rich in protein, fat, inorganic salts, and vitamins, although excessive intake may increase the risk of cardiovascular disease. Its proportion can reflect the quality of the diet:

$$P_a = \frac{C_a}{T_c} \times 100\,\% \tag{9}$$

where P_a is the proportion of calories from food of animal origin in total food, C_a is the calorie content of food of animal origin, and T_c is the calorie content of total food.

Qualified ratio of pesticide residues Pesticides are widely used in China; they effectively protect grains from pests and insects and raise yields. However, some pesticide residues found in food do great harm to human health. Therefore, the qualified ratio of pesticide residues is considered a key indicator of food quality and safety. (This indicator can be directly determined according to the sampling data collected by the Agricultural Product Quality Monitoring Center of Hunan Province).

Qualified ratio of veterinary drug residues As for food of animal origin, direct pollution sources are veterinary drugs and feed additives. Residues of veterinary drugs in food pose a direct hazard to human health. The qualified ratio of veterinary drug residues is an important indicator of the quality and safety of food of animal origin (This indicator can be directly determined according to the sampling data collected by the Agricultural Product Quality Monitoring Center of Hunan Province).

Amount of heavy metal residues Environmental problems in China are increasingly serious. Pollution comes mainly from agricultural chemicals, solid waste, and sewage irrigation, resulting in greater or lesser amounts of residues, among which heavy metal residues in food are extremely dangerous. Therefore, the amount of heavy metal residues is regarded as an important indicator of food quality and safety (This indicator can be directly determined according to the sampling data collected by the Agricultural Product Quality Monitoring Center of Hunan Province).

Sustainable food security indices

Sustainable food security includes socioeconomic sustainability and the sustainability of resources and the environment; its evaluation indicators are described below.

Rate of increase in agricultural investment Sustained agricultural investment is critical to the development of agricultural production. In a developing country such as China, a sustainable food supply cannot be achieved without agricultural modernization and mechanization, which depend on an increase in agricultural investment:

$$R_i = \frac{I_t - I_{t-1}}{I_{t-I}} \times 100\,\% \quad (10)$$

where R_i is the rate of increase in agricultural investment, I_t is the total agricultural investment in a given year, and I_{t-1} is the total agricultural investment in the previous year.

Engel's coefficient This indicator refers to food expenditure as a proportion of total household spending and is widely used to measure people's living standards:

$$E = \frac{F}{T} \times 100\,\% \quad (11)$$

where E is Engel's coefficient, F is food expenditure per capita, and T is total expenditure per capita.

Ratio of per-capita income in high-poverty areas This indicator refers to the per-capita income in high-poverty areas as a proportion of regional per-capita income. It reflects the food-purchasing power of poor people:

$$R_p = \frac{I_p}{I_t} \times 100\,\% \quad (12)$$

where R_p is the ratio of per-capita income in high-poverty areas, I_p is the per-capita income in high-poverty areas, and I_t is the regional per-capita income.

Cultivated area per capita As the world's most populous country, China has per-capita natural resources substantially below the world average. A certain amount of cultivated land must be maintained to achieve sustainable food security when China reaches its peak population. (The indicator value was taken directly from the *Hunan statistical yearbook*).

Effective proportion of irrigated land Per-capita water resources in China are less than one-quarter of the world average, and their spatial and temporal distributions are uneven. The effective proportion of irrigated land has become a major factor in regional grain-production capacity:

$$P_e = \frac{E_i}{T_c} \times 100\,\% \quad (13)$$

where P_e is the effective proportion of irrigated land, E_i is the effective irrigated area, and T_c is the total cultivated area.

Level of risk from natural disasters The average annual grain losses caused by natural disasters represent more than 7 % of total grain production in China (NBSC 2014). Therefore, the level of risk from natural disasters must be treated as an important environmental indicator of sustainable food security:

$$P_n = \frac{N_s}{T_s} \times 100\,\% \quad (14)$$

where P_n is the level of risk from natural disasters, N_s is the area at risk from natural disasters [i.e., where yields are reduced more than 10 % due to natural disasters (Simelton 2011)], and T_s is the total cultivated area.

Amount of waste discharge Waste discharge is the major source of environmental pollution in China. It poses risks not only to sustainable food quantity security but also to sustainable food quality security:

$$P_w = P_t - P_c \quad (15)$$

where P_w is the amount of waste discharge, P_t is the total amount of waste, and P_c is the amount of controlled waste.

Calculation of normalized values and weights

Because the dimensions of these evaluation indicators vary, all of the indicators must be transformed into dimensionless values. The normalization equation is:

$$z_i = \frac{x_i - x_{i(min)}}{x_{i(max)} - x_{i(min)}}, \quad i = 1, 2, \ldots, n. \quad (16)$$

where x_i is the real value of the ith indicator, $x_{i(min)}$ is the smallest real value of the ith indicator, $x_{i(max)}$ is the greatest real value of the ith indicator, and z_i is the normalized value of the ith indicator. In this paper, the integrated food security risk indicators can be divided into positive indicators and reverse indicators. For a positive indicator, the greater its value, the more security it reflects; its normalized value is z_i. For a reverse indicator, the greater its value, the less security it reflects; its normalized value is $1 - z_i$. After conversion, the normalized values are all between 0 and 1; 1 indicates the highest security, and 0 indicates the lowest security.

After calculating the normalized value of each indicator, weights must be defined. Although a balanced weight approach is the simplest method and has been widely used in relevant studies (Sullivan 2002; Hahn et al. 2009; Krishnamurthy et al. 2014), an approach incorporating expert opinion (i.e., the Delphi method) is preferable for determining the weighting scheme because it can reflect the perceived importance of specific factors (Chang 1996; Eakin and Bojórquez-Tapia 2008; Ma et al. 2011). The calculation process for the latter approach is as follows.

Construction of comparison matrix

To quantify the perceived importance of the 19 indicators (Fig. 2), seven experts were invited to make pairwise comparisons of the food quantity security indices, food quality security indices, and sustainable food security indices based on their expertise (e.g., an expert familiar only with food quality security was asked to compare only the food quality security indices). Using the food quantity security indices as an example, the analysis steps are as follows:

Considering an evaluation value a_{ij} denotes the proportion of indicator A_i and A_j:

$$a_{ij} = A_i / A_j, \quad a_{ij} > 0 \tag{17}$$

where a_{ij} is the ratio of relative importance of A_i and A_j for food quantity security. Assuming A_i is more important than A_j, or at least equally important, i.e., $a_{ij} \geq 1$ (then $a_{ij} = 1/a_{ij} \leq 1$), a five-level comparison measure method can be provided with reference to the relevant studies as shown in Table 1 (Zhang 2008; Gumus 2009).

Calculation of preliminary weights

After a pairwise comparison based on the measures shown in Table 1, an orthogonal matrix can be formed:

$$V = \begin{bmatrix} a_{11} & \cdots & a_{ij} \\ \vdots & \ddots & \vdots \\ a_{ji} & \cdots & a_{nm} \end{bmatrix}, \quad i,j = 1, 2, \ldots, n. \tag{18}$$

where V is a pairwise comparison matrix of the food quantity security indices. Then, the weights of these indicators can be calculated by the following functions:

Table 1 Comparison measures of two specified indicators

Evaluation value	Interpretation
1	A_i and A_j are *equally* important
2	A_i is *slightly* more important than A_j
3	A_i is *obviously* more important than A_j
4	A_i is *strongly* more important than A_j
5	A_i is *extremely* more important than A_j

$$w_i = \frac{1}{n} \sum_{j=1}^{n} \frac{a_{ij}}{\sum_{k=1}^{n} a_{kj}}, \quad i = 1, 2, \ldots, n. \tag{19}$$

where w_i is the weight of the indicator A_i.

Determination of final weights

Logically speaking, if A_i is more important than A_j, and A_j is more important than A_k, A_i should be more important than A_k. However, in a practical comparison, the opposite situation may occur and result in unreasonable results. To ensure that the weights are logical and consistent with each other, the results must be checked. The calculation functions are as follows:

$$AW = \lambda_{max} W \tag{20}$$

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{21}$$

$$CR = CI / RI \tag{22}$$

where $W = (w_1, w_2, \ldots, w_n)^T$ and λ_{max} are the corresponding eigenvector, and the maximal eigenvalue of the matrix V, CI is the consistency index, RI is the random index (it is a constant that can be directly determined by the order of the matrix) (Zhang 2008), and CR is the consistency ratio. If $CR < 0.1$, then the degree of consistency is satisfactory and the preliminary weights can be regarded as the effective weights; otherwise, the pairwise comparison is invalid. After the consistency check, the final weights (i.e., the average effective weights of all of the experts) of these indicators are determined as shown in Table 2.

After the normalized values and weights of each indicator have been calculated, the integrated index value can be calculated as:

$$Z = \frac{\sum_{i=1}^{n} z_i w_i}{\sum_{i=1}^{n} w_i}, \quad i = 1, 2, \ldots, n. \tag{23}$$

where Z is the integrated index value and z_i and w_i are the normalized value and the weight of each indicator.

Identification of warning thresholds and warning ranges

Based on relevant standards, the warning thresholds of the following indicators were established as follows.

Warning threshold for proportion of high-quality protein The Chinese Nutrition Society suggests that the proportion of high-quality protein should optimally be 62.5 % and no lower than 40 % (CNS 2008). Therefore, 40 % has been recognized as the warning threshold for the proportion of high-quality protein.

Warning threshold for food self-sufficiency ratio Many researchers have argued that the Chinese government should maintain at least 95 % food self-sufficiency to

Table 2 Weights of regional integrated food security risk indicators

Indices category	Weights						
Food quantity security indices	A_1: 0.395	A_2: 0.213	A_3: 0.213	A_4: 0.046	A_5: 0.075	A_6: 0.057	
Food quality security indices	B_1: 0.116	B_2: 0.109	B_3: 0.064	B_4: 0.313	B_5: 0.222	B_6: 0.176	
Sustainable food security indices	C_1: 0.130	C_2: 0.044	C_3: 0.109	C_4: 0.273	C_5: 0.243	C_6: 0.101	C_7: 0.100

Data source: Hunan statistical yearbook and *Hunan rural statistical yearbook* 1987–2012 (SBHP 2013; RITHP 2013)

ensure national food security, although the government has considered 90 % food self-sufficiency acceptable (Felloni et al. 2003; NDRC 2008; Qi et al. 2014). However, because Dongting Lake is a major grain-producing area with a food self-sufficiency ratio of approximately 100 % in the past decade (SBHP 2013), a 100 % food self-sufficiency ratio has been considered to be the warning threshold.

Warning threshold for food-grain reserve ratio The food-grain reserve ratio in China was approximately 25 % in the last century but has achieved 30 % in recent years (Zhu 1998; Ding 2008). Taking into account the upcoming population peak (Simelton 2011), 30 % has been recognized as the warning threshold.

Warning thresholds for Engel's coefficient According to the FAO standards, an Engel's coefficient above 59 % represents absolute poverty; 50–59 % barely enough food and clothing; 40–50 % a "moderately well-off" standard of living; 30–40 % a "well-to-do" standard of living; and below 30 % a "wealthy" life (Kai and Qin 2011). China has reached the stage of "moderately well-off", and therefore 40 % was set as the warning threshold.

Warning thresholds for proportion of fat in total calories The World Health Organization recommends that 15–30 % of total calories be derived from fat (WHO 1990). China's nutritionists have also suggested that caloric consumption per capita per day should be limited to between 2,300 and 2,600 kcal, with a fat proportion between 20 and 30 % (Feng 2007). Therefore, 30 and 20 % were considered the upper and lower warning thresholds, respectively.

Warning thresholds for proportion of calories from food of animal origin in total food Countries differ significantly in dietary structure. Consistent with the recommendations of the Chinese Nutrition Society and relevant studies (Zhang 2006; CNS 2008), 20 and 10 % were considered the upper and lower warning thresholds, respectively.

Warning thresholds for qualified ratios of pesticide and veterinary drug residues and amount of heavy metal residues Consistent with the relevant studies and the quality status of agricultural products in China (Li 2003), 50 % was set as the warning threshold for qualified ratios of pesticide and veterinary drug residues. The warning threshold for amount of heavy metal residues was determined by the Agricultural Professional Standard of China (NY861-2004) (MAC 2005).

For the remaining indicators, there are no relevant standards by which to set warning thresholds. Based on relevant studies, the majority principle has been used to calculate their thresholds (Zhao 2007; Zhong et al. 2010). This principle is based on historical annual data, selecting each indicator in two-thirds of the past years—with relatively higher normalized values—as a warning-free period and classifying the indicators in the remaining third of the years into no-alarm, low-alarm, medium-alarm, high-alarm, and huge-alarm categories.

The warning ranges of each evaluation indicator were calculated using the methods described above (Table 3). According to the meaning of the integrated index value (described in "Calculation of normalized values and weights"), the warning ranges of the integrated food security indicators can be equally divided into five parts, as shown in Table 3.

Results and discussion

With reference to the framework for integrated food security early warning described above, the integrated index values and the corresponding warning ranges can be calculated as shown in Table 4, and the trends of these values are indicated in Fig. 3.

The results show that the overall integrated food security situation in the Dongting Lake area was generally in the low-alarm range between 1986 and 2011; the primary causes of this status were food quality insecurity, which was generally in the low- or medium-alarm range, and sustainable food security, which in 14 out of the 26 years was in the low-alarm range.

From the perspective of food quantity security, as a major grain producer, the status of the Dongting Lake area was basically safe and stable between 1986 and 2011. Over the last two decades, the food self-sufficiency and food-grain reserve ratios remained above the security thresholds (i.e., warning-free), and the indicators used to evaluate supply and demand stability (i.e., the fluctuation ratios of food yield, food market price, and food demand) were sometimes in the low- or medium-alarm ranges, which somewhat affected regional food quantity security. However, when viewed holistically, these effects were slight.

Table 3 Warning ranges of each evaluation indicator and the integrated food security index

Evaluation indicators	No-alarm	Low-alarm	Medium-alarm	Heavy-alarm	Huge-alarm
Ratio of dietary energy supply and demand (%)	$91.8 \le X$	$68.9 \le X < 91.8$	$45.9 \le X < 68.9$	$22.9 \le X < 45.9$	$0.0 \le X < 22.9$
Food self-sufficiency ratio (%)	$100.0 \le X$	$95.0 \le X < 100.0$	$90.0 \le X < 95.0$	$85.0 \le X < 90.0$	$X < 85.0$
Food-grain reserve ratio (%)	$30.0 \le X$	$25.0 \le X < 30.0$	$20.0 \le X < 25.0$	$15.0 \le X < 20.0$	$X < 15.0$
Fluctuation ratio of food yield (%)	$-1.3 < X$	$1.9 < X \le 2.8$	$2.8 < X \le 3.7$	$3.7 < X \le 4.6$	$4.6 < X$
	$X \le 1.9$	$-2.6 < X \le -1.3$	$-3.9 < X \le -2.6$	$-5.3 < X \le -3.9$	$X \le -5.3$
Fluctuation ratio of food demand (%)	$-2.4 \le X$	$1.9 \le X < 2.9$	$2.9 \le X < 3.9$	$3.9 \le X < 4.8$	$4.8 \le X$
	$X \le 1.9$	$-3.2 \le X < -2.4$	$-4.0 \le X < -3.2$	$-4.8 \le X < -4.0$	$X < -4.8$
Food market price fluctuation ratio (%)	$-14.5 \le X$	$14.5 \le X < 23.5$	$23.5 \le X < 32.4$	$32.4 \le X < 41.3$	$41.3 \le X$
	$X \le 14.5$	$-23.5 \le X < -14.5$	$-32.4 \le X < -23.5$	$-41.3 \le X < -32.4$	$X < -41.3$
Proportion of high-quality protein (%)	$40.0 \le X$	$30.0 \le X < 40.0$	$20.0 \le X < 30.0$	$10.0 \le X < 20.0$	$X < 10.0$
Proportion of fat in total calories (%)	$20.0 \le X < 30.0$	$15.0 \le X < 20.0$	$10.0 \le X < 15.0$	$5.0 \le X < 10.0$	$X < 5.0$
		$30.0 \le X < 35.0$	$35.0 \le X < 40.0$	$40.0 \le X < 45.0$	$45.0 \le X$
Proportion of calories from food of animal origin in total food (%)	$10.0 \le X < 20.0$	$20.0 \le X < 25.0$	$25.0 \le X < 35.0$	$35.0 \le X < 50.0$	$50.0 \le X$
		$7.5 \le X < 10.0$	$5.0 \le X < 7.5$	$2.5 \le X < 5.0$	$X < 2.5$
Qualified ratio of pesticide residues (%)	$95.0 \le X$	$85.0 \le X < 95.0$	$70.0 \le X < 85.0$	$50.0 \le X < 70.0$	$X < 50.0$
Qualified ratio of veterinary drug residues (%)	$95.0 \le X$	$85.0 \le X < 95.0$	$70.0 \le X < 85.0$	$50.0 \le X < 70.0$	$X < 50.0$
Rate of increase in agricultural investment (%)	$11.9 \le X$	$7.2 \le X < 11.9$	$2.5 \le X < 7.2$	$-2.1 \le X < 2.5$	$X < -2.1$
Engel's coefficient (%)	$X \le 40.0$	$40.0 \le X < 50.0$	$50.0 \le X < 59.0$	$59.0 \le X < 70.0$	$70.0 \le X$
Ratio of per-capita income in high-poverty areas (%)	$30.8 \le X$	$29.8 \le X < 30.8$	$28.8 \le X < 29.8$	$27.8 \le X < 28.8$	$X < 27.8$
Cultivated area per capita (hm^2)	$0.053 \le X$	$0.052 \le X < 0.053$	$0.051 \le X < 0.052$	$0.050 \le X < 0.051$	$X < 0.050$
Effective proportion of irrigated land (%)	$86.8 \le X$	$86.1 \le X < 86.8$	$85.5 \le X < 86.1$	$84.8 \le X < 85.5$	$X < 84.8$
Level of risk from natural disasters (%)	$X \le 32.8$	$32.8 < X \le 41.8$	$41.8 < X \le 51$ %	51 % $< X \le 60.1$	$60.1 < X$
Amount of waste discharge (t)	$X \le 1.6 \times 10^4$	$1.6 \times 10^4 < X \le 1.8 \times 10^4$	$1.8 \times 10^4 < X \le 2.0 \times 10^4$	$2.0 \times 10^4 < X \le 2.2 \times 10^4$	$2.2 \times 10^4 < X$
Integrated food-security index value	$0.8 \le Z \le 1$	$0.6 \le Z < 0.8$	$0.4 \le Z < 0.6$	$0.2 \le Z < 0.4$	$0 \le Z < 0.2$

Data source: *Hunan statistical yearbook* and *Hunan rural statistical yearbook* 1987–2012 (SBHP 2013; RITHP 2013)

The warning ranges of amount of heavy metal residues are not listed in this table. With reference to the Agricultural Professional Standard of China (NY861-2004), we propose that if one of the heavy metal residues above the threshold, the corresponding warning range is medium-alarm; two is heavy-alarm; more than two is huge-alarm

Table 4 Integrated index values and the corresponding warning ranges

Year	Food quantity security index	Warning range	Food quality security index	Warning range	Sustainable food security index	Warning range	Integrated food security index	Warning range
1986	–	–	0.61	Low-alarm	0.87	No-alarm	0.74	Low-alarm
1987	0.94	No-alarm	0.65	Low-alarm	0.89	No-alarm	0.83	No-alarm
1988	0.87	No-alarm	0.63	Low-alarm	0.75	Low-alarm	0.75	Low-alarm
1989	0.88	No-alarm	0.60	Medium-alarm	0.91	No-alarm	0.79	Low-alarm
1990	0.90	No-alarm	0.63	Low-alarm	0.73	Low-alarm	0.75	Low-alarm
1991	0.87	No-alarm	0.65	Low-alarm	0.87	No-alarm	0.79	Low-alarm
1992	0.88	No-alarm	0.66	Low-alarm	0.83	No-alarm	0.79	Low-alarm
1993	0.83	No-alarm	0.56	Medium-alarm	0.87	No-alarm	0.75	Low-alarm
1994	0.86	No-alarm	0.60	Medium-alarm	0.75	Low-alarm	0.73	Low-alarm
1995	0.88	No-alarm	0.68	Low-alarm	0.88	No-alarm	0.82	No-alarm
1996	0.93	No-alarm	0.68	Low-alarm	0.88	No-alarm	0.83	No-alarm
1997	0.92	No-alarm	0.67	Low-alarm	0.89	No-alarm	0.83	No-alarm
1998	0.93	No-alarm	0.64	Low-alarm	0.84	No-alarm	0.80	No-alarm
1999	0.91	No-alarm	0.66	Low-alarm	0.75	Low-alarm	0.77	Low-alarm
2000	0.92	No-alarm	0.65	Low-alarm	0.72	Low-alarm	0.76	Low-alarm
2001	0.91	No-alarm	0.58	Medium-alarm	0.83	No-alarm	0.77	Low-alarm
2002	0.86	No-alarm	0.58	Medium-alarm	0.78	Low-alarm	0.74	Low-alarm
2003	0.88	No-alarm	0.55	Medium-alarm	0.56	Medium-alarm	0.66	Low-alarm
2004	0.86	No-alarm	0.45	Medium-alarm	0.72	Low-alarm	0.67	Low-alarm
2005	0.83	No-alarm	0.47	Medium-alarm	0.78	Low-alarm	0.69	Low-alarm
2006	0.93	No-alarm	0.54	Medium-alarm	0.79	Low-alarm	0.75	Low-alarm
2007	0.94	No-alarm	0.52	Medium-alarm	0.77	Low-alarm	0.74	Low-alarm
2008	0.90	No-alarm	0.48	Medium-alarm	0.71	Low-alarm	0.70	Low-alarm
2009	0.88	No-alarm	0.63	Low-alarm	0.77	Low-alarm	0.68	Low-alarm
2010	0.90	No-alarm	0.51	Medium-alarm	0.72	Low-alarm	0.71	Low-alarm
2011	0.84	No-alarm	0.57	Medium-alarm	0.73	Low-alarm	0.74	Low-alarm

Data source: *Hunan statistical yearbook* and *Hunan rural statistical yearbook* 1987–2012 (SBHP 2013; RITHP 2013)

From the viewpoint of food quality security, the situation in the Dongting Lake area was very poor. The warning range in half of the past 26 years was in the medium-warning range and in the low-warning range for the other half, and the situation was increasingly serious. The proportions of high-quality protein and food supply of animal origin were generally in the no-alarm range, while the proportion of fat in the food supply was consistently in the medium-alarm range. On the whole, the main factors triggering alarms for food quality insecurity were pesticide residues, veterinary drug residues, and heavy metal residues.

Sustainable food security in the Dongting Lake area was at an intermediate level compared with food quantity and food quality security. Three of the seven indicators (rate of increase in agricultural investment, cultivated area per capita, and effective proportion of irrigated land) were in the no-alarm range during most years. The low per-capita income in high-poverty areas and the increasing amount of waste discharge were the main causes of sustainable food security alarms. One major concern is the overall trend of the integrated index value, which indicated that the sustainable food security situation was becoming graver.

Policy implications

China's population is expected to reach a peak in the 2030s, and urbanization rates are projected to increase from 40 % in 2000 to 80 % in 2050 (Ye and Van Ranst 2009); meanwhile, the dietary trend is toward more meat and less grain, with grain fed to animals instead (Simelton 2011). Although the food quantity security of the Dongting Lake area is good at present, the accelerating processes of urbanization, industrialization, and consumption growth in the coming years will pose even greater challenges to maintaining food quantity security. Moreover, most of the land occupied by urbanization and industrialization is high-quality agricultural land (Li et al. 2003), and to compensate for its loss, more land will be required to reach the same productivity. How to control the total cultivated area and

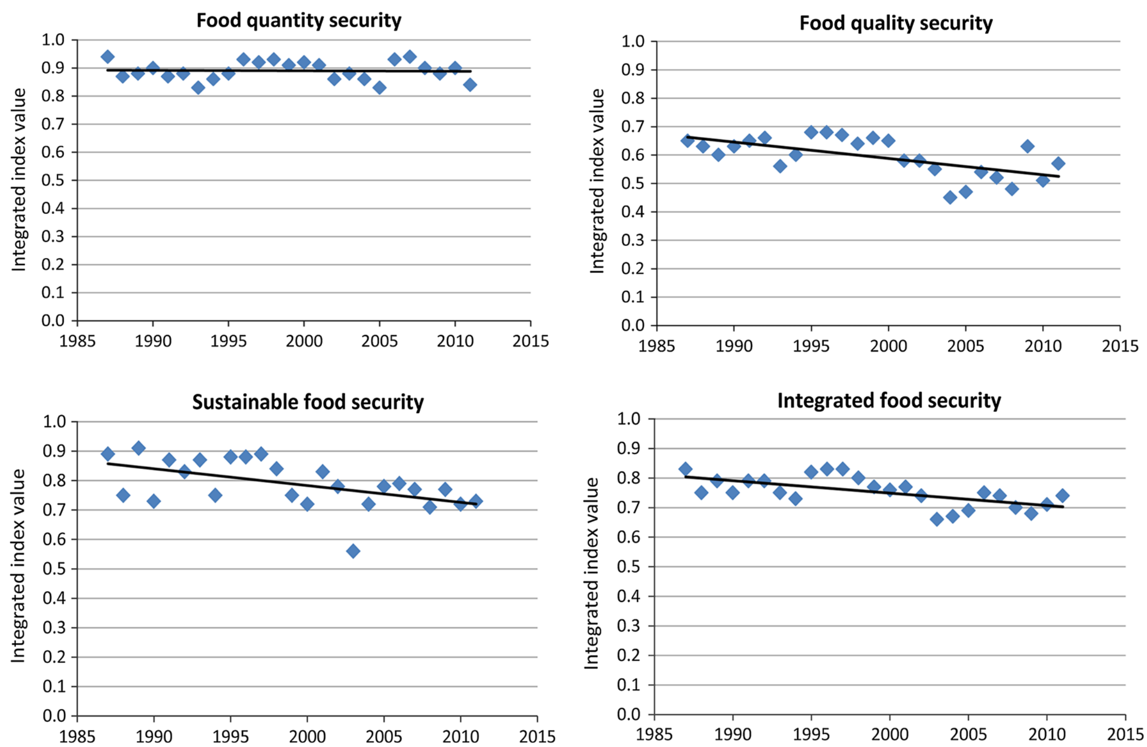

Fig. 3 Trends of the integrated index values. *Data source*: *Hunan statistical yearbook* and *Hunan rural statistical yearbook* 1987–2012 (SBHP 2013; RITHP 2013)

the effective irrigated area in a reasonable manner without reducing their quality will be challenging issues for both researchers and policymakers.

Due to abuse of agrochemicals and wastewater irrigation in agriculture over the past two decades, pesticide residues, veterinary drug residues, and heavy metal residues in many regions of China have exceeded the maximum residue limits allowed by the Ministry of Health (Bai et al. 2006; Khan et al. 2008; Wang et al. 2008). One major concern for food quality security in the Dongting Lake area is that the qualified ratios of pesticide residues and veterinary drug residues were both below 50 %, and the heavy metal residues have far exceeded the maximum residue limits in most years, due primarily, many believe, to wastewater irrigation and over use of pesticides and fertilizers (Qian et al. 2006; Zhong et al. 2012). Meanwhile, these residues have caused soil pollution and environmental deterioration and finally led to deteriorated sustainable food security. The government should establish a more robust system for monitoring the quality of agricultural products and take strict measures to control wastewater discharge and close those factories that have caused serious pollution of the irrigation water. Additionally, relevant studies have shown that pesticide and fertilizer inputs are no longer obstacles to increasing food production in this area (Qi et al. 2013, 2014); policies on pesticide and fertilizer application, then, should shift from actively encouraging more use to controlling excess application.

Although there will not be a significant change in the short-term sustainable food security status in the Dongting Lake area due to favorable resource status and agricultural production conditions, unrestrained waste discharge and excessive reclamation and high-intensity land use patterns of cultivated areas will lead to land/ecological degradation and weaken long-term sustainability. Moreover, the average annual grain shortfall caused by natural disasters has reached 11 % over the past two decades in this area, far exceeding the national average (approximately 7 %) (RITHP 2013; NBSC 2014). Therefore, controlling waste discharge, developing niche and conservation agriculture, and establishing a robust ecological compensation mechanism will be of great importance to preventing future sustainable food insecurity. Additionally, constructing a comprehensive risk prevention system to provide farmers early warnings of natural disasters and establishing social support mechanisms to give them technical, financial, and/or physical support will be useful in directly reducing sustainable food insecurity risk caused by natural disasters. Moreover, the government should take effective measures to guarantee people in high-poverty areas access to sufficient, safe, and nutritious food to meet their dietary needs.

Not all studies must be conducted from an integrated perspective when replicating this analysis. For example, if food quality security were generally at a no-alarm level, while food quantity security and sustainable food security were generally in the low- to huge-alarm ranges in a targeted region, only the latter two aspects would need to be considered; if the regional food supply capacity and stability were always able to meet the national needs and the resources and environment were always in good condition, a more comprehensive indicator system could be applied to monitor the regional food quality security based on available data. Overall, attention should be placed where it is most needed.

Comparison with relevant studies

The most common method of analysis usually evaluates food security in three aspects: food availability, access, and utilization (Gregory et al. 2005; Ericksen 2008). The method contains many scale-differentiated issues and utilizes national, household, and individual level indicators. Although this method is an excellent way to evaluate individual, national or international food security, the lack of specific information on socioeconomic status, resources, and environmental conditions make it difficult for regional policymakers to adopt and act upon the results of studies using this method. Additionally, this method is not useful in examining the differentiated foci during the phased development of food security, especially for developing countries where attention is gradually turning to food quality and safety and sustainable development after the national total food demand has essentially been met.

China has only approximately 7 % of the world's total cultivated area, but more than one-fifth of the world's population. As a result, most past studies on China's food security have focused on quantity and attempts to increase food production through various approaches, neglecting food quality and environmental issues arising in the process. The recent studies focused on food quality and safety status or resources and environmental issues usually constructed indicator systems from one single aspect, and none has been conducted from the perspective of early warning. Therefore, regional policymakers had difficulty obtaining comprehensive targeted information from these studies.

However, using the analytical framework proposed in this paper, the situation could be effectively improved. According to the differentiated development phases of food security, the indicator system for integrated food security risk was divided into food quantity security indices, food quality security indices, and sustainable food security indices; this decision-oriented classification will make it easier for policymakers to monitor different aspects of food security. Moreover, the weighting scheme based on the Delphi method could reflect the perceived importance of specific indicators, and the warning thresholds and warning ranges were determined by regional socioeconomic status, resources, and environmental conditions; this makes the framework more capable of being reasonably and effectively applied in a regional study.

Limitations of the indicator system

Because this paper aimed to provide a decision-oriented framework for monitoring regional integrated food security status and divided the indicator system into three main aspects (quantity, quality and sustainability) according to the social characteristics and the development phases of food security, some conflicts were inevitable between or within the indicators. To avoid these complex conflicts and facilitate the decision-making process, environmental sustainability has been ignored when it has conflicted with food production. This practice has made this framework more suitable for monitoring integrated food security status in developing countries where ensuring continued growth of food production is the most critical priority for policymakers.

Due to limitations in the available data, several indicators that could be used to evaluate food quality security (e.g., additive residues, toxin residues, child stunting) were not included in this framework. However, with the improvement of the food safety monitoring system and the acceleration of government transparency in China, this situation will largely improve in the foreseeable future.

This paper mainly focused on socioeconomic sustainability, particularly on the sustainability of food supply capacity, and attempted to provide intuitive information for regional policymakers. Consequently, several ecology-biased or composite indicators—such as ecosystem services, water footprint, biodiversity and ecological degradation—were excluded from the framework, and these risk factors, which will affect long-term food production conditions, may not be adequately revealed.

Additionally, the degree of sensitivity of the indicators to the allocation of weights may have a significant effect on the warning ranges. Because of favorable natural resource conditions and socioeconomic status in the Dongting Lake area, all of the food quantity security indicators and most of the sustainable food security indicators were basically in the no- or low-alarm range and therefore were not sensitive to the allocation of weights. However, due to wastewater irrigation and overuse of pesticides and veterinary drugs, the qualified ratios of pesticide and veterinary drug residues and amount of waste discharge were all in the heavy- or huge-alarm range, and all were very sensitive to the allocation of weights. Therefore, although the weighting scheme proposed in this paper could reflect the perceived importance of specific factors and was regarded as a better approach than a balanced weighting scheme in regional studies, the weights may need to be adjusted in regions with significant differences in socioeconomic status, resources or environmental conditions.

Conclusion

To date, the most common method of analysis has generally evaluated food security from the three aspects of food availability, access, and utilization, and such studies have typically been conducted at the national or global level. These studies' lack of specific information on socioeconomic status, resources, and environmental conditions made it difficult for regional policymakers to adopt and act upon the results. To provide targeted information for regional policymakers to monitor food security status, based on the differentiated focuses during the phased development of food security, this paper took the perspective of early warning and proposed a framework for regional integrated food security that incorporates food quantity security, food quality security, and sustainable food security. This framework is more suitable for monitoring regional food security, especially for developing countries where attention is gradually turning to food quality, food safety, and sustainable development after the national total food demand has essentially been met.

To test the approach, a case study was conducted in the Dongting Lake area. The results showed that the overall integrated food security situation in this area was generally in the low-alarm range between 1986 and 2011; the primary causes of this status were food quality security, which was generally in the low- or medium-alarm range, and sustainable food security, which in 14 of the 26 years was in the low-alarm range. Wastewater irrigation and overuse of pesticides and fertilizers have caused serious food quality security issues and finally led to deteriorated sustainable food security. The government should establish a more robust system to monitor the quality of agricultural products, and policies on pesticide and fertilizer application should shift from actively encouraging more use to controlling excess application. Additionally, controlling waste discharge, developing niche and conservation agriculture, establishing an explicit ecological compensation mechanism and providing farmers early warning information and technical, financial, and/or physical support against natural disasters will be important to preventing future sustainable food insecurity. Moreover, the government should take effective measures to guarantee that people in high-poverty areas have access to sufficient, safe, and nutritious food to meet their dietary needs.

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References

Acheampong, E., R.W. Campbell, A.B.S. Diekmann, and M.A. St John. 2011. Food availability effects on reproductive strategy: The case of *Acartia tonsa* (Copepoda: Calanoida). *Marine Ecology Progress Series* 428: 151–159. doi:10.3354/meps09061.

Ashraf, S., M. Iftikhar, B. Shahbaz, G.A. Khan, and M. Luqman. 2013. Impacts of flood on livelihoods and food security of rural communities: A case study of southern Punjab, Pakistan. *Pakistan Journal of Agricultural Sciences* 50(4): 751–758.

Azar, C., J. Holmberg, and K. Lindgren. 1996. Socio-ecological indicators for sustainability. *Ecological Economics* 18(2): 89–112.

Bai, L., C. Ma, S. Gong, and Y. Yang. 2007. Food safety assurance systems in China. *Food Control* 18(5): 480–484.

Bai, Y., L. Zhou, and J. Wang. 2006. Organophosphorus pesticide residues in market foods in Shaanxi area, China. *Food Chemistry* 98(2): 240–242.

Barrett, C.B. 2010. Measuring food insecurity. *Science* 327(5967): 825–828.

Brickley, E.B. 2012. Evaluating the use of remote sensing data in the US Agency for International Development Famine Early Warning Systems Network. *Journal of Applied Remote Sensing* 6(1): 063511.

Carney, M. 2012. Compounding crises of economic recession and food insecurity: A comparative study of three low-income communities in Santa Barbara County. *Agriculture and Human Values* 29(2): 185–201.

Carvalho, F.P. 2006. Agriculture, pesticides, food security, and food safety. *Environmental Science and Policy* 9(7–8): 685–692.

Chang, D. 1996. Applications of the extent analysis method on fuzzy AHP. *European Journal of Operational Research* 95(3): 649–655.

Chen, H., J. Wang, and J. Huang. 2014. Policy support, social capital, and farmers' adaptation to drought in China. *Global Environmental Change* 24: 193–202.

CNS. 2008. *Chinese food guide*. Tibet: People's Publishing House of Tibet. (in Chinese).

Desjardins, E., R. MacRae, and T. Schumilas. 2010. Linking future population food requirements for health with local production in Waterloo Region, Canada. *Agriculture and Human Values* 27(2): 129–140.

Ding, S. 2006. Discuss and representative definition about food security. *World Agriculture* 322(2): 4–6. (in Chinese).

Ding, S. 2008. Implementation "take grain as key integrated food security" new strategy. *Grain Issues Research* 3: 10–21. (in Chinese).

Eakin, H., and L.A. Bojórquez-Tapia. 2008. Insights into the composition of household vulnerability from multicriteria decision analysis. *Global Environmental Change* 18(1): 112–127.

Ensminger, M.E., and A.H. Ensminger. 1993. *Foods and nutrition encyclopedia*. Boca Raton: CRC Press.

Ericksen, P.J. 2008. Conceptualizing food systems for global environmental change research. *Global Environmental Change* 18(1): 234–245.

FAO. 2000. Handbook for defining and setting up a food security information and early warning system (FSIEWS). http://www.fao.org/DOCREP/003/X8622E/x8622e01.htm. Accessed 23 May 2013.

FAO. 2003. *Trade reforms and food security: Conceptualizing the linkages*. Rome: FAO.

Felloni, F., J. Gilbert, T.I. Wahl, and P. Wandschneider. 2003. Trade policy, biotechnology, and grain self-sufficiency in China. *Agricultural Economics* 28(3): 173–186.

Feng, Z. 2007. Future food security and arable land guarantee for population development in China. *Population Research* 31(2): 15–29. (in Chinese).

Foley, J.A., N. Ramankutty, K.A. Brauman, E.S. Cassidy, J.S. Gerber, M. Johnston, N.D. Mueller, et al. 2011. Solutions for a cultivated planet. *Nature* 478(7369): 337–342.
Genesio, L., M. Bacci, C. Baron, B. Diarra, A. Di Vecchia, A. Alhassane, I. Hassane, et al. 2011. Early warning systems for food security in West Africa: Evolution, achievements, and challenges. *Atmospheric Science Letters* 12(1): 142–148.
Giombolini, K.J., K.J. Chambers, S.A. Schlegel, and J.B. Dunne. 2010. Testing the local reality: Does the Willamette Valley growing region produce enough to meet the needs of the local population? A comparison of agriculture production and recommended dietary requirements. *Agriculture and Human Values* 28(2): 247–262.
Godfray, H.C., J.R. Beddington, I.R. Crute, L. Haddad, D. Lawrence, J.F. Muir, J. Pretty, S. Robinson, S.M. Thomas, and C. Toulmin. 2010. Food security: The challenge of feeding none billion people. *Science* 327(5967): 812–818.
Gregory, P.J., J.S. Ingram, and M. Brklacich. 2005. Climate change and food security. *Philosophical Transactions of the Royal Society B: Biological Sciences* 360(1463): 2139–2148.
Groenewald, S.F., and E. Bulte. 2013. Trust and livelihood adaptation: Evidence from rural Mexico. *Agriculture and Human Values* 30(1): 41–55.
Gumus, A.T. 2009. Evaluation of hazardous waste transportation firms by using a two-step fuzzy-AHP and TOPSIS methodology. *Expert Systems with Applications* 36(2): 4067–4074.
Hahn, M.B., A.M. Riederer, and S.O. Foster. 2009. The Livelihood Vulnerability Index: A pragmatic approach to assessing risks from climate variability and change—A case study in Mozambique. *Global Environmental Change* 19(1): 74–88.
Husak, G.J., C.C. Funk, J. Michaelsen, T. Magadzire, and K.P. Goldsberry. 2013. Developing seasonal rainfall scenarios for food security early warning. *Theoretical and Applied Climatology* 114(1–2): 291–302.
Ilbery, B., and D. Maye. 2005. Food supply chains and sustainability: Evidence from specialist food producers in the Scottish/English borders. *Land Use Policy* 22(4): 331–344.
Ingram, J. 2011. A food systems approach to researching food security and its interactions with global environmental change. *Food Security* 3(4): 417–431.
Kai, T., and L. Qin. 2011. Analysis on consumption structure of Shanghai resident by using panel data model. In *Software engineering and service science (ICSESS)*, ed. W. Li, 819–822. Beijing: IEEE.
Khan, S., Q. Cao, Y. Zheng, Y. Huang, and Y. Zhu. 2008. Health risks of heavy metals in contaminated soils and food crops irrigated with wastewater in Beijing, China. *Environmental Pollution* 152(3): 686–692.
Kiriti, T.W., and C. Tisdell. 2004. Commercial agriculture, marital status, and other influences on food availability: A Kenyan case study. *Journal of Food, Agriculture and Environment* 2(3–4): 141–148.
Krishnamurthy, P.K., K. Lewis, and R.J. Choularton. 2014. A methodological framework for rapidly assessing the impacts of climate risk on national-level food security through a vulnerability index. *Global Environmental Change* 25: 121–132.
Li, J.P., and Z.P. Shangguan. 2012. Food availability and household food security: A case study in Shaanxi, China. *Outlook on Agriculture* 41(1): 57–63.
Li, R., D. Zhuang, H. Wang, and S. Wu. 2003. Spatial temporal changes of the land cover in the Dongting Lake area during the last 20 years. *Progress in Geography* 22(2): 164–169.
Li, Z. 2003. *Theoretical analysis and comprehensive evaluation of food security index system*. Beijing: Chinese Academy of Agricultural Sciences. (in Chinese).
Liu, Y., L. Liu, D. Xu, and S. Zhang. 2010. Risk assessment of flood and drought in major grain-producing areas based on information diffusion theory. *Transactions of the CSAE* 26(8): 1–7. (in Chinese).
Louden, F.N., and R.J. MacRae. 2010. Federal regulation of local and sustainable food claims in Canada: A case study of Local Food Plus. *Agriculture and Human Values* 27(2): 177–188.
Ma, S., and Q. Wang. 2010. Connotation, evaluation indices, methods, and safeguard measures for regional grain security. *Resources Science* 32(1): 35–41. (in Chinese).
Ma, Z., C. Shao, S. Ma, and Z. Ye. 2011. Constructing road safety performance indicators using Fuzzy Delphi Method and Grey Delphi Method. *Expert Systems with Applications* 38(3): 1509–1514.
MAC (Ministry of Agriculture of China). 2005. The limits of eight elements in cereals, legumes, straws, and plant products of China. *Agricultural professional standard of China*. Beijing: China Agriculture Press. (in Chinese).
NBSC. 2014. *China statistical yearbook 1987–2013*. Beijing: National Bureau of Statistics of China.
NDRC. 2008. National food security and long-term planning framework. http://www.china.com.cn/policy/txt/2008-11/13/content_16757540.htm. Accessed 04 May 2013. (in Chinese).
OECD. 1999. *Agriculture in China and OECD countries*. Paris: OECD Publishing.
Ortega, D.L., H.H. Wang, L. Wu, and N.J. Olynk. 2011. Modeling heterogeneity in consumer preferences for select food safety attributes in China. *Food Policy* 36(2): 318–324.
Qi, X., L. Liu, Y. Liu, and L. Yao. 2013. Risk assessment for sustainable food security in China according to integrated food security-taking Dongting Lake area for example. *Environmental Monitoring and Assessment* 185(6): 4855–4867.
Qi, X., P.M. Vitousek, and L. Liu. 2014. Identification and evaluation of risk factors related to provincial food insecurity in China. *Journal of Risk Research*. doi:10.1080/13669877.2014.913667.
Qian, Y., M. Zheng, B. Zhang, L. Gao, and W. Liu. 2006. Determination and assessment of HCHs and DDTs residues in sediments from Lake Dongting, China. *Environmental Monitoring and Assessment* 116(1–3): 157–167.
Quave, C.L., and A. Pieroni. 2014. Fermented foods for food security and food sovereignty in the Balkans: A case study of the Gorani people of northeastern Albania. *Journal of Ethnobiology* 34(1): 28–43.
RITHP. 2013. *Hunan rural statistical yearbook 1987–2012*. Changsha: Hunan Statistics Press.
Rocha, C., and R.S. Liberato. 2013. Food sovereignty for cultural food security: The case of an indigenous community in Brazil. *Food, Culture and Society* 16(4): 589–602.
SBHP. 2013. *Hunan statistical yearbook 1987–2012*. Beijing: China Statistics Press.
Simelton, E. 2011. Food self-sufficiency and natural hazards in China. *Food Security* 3(1): 35–52.
Sullivan, C. 2002. Calculating a water poverty index. *World Development* 30(7): 1195–1210.
Suresh, B., and A. Ergeneman. 2005. A framework for evaluating food security and nutrition monitoring systems. *African Journal of Food Agriculture and Nutritional Development* 5(2): 1–26.
Tadesse, T., M. Haile, G. Senay, B.D. Wardlow, and C.L. Knutson. 2008. The need for integration of drought monitoring tools for proactive food security management in sub-Saharan Africa. *Natural resources forum* 32(4): 265–279.
Tirivarombo, S., and D.A. Hughes. 2011. Regional droughts and food security relationships in the Zambezi River Basin. *Physics and Chemistry of the Earth* 36(14–15): 977–983.
Wang, L., Y. Liang, and X. Jiang. 2008. Analysis of eight organophosphorus pesticide residues in fresh vegetables retailed in agricultural product markets of Nanjing, China. *Bulletin of Environmental Contamination and Toxicology* 81(4): 377–382.

WHO. 1990. Diet, nutrition, and the prevention of chronic diseases: Report of a WHO study group held in Geneva 6–13 March 1989. WHO Technical Report Series 797.

Xu, Z., J. Xu, X. Deng, J. Huang, E. Uchida, and S. Rozelle. 2006. Grain for green versus grain: Conflict between food security and conservation set-aside in China. *World Development* 34(1): 130–148.

Ye, L., and E. Van Ranst. 2009. Production scenarios and the effect of soil degradation on long-term food security in China. *Global Environmental Change* 19(4): 464–481.

Zhang, H. 2008. The analysis of the reasonable structure of water conservancy investment of capital construction in China by AHP method. *Water Resources Management* 23(1): 1–18.

Zhang, Y. 2006. *Chinese health survey report*. Jilin: Literature and History Press of Jilin. (in Chinese).

Zhao, C., J. Liu, R. Lu, and A. Zhang. 2006. Study on early warning system of food security in Xuzhou City. *Hubei Agricultural Sciences* 45(1): 4–7. (in Chinese).

Zhao, Y. 2007. Research on the early warning model of grain price and risk prevention mechanism. *Economic Survey* 1: 125–128. (in Chinese).

Zhong, L., L. Liu, X. Wang, and Y. Liu. 2010. Early warning index system of regional integrated food security and risk. *Transactions of the CSAE* 26(3): 374–379. (in Chinese).

Zhong, L., L. Liu, and J. Yang. 2012. Characterization of heavy metal pollution in the paddy soils of Xiangyin County, Dongting lake drainage basin, central south China. *Environmental Earth Sciences* 67(8): 2261–2268.

Zhou, D., H. Matsuda, Y. Hara, and K. Takeuchi. 2012. Potential and observed food flows in a Chinese city: A case study of Tianjin. *Agriculture and Human Values* 29(4): 481–492.

Zhu, Z. 1998. *The problem of China's food security: Demonstration and policy*. Hubei: Hubei Science and Technology Publishing House. (in Chinese).

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