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ORIGINAL ARTICLE

Building a sustainable food security evaluation system for the Yangtze River Economic Belt: Analysis based on entropy weight TOPSIS model method

Xiaolong Chen[1,2], Cora Un In Wong[1], Johnny F. I. Lam[1] and Hongfeng Zhang[1,*]

[1] *Faculty of Humanities and Social Sciences, Macao Polytechnic University, Macao,China*

[2] *Department of Tourism, Henan Normal University, Xinxiang, Henan 453000, China*

ABSTRACT

[Objective]In order to explore the sustainable food security level in the Yangtze River Economic Belt, ensure food security and sustainable development of agricultural modernization, it is necessary to establish a scientific food security evaluation system to safeguard local food security.[Methods]This paper takes the food system of the Yangtze River Economic Belt in China as the research object, based on the food security research results at home and abroad, based on sustainable development thinking, combined with a new perspective of dynamic equilibrium research: Beginning with food normalcy, a comprehensive analysis of food production, food economy, social development, ecological security, and technical support for sustainable development is presented using the entropy-weighted TOPSIS model to build a food security evaluation system for sustainable development. [Conclusion]After systematic analysis, it is concluded that (1) the average value of food security score of the Yangtze River Economic Belt from 2008 to 2021 is 0.429, and the overall food in the Yangtze River Economic Belt is in general security level ($0.400 \leq Q1 \leq 0.600$), and the overall situation of food security is not optimistic, (2) from the segmentation of the Yangtze River Economic Belt, the high and low level of food security are divided into sections: midstream > downstream > upstream, and each province and city is slowly rising to different degrees. In this way, we propose general countermeasures to ensure local food security from the perspective of sustainable development.

KEYWORDS

sustainable food production; sustainable development goals; Yangtze River Economic Belt; food security; entropy model

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*CORRESPONDING AUTHOR
Hongfeng Zhang,
Faculty of Humanities and Social Sciences,Macao Polytechnic University, Macao,China
hfengzhang@mpu.edu.mo

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1. Introduction

Food is a necessity for people's daily lives and a stabilizer of social security, and ensuring food security is ensuring national security (Kang, 2014; Li, 2013). As an important area related to national security and people's livelihoods, food security is closely related to regional security, national security and human security, and is a major issue that state and non-state actors cooperate to actively address. Since 2020, a combination of factors, such as the spread of the new crown pneumonia epidemic, increasing climate extremes, a weak global economy, and ongoing local wars and conflicts, have weakened the resilience of the global food system and led to a worsening global food security situation (Cao, 2013; Wang and Zhao, 2021; Xu, 2012). China has put forward the clear requirements of "improving the institutional policy of giving priority to the development of agriculture and rural areas and ensuring national food security" and "improving the quality, efficiency, and competitiveness of agriculture". The important document of the Central Government in 2022 believed that the responsibility system for food security should be strictly assessed and pointed out the need to accelerate the construction of national food security industrial zones. Obviously, safeguarding food security is an urgent and important task for a country and region in the long run.

The Yangtze River Economic Belt is one of the country's main grain-producing regions, with Sichuan, Anhui and Hunan all in the top ten of the country in terms of grain production (Fang and Liu,2022; Zhong, 2022). Therefore, this paper takes the food system of Yangtze River Economic Belt as the research object, based on the theory of sustainable development, integrates the theories and methods such as food security, dynamic equilibrium, and fuzzy integrated algorithm, systematically analyzes the current situation of food security in Yangtze River Economic Belt, and constructs the food security index system and evaluation model based on sustainable development from typical scenarios such as food normalization and food emergencies in order to provide food security in Yangtze River Economic Belt with It provides operational ideas and methodologies for national and local food security and also provides reference experience for the construction of the security system in related industries.

2. Review of literature

2.1. A review of foreign research

Internationally, food experts and scholars have also done a lot of research on food security. In 1974, the Food and Agriculture Organization of the United Nations (FAO) first introduced the concept of "food security", which means "to ensure that all people have access to adequate food at all times in order to meet their survival and health needs". In 1983, FAO revised the concept of food security again, stating that "the goal of food security is to ensure that all people have both affordable and timely access to the basic foodstuffs they need at all times (Pinstrup-Andersen, 2009; Tacon and Metian, 2008). Subsequently, FAO introduced the concept of sustainable development into the concept of food security and proposed a new concept of sustainable food security, arguing that "healthy, green, nutritious food and food supplies to consumers enhance physical vitality" (Sonnino et al., 2014).

Researchers have investigated national food security, proposing that the concept is critical in current and future times-specifically, a country's capacity to ensure adequate food for its citizens (Khoury et al., 2014). Food security encompasses five critical elements: nutritional and caloric necessities for human health, unpredictability and hazards in food production, fluctuations in consumption over time, detriment of food security threats, and the extent of assured supply (Marie, 2003).

Some researchers also propose that key factors impacting food security include acute water resource scarcity, decreasing arable land, and the expanding disparity between food supply and demand (Dinar et al., 2019). A country's overall political climate, social and economic development, food economy, sanitation infrastructure, food processing, dietary patterns, and more may also influence food security (Jennifer, 2013).

2.2. A review of domestic research

Compared with foreign countries, there are more studies on food security in China, and the research objects are partly based on the national level, partly on the provincial level, and also partly on comparative studies based on multiple objects; the research methods include PCA (Principal component analysis), SD (System dynamics), AHP (Analytic hierarchy process), GRA (Grey relation analysis) and FCEM (Fuzzy comprehensive evaluation method) (Quan, 2022; Peng, 2008; Zhao et al., 2011); On research content, Researchers have investigated food security in New China for 70 years Based on the evaluation index system (Jiang et al.,2022).

Some researchers also propose that the evolutionary path of China's food security strategy based on the 70-year development history of New China and revealed its inner logic (Wang and Qian, 2019); Relevant research has also focused on China's grain circulation issues, based on analysis of key nodes (Yang et al.,2017).

Relevant studies have shown that paying attention to China's food security issues from the perspectives of security (Jiang, 2022), policies (Li and Niu, 2022) and security systems (Wan, 2021) can also promote sustainable food development.

China's food security evaluation index system from four aspects, including resources, availability and stability, accessibility, and utilization level (Yao and Huang,2014). This paper analyzes the current situation, trends and problems of my country's food security from eight aspects including supply and distribution, and puts forward relevant policy suggestions (Zhang et al.,2015).

Relevant scholars have also analyzed the contribution of Hunan Province to China's food security from the perspective of contribution, which has promoted the sustainable development of Hunan's food security (Chen et al., 2022).

According to Xu, 2021 the connotation and extension of food security are constantly enriched, and its relationships are interlinked and mutually influenced by four kinds of "security", namely, quantity security, ecological security, food safety, and food sovereignty security; The connotation and extension of food security are constantly enriched, and its relationship is composed of four "securities": quantitative security, ecological security, food security, and food security (Zeng, 2006).

Researchers have analyzed food security through a macro lens, considering elements such as a country's capacity for stable food production, effectiveness of storage and transportation infrastructure, trade policies, and socioeconomic factors influencing access (Gong and Wang, 2010).

To sum up, domestic and foreign food experts and scholars have done a lot of research on the food security evaluation system and have achieved rich research results, mainly focusing on the national macro-level food security policies and influencing factors, while the research on sustainable development of food security evaluation is relatively small and the research on sustainable development of food security evaluation of cities in the joint regional economic belt is rare, basically in a blank state. Therefore, based on the thinking of sustainable development and the new research perspective of dynamic balance, the index system and evaluation model of food security for sustainable development are constructed to guide the practice of food security work and effectively improve the scientific decision-making and sustainable security capacities of relevant departments.

3. Methodology

3.1. Study area

The Yangtze River Economic Belt includes nine provinces and two cities, including Shanghai, Jiangsu, Zhejiang, and Hunan, and the upstream cities include Yunnan, Guizhou, Sichuan, and Chongqing (**Figure 1**). Petro China cities include those in Hunan, Hubei, and Jiangxi provinces. Downstream cities include Anhui, Zhejiang, Jiangsu, and Shanghai. It has an area of approximately 2052,300 square kilometers and accounts for 21.4% of the country's total population and GDP, both of which exceed 40% (Li et al., 2022; Yang and Zuo, 2022; Zhang and Li, 2022). It is the largest major rice-producing area in China, with a perennial rice planting area of about 290 million mu and a total output of about 140 million tons, accounting for about 65% of the country's rice(Zhang et al., 2021). However, in recent years, the green development of rice production in the Yangtze River Economic Belt has encountered numerous deep-level issues, such as tightening resource and environmental constraints, low rice yields and low farmer enthusiasm for planting. The Yangtze River Economic Belt plays an important role in China's regional development strategy. Six provinces are the main grain production areas of the country and are also the core areas for the production of double-cropping rice and high-quality special wheat in China (Chen et al.,2017). The Yangtze River Economic Belt, as the main artery of smooth domestic and international circulation, should play a more important role in ensuring national food security.

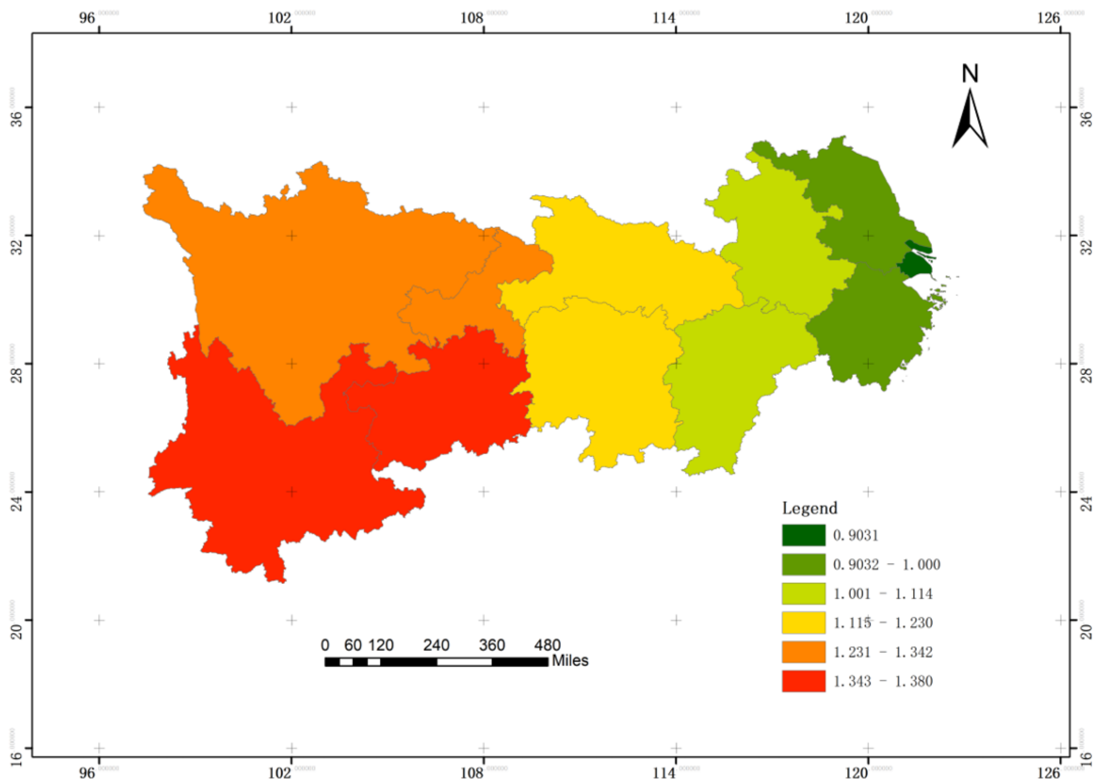


Figure 1. Yangtze River Economic belt research location map.

3.2. Data sources

From a sustainable development perspective grounded in dynamic equilibrium, we established an evaluation index system for food security that supports sustainable development in the Yangtze River Economic Belt. The index system encompasses normal and emergency food security scenarios. We collected and sorted relevant data per this index framework. We primarily collected evaluation data from the China Rural Statistical Yearbook spanning 2008–2021 and from provincial (city) statistical yearbooks within the Yangtze River Economic Belt. We handled missing values via linear fitting and nearby approximations.

4. Construction of a grain security evaluation system in the Yangtze River Economic Belt

4.1. Construction of an evaluation index system

Based on the perspective of sustainable development, this paper establishes a food security evaluation system from the five dimensions of food production, food economy, social development, ecological security, and technical support, with a view to providing a reference for provinces and cities in the Yangtze River Economic Belt to formulate food security policies (**Table 1**).

Table 1. Three-level evaluation index of food security in Yangtze River Economic Belt based on sustainable development.

Primary index	Secondary indicators	Tertiary indicators	Unit	Index nature
Food security evaluation index of Yangtze River Economic Belt based on sustainable development	Sustainable food production	Grain Sown Area	hm^2	+
		Total Grain Production	*t*	+
		Grain reserve rate	%	+
		Grain self-sufficiency rate	%	+
		Grain production per capita	*kg*	+
	Sustainable food economy	Agricultural labor productivity	%	+
		Grain consumption productivity	%	+
		Food land productivity	%	+
	Sustainable Social Development	Per capita disposable income of the population	*yuan*	+
		Engel Coefficient	%	+
		Food consumption structure	%	+
		Food price volatility coefficient	%	+
	Technical support sustainability	Total power of agricultural machinery	*kW*	+
		Science and technology input volume	*yuan*	+
		Contribution rate of agricultural science and technology	%	+
		Contribution of Agricultural Specialists	%	+
	Sustainable Ecological Security	Natural disaster area	hm^2	-
		Effective irrigated area	hm^2	+
		Fertilizer use rate	%	-
		Pesticide use rate	%	-

4.1.1. Sustainable food production

Food production will maintain high-quality output for a long period of time. High-yielding areas will maintain the original level. Low-yielding areas need to speed up the rate of food production, which requires more food to meet the needs of population growth and dietary structure and ensure national food security. Indicators adopted: grain sown area, per capita grain output, total grain output, grain reserve rate and grain self-sufficiency rate (Zuo et al., 2021; Xie et al., 2012).

4.1.2. Sustainable food economy

While ensuring the rising trend of land productivity and reducing the carrying capacity of land, we should ensure that the benefits of food production continue to improve and the efficiency of food production achieves the goal of long-term stable growth in the agricultural economy. Indicators adopted: grain labor productivity, grain consumption productivity, agricultural land productivity (Wang et al., 2015; Zhou and Cui, 2013).

4.1.3. Sustainable social development

Grain production requires balanced coordination across production, economy, and ecology. Ecology itself represents the economy, with ecological protection enabling production development. All three spheres connect directly to the social environment necessary for promoting sustainable growth. The sustainable development of society directly affects the food security situation and continuously meets the rigid demand for food. Selected indicators: per capita disposable income of residents, Engel coefficient (Chen et al., 2009; Zhang, 2007), grain price fluctuation coefficient (Li, 2013), and grain consumption structure (Liu, 2022).

4.1.4. Technical support sustainability

Technical support Sustainable technical support is an effective way to improve food production capacity and ensure food security (Zhang et al.,2022), scientifically and reasonably develop and utilize agricultural resources, and maintain the sustainable development capacity of food security. Selected indicators: total power of agricultural machinery (Su, 2014), scientific and technological expenses (Gao,2011), agricultural scientific and technological contribution rate (Wu, 2001), and number of agricultural scientific and technological personnel.

4.1.5. Sustainable ecological security

Ecological sustainability, ecological security and sustainability are the carriers and foundations of other sustainable factors, which depend on the agricultural natural ecological environment and reflect the carrying capacity of agricultural resources and environmental buffer capacity (Liu, 2022; Li et al., 2022). The selected indicators were: natural disaster area, effective irrigation area, fertilizer application amount, and pesticide use amount.

4.2. Determination of evaluation index weight

The concept of “entropy” for determining evaluation index weights was first proposed in 1865 by the German physicist Clausius. Entropy measures uncertainty and expresses the degree of order within a system (Zhang et al.,2021). A large difference between index values for a given indicator signifies greater information content, lower entropy, and larger corresponding weight. Conversely, small differences among index values denote less information, higher entropy, and smaller weights. Determining index weights via the entropy method avoids subjective artificial influences of qualitative weighting and enables more scientific, objective weight assignments (Yan, 2021).

The entropy weighting method provides an objective approach to determining the weights of individual indices within a composite indicator system. Its core premise is that indices with greater information entropy and uncertainty should be assigned lower weights, while those offering more definitive information merit stronger weights.

Specifically, entropy weighting involves:

(1) Constructing a matrix comprising all evaluation indices, with rows representing distinct evaluation objects and columns the indices.

(2) Standardizing the matrix using suitable techniques to eliminate dimensional impacts across indices.

(3) Calculating information entropy for each index, reflecting the informational content. Higher values denote greater uncertainty.

(4) Deriving index weights as inversely proportional to their information entropies. Lower entropies give larger weights.

(5) Verifying weights sum to one for consistency.

In summary, by objectively determining information entropy, the entropy weighting method provides an impartial means of assigning reasonable weights to avoid subjectively introduced biases.

We chose the objective entropy method to evaluate food security for sustainable development and determine the weight of each index; this improves the evaluation efficiency of food security capabilities and the practical impact of sustainably enhancing food security. The calculation steps are as follows:

(1) Data standardization

In the evaluation index, it is necessary to convert the original data into dimensionless standard values, and the formula is:

Positive indicators (P or +):

$$x'_{ij} = (x_{xj} - \overline{x}_{xj})/s_j \quad (1)$$

Negative indicator (N or –):

$$x'_{ij} = (\overline{x}_{xj} - x_{xj})/s_j \quad (2)$$

where x'_{ij} is the index value after assimilation; $\overline{x}_{xj}$ is the average value of index *j*; *s* is the standard deviation of index *j*.

(2) The proportion of the index value of item *j* in year *i* is as follows:

$$P_{ij} = x_{ij}/\sum_{i=1}^{n} x_{ij} \quad (3)$$

(3) The entropy value e_j of the *jth* index is:

$$e_{ij} = -k\sum_{i=1}^{n} P_{ij} \ln P_{ij} \quad (4)$$

(4) Difference coefficient *j* of index,The formula is:

$$\lambda_j = 1 - e_j \quad (5)$$

(5) The weight of the index x_j is ω_j,The formula is:

$$\omega_j = \frac{\lambda_j}{\sum_{j=1}^{m}\lambda_j} = \frac{1 - e_j}{\sum_{j=1}^{m}(1 - e_j)} \quad (6)$$

Since the standardized value of the range is 0~1, and the weight of each index is less than 1, the result of the comprehensive evaluation is also 0~1. In order to more intuitively represent the level of food security in each region, the study divides food security into five levels, as shown in **Table 2**.

Table 2. Grading standard for food security.

Number	Value range	Security levels
1	$0.000 \leq Q1 \leq 0.200$	more insecure
2	$0.200 \leq Q1 \leq 0.400$	unsafe
3	$0.400 \leq Q1 \leq 0.600$	general safety
4	$0.600 \leq Q1 \leq 0.800$	more secure
5	$0.800 \leq Q1 \leq 1.000$	safest

5. Results and analysis

5.1. On the whole, the overall food in the Yangtze River Economic Zone is at a general safety level ($0.400 \leq Q1 \leq 0.600$)

From an overall perspective, the mean food security score of the Yangtze River Economic Zone from 2008 to 2021 is only 0.429 (**Table 3**), which is less than 0.600 and only reaches the general security level, indicating that the Yangtze River Economic Zone has a low level of food security and certain risks during this period. Horizontally, it only peaks in 2008, 2011 and 2013 and the value exceeds 0.500, in 2009, 2010, 2011, 2016, 2017, 2020 and 2021 the food security score is greater than 0.400, the scores of the remaining years are less than 0.400, general security accounts for 65% and insecurity accounts for 35% of the total sample. It shows that the overall food security in the Yangtze River Economic Zone is at the general security level ($0.400 \leq Q1 \leq 0.600$), and overall, the overall food security in the Yangtze River Economic Zone is not optimistic, but the data show a stable upward trend from 2019.

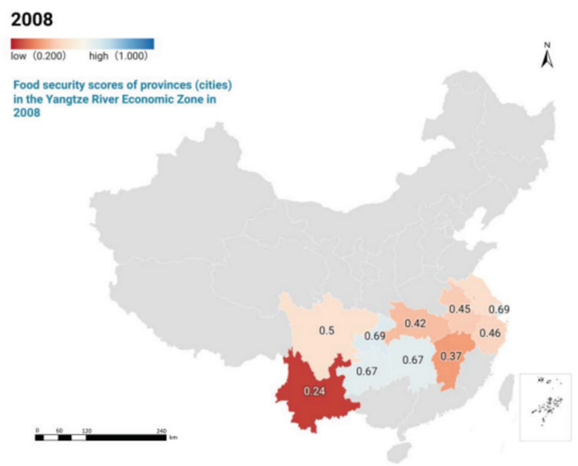
Table 3. Comprehensive score of food security in the Yangtze River Economic Belt from 2008 to 2010.

Areas	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	Average value
upstream	0.524	0.442	0.300	0.645	0.357	0.526	0.374	0.299	0.346	0.223	0.286	0.371	0.449	0.446	0.399
midstream	0.486	0.429	0.614	0.402	0.243	0.548	0.286	0.296	0.539	0.439	0.408	0.638	0.628	0.648	0.472
downstream	0.549	0.363	0.522	0.479	0.409	0.583	0.434	0.424	0.369	0.292	0.391	0.456	0.249	0.314	0.417
Overall average score	0.519	0.411	0.479	0.509	0.336	0.552	0.365	0.339	0.418	0.318	0.362	0.488	0.442	0.469	0.429

upstream:*Upper Yangtze River;* ***midstream***:*Middle reaches of the Yangtze River;* ***downstream***:*downstream Yangtze River region;* ***Overall average score***:*Comprehensive Food Security Score of Yangtze River Economic Zone*

From the perspective of the evolution process of the food security level of the Yangtze River Economic Belt from 2008 to 2021 (**Figure 2**). The overall situation of food security in the Yangtze River Economic Belt between 2008 and 2012 is not optimistic, which has caused great obstacles to the food security and economic and social development of the Yangtze River Economic Belt.

The Yangtze River Economic Belt has a wide span and a large radiation area, resulting in a lack of regional cooperation and coordinated development of agricultural production. Provincial food security development within the region is unbalanced, limiting overall development. Moreover, under the new normal, food security encompasses more than just quantitative security; it results from the joint aggregation of multilevel factors. Increased attention is paid to quality security, nutritional security, ecological security, and social security.



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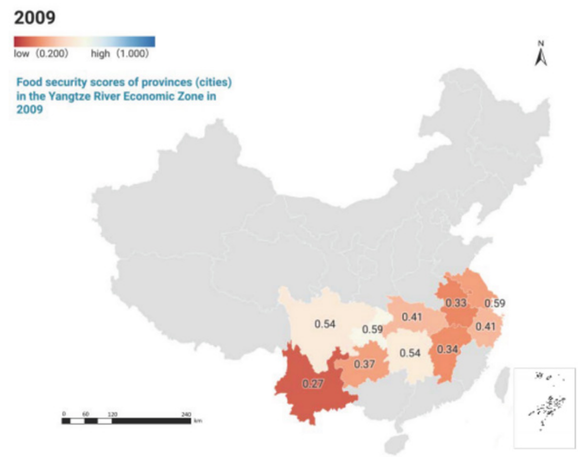

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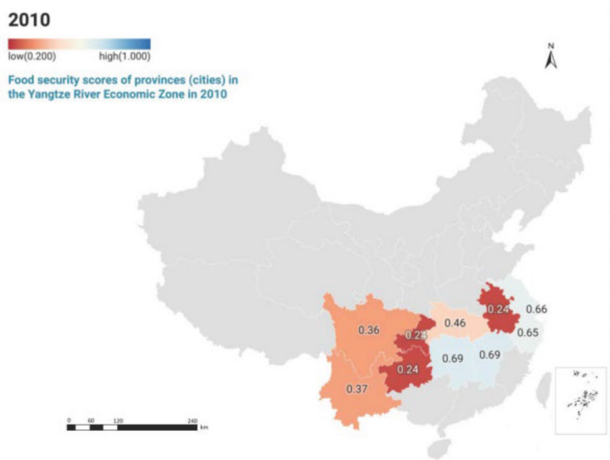

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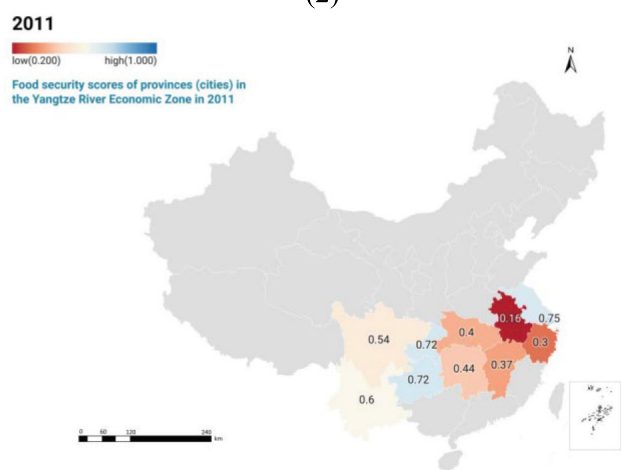

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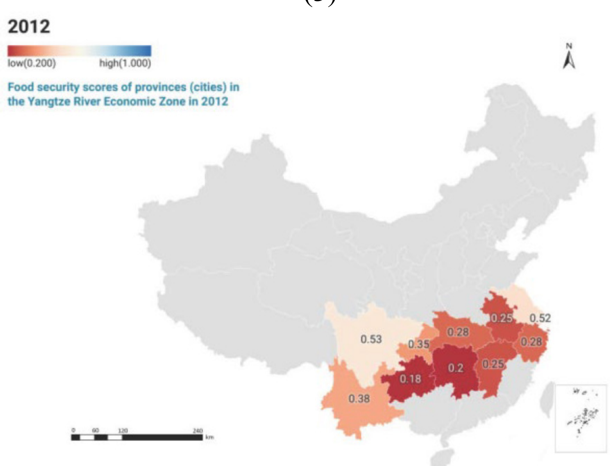

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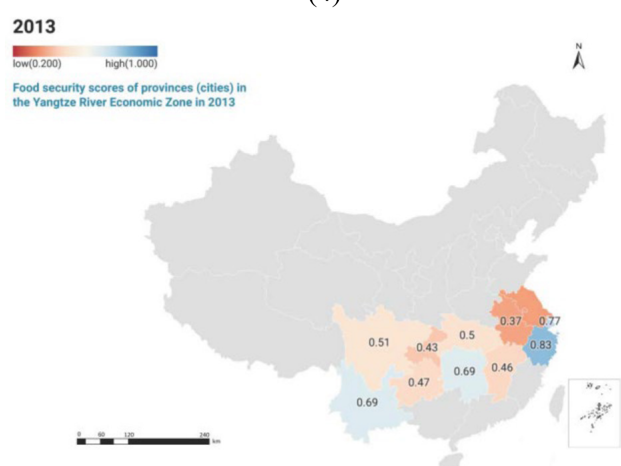
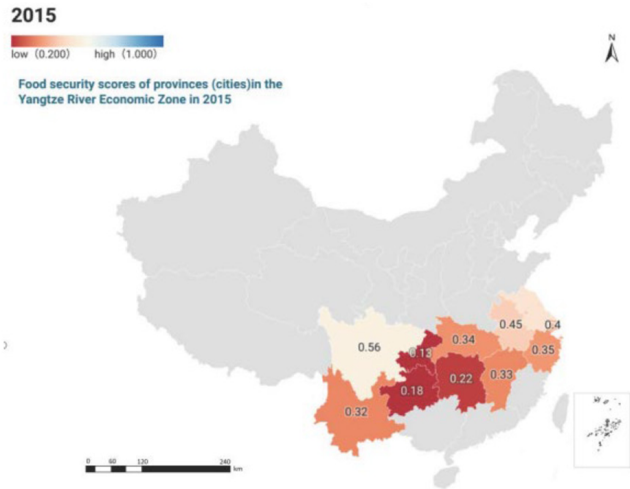


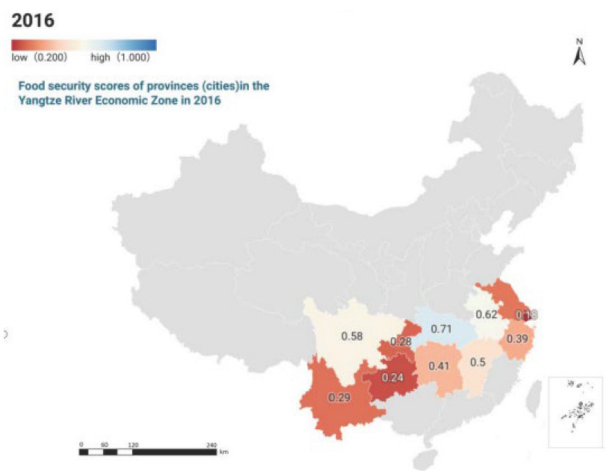
(6)


2014
low (0.200) high (1.000)
Food security scores of provinces (cities)in the Yangtze River Economic Zone in 2014
0.5
0.44
0.3
0.28
0.25
0.28
0.29
0.49
0.59
0.23

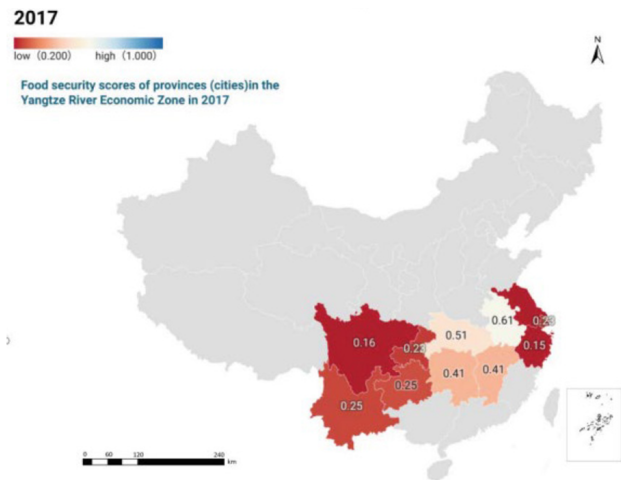
(7)


2015
low (0.200) high (1.000)
Food security scores of provinces (cities)in the Yangtze River Economic Zone in 2015
0.56
0.32
0.18
0.34
0.22
0.33
0.45
0.4
0.35

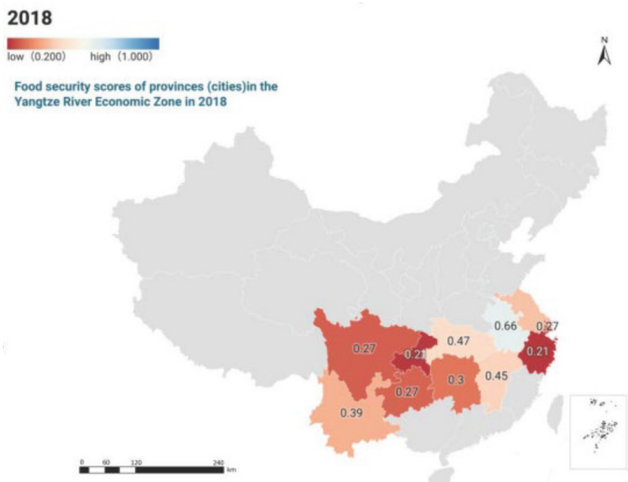
(8)


2016
low (0.200) high (1.000)
Food security scores of provinces (cities)in the Yangtze River Economic Zone in 2016
0.58
0.29
0.28
0.24
0.71
0.41
0.5
0.62
0.39

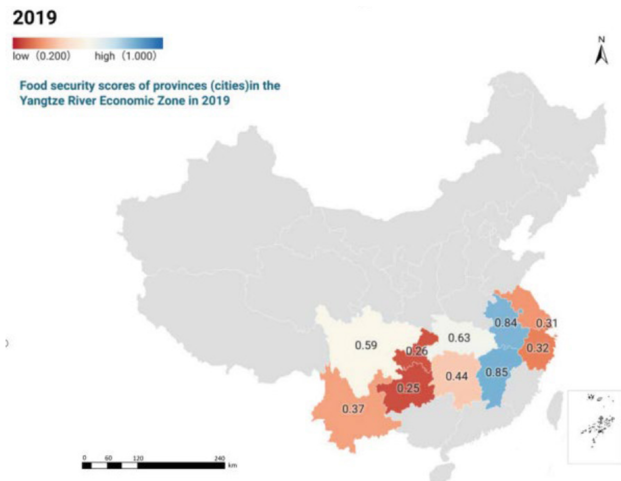
(9)


2017
low (0.200) high (1.000)
Food security scores of provinces (cities)in the Yangtze River Economic Zone in 2017
0.16
0.25
0.25
0.51
0.41
0.41
0.61
0.15

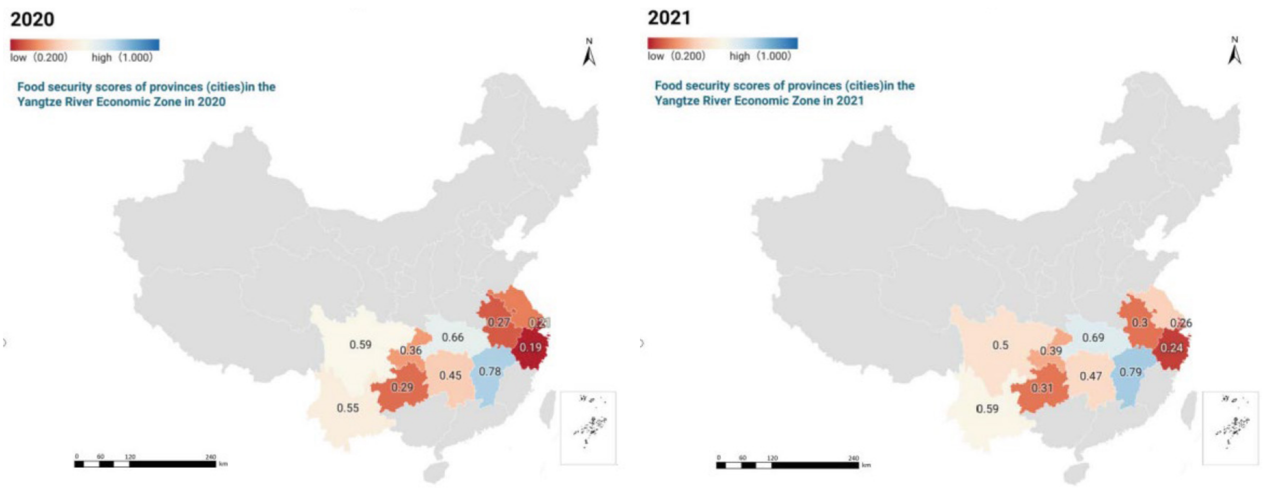
(10)


2018
low (0.200) high (1.000)
Food security scores of provinces (cities)in the Yangtze River Economic Zone in 2018
0.27
0.39
0.27
0.3
0.47
0.45
0.66
0.27
0.21

(11)


2019
low (0.200) high (1.000)
Food security scores of provinces (cities)in the Yangtze River Economic Zone in 2019
0.59
0.37
0.26
0.25
0.63
0.44
0.84
0.85
0.31
0.32

(12)



(13) (14)

Figure 2. Evolution process of grain security level in the Yangtze River Economic Belt from 2008 to 2021.

5.2. Food security level by segment location: midstream > downstream > upstream

From the upstream, middle and downstream, only the upstream food security score is 0.399, which is in the unsafe level (0.200 ≤ Q1 ≤ 0.400) (**Table 4**). The middle reaches exhibited the highest level but only reached 0.472, just below the general safety threshold. The lower reaches ranked intermediate yet barely met the general safety level. This shows that the food security level in the upper, middle and lower reaches of the Yangtze River Economic Belt is not high, and the upper reaches are even more unsafe. The predominance of plains in the middle and lower Yangtze River region provides favorable conditions for food production. However, the more advanced economic development in the lower reaches shifts daily consumption towards purchased foods from other areas. This reduces self-sufficiency and attention to local production, culminating in poorer food security in the lower reaches; Within the upstream region, only the Sichuan Basin offers suitable grain production conditions; other areas have relatively poor conditions that struggle to meet production needs, resulting in lower food security compared to the middle and downstream regions.

Table 4. Ranking of the average score of food security in the Yangtze River Economic Belt (upstream, midstream and downstream) from 2008 to 2010.

Areas	Average value	Rank
upstream	0.399	3
midstream	0.472	1
downstream	0.417	2

upstream*:Upper Yangtze River;* ***midstream****:Middle reaches of the Yangtze River;* ***downstream****:downstream Yangtze River region; Overall average score:Comprehensive Food Security Score of Yangtze River Economic Zone.*

Upstream and midstream food security exhibited a "U-shaped" trend, with steady increases in 2019. Compared to the upstream and midstream, downstream grain security has not significantly improved over this period (**Table 5**).

Table 5. Average score of grain security of 12 provinces in the Yangtze River Economic Belt from 2008 to 2010.

Areas	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	Average value
Chongqing	0.688	0.593	0.718	0.236	0.353	0.433	0.299	0.133	0.275	0.234	0.211	0.262	0.362	0.389	0.370
Sichuan	0.502	0.537	0.542	0.361	0.528	0.509	0.501	0.563	0.575	0.159	0.266	0.593	0.593	0.503	0.481
Guizhou	0.673	0.367	0.721	0.238	0.175	0.467	0.253	0.177	0.243	0.254	0.273	0.254	0.294	0.306	0.336
Yunnan	0.236	0.269	0.597	0.366	0.375	0.694	0.443	0.324	0.292	0.246	0.393	0.373	0.549	0.588	0.41
Jiangxi	0.366	0.337	0.694	0.372	0.250	0.462	0.293	0.326	0.500	0.406	0.453	0.847	0.779	0.789	0.491
Hubei	0.420	0.412	0.456	0.396	0.281	0.496	0.283	0.340	0.711	0.507	0.471	0.628	0.661	0.688	0.482
Hunan	0.673	0.539	0.693	0.437	0.198	0.686	0.283	0.221	0.405	0.405	0.300	0.439	0.445	0.467	0.442
Shanghai	0.691	0.588	0.656	0.750	0.523	0.770	0.588	0.398	0.175	0.229	0.274	0.309	0.214	0.263	0.459
Jiangsu	0.492	0.366	0.656	0.708	0.487	0.361	0.473	0.505	0.301	0.179	0.423	0.355	0.319	0.453	0.434
Zhejiang	0.459	0.409	0.651	0.301	0.280	0.828	0.227	0.349	0.386	0.154	0.209	0.322	0.193	0.236	0.357
Anhui	0.445	0.326	0.236	0.156	0.248	0.371	0.485	0.445	0.615	0.607	0.660	0.839	0.272	0.303	0.429

5.3. In terms of the year, the security level of the upstream, middle and downstream has different peaks

Looking at specific years, the upstream region reached a relatively safe level in 2011, a general level in 2008, 2009, 2013, 2020 and 2021, while the average across remaining years was only unsafe. The upstream food security problem was relatively large; The middle reaches scored less than 0.400 in food security in 2012, 2014 and 2015, and more than 0.600 in 2010, 2019, 2020 and 2021, reaching a relatively safe level; The downstream reached a peak of 0.583 in 2013, reaching the general safety level. The food security score from 2016 to 2018 and 2020 to 2021 is less than 0.400. While other years scored higher than 0.400, none surpassed 0.600, indicating that downstream food security exceeded upstream levels yet remained suboptimal overall. (**Table 6**).

Table 6. Average score of grain security in the Yangtze River Economic Belt (upstream, midstream and downstream) from 2008 to 2010.

Areas	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
upstream	0.524	0.442	0.300	0.645	0.357	0.526	0.374	0.299	0.346	0.223	0.286	0.371	0.449	0.446
midstream	0.486	0.429	0.614	0.402	0.243	0.548	0.286	0.296	0.539	0.439	0.408	0.638	0.628	0.648
downstream	0.549	0.363	0.522	0.479	0.409	0.583	0.434	0.424	0.369	0.292	0.391	0.456	0.249	0.314

5.4. From the inter-provincial perspective, the grain security score of each province (city) is less than 0.600, and the inter-provincial state of grain security in the Yangtze River Economic Belt is poor

At the inter-provincial level, no province (city) surpassed a 0.600 grain security score. Across the Yangtze River Economic Belt, provincial (city) grain security scores remain low. From an inter-provincial point of view, the grain security score of each province (city) does not exceed 0.600. The grain security score of three provinces (cities), including Zhejiang Province, Chongqing City, and Guizhou Province, is lower than 0.400 (Table 5). Among all provinces (cities), Jiangxi Province exhibited the highest average food security score. Zhejiang Province and Guizhou Province had the second-lowest and lowest average scores, respectively, with averages below 0.400. The main reason is that Guizhou has more mountains and less arable land suitable for grain cultivation. Among the midstream provinces, Hunan Province, Hubei Province, and Jiangxi Province scored lower than 0.500 in terms of food security. However, considering the level of all the Yangtze River Economic Belt, the value is relatively stable, higher than 0.400, and the midstream comprehensive score is still the highest; Among downstream provinces (cities), all except Zhejiang Province scored at the middle level, with Zhejiang falling below 0.400. The primary driver of Zhejiang's food insecurity is arable land loss to industrialization, shrinking planting area.

6. Conclusions

6.1. Conclusions

The average overall food security score for the Yangtze River Economic Belt was just 0.429, barely reaching an average level with some inherent risks. The score of food security in all provinces (cities) is less than 0.600. Although the level of food security in the middle reaches is the highest, it is only 0.472. The level of food security in the lower reaches is in the middle, and the level of food security in the upper reaches is reached. The level of food security is: midstream > downstream > upstream, and each province and city have a slow rise in varying degrees. From the perspective of influencing factors, the urbanization rate, the proportion of fiscal support for agriculture and the total population have no significant impact on the overall food security of the Yangtze River Economic Belt, the promotion of the per capita total mechanical power is not significant, and the negative effects of the per capita fertilizer application and the total afforestation area are not significant.

6.2. Suggestions

6.2.1. Improve safety awareness, give full play to leading role

As a traditional livelihood industry that benefits producers and consumers alike, the grain sector constitutes a vital pillar of China's national economy. Aligned with the overarching strategies of fortifying domestic manufacturing and constructing a healthy China, the food industry maintains crucial linkages across agriculture, industry, distribution and other domains related to the national economy and public welfare (Li, 2009 ; Jin,2017). The Yangtze River Economic Belt depends on economic connections for regional development. Food security relates to stability and sustainability across the entire Yangtze basin. All the provinces (cities) in the economic belt must enhance their awareness of food security, promote the coordination of food security and economic development, extend economic exchanges and cooperation to agricultural exchanges and cooperation, and form the optimal allocation of resources in the Yangtze River Economic Belt. The Yangtze River Economic Belt contains six major grain-producing areas, and the six provinces have good food security. To ensure the overall food security, we can adopt complementary advantages, utilize the advanced production advantages and experience of the main grain-producing areas to drive the development of grain in backward areas, and form a scale effect through technological exchange and capital accumulation to enhance the food security of the entire economic belt.

6.1.2. Seize policy opportunities to promote multi-dimensional development

As China's current pilot region for opening and reform, the Yangtze River Economic Belt receives substantial national attention regarding comprehensive development. The state provides preferential policies supporting each provincial (city) unit to bolster overall belt growth—a unique opportunity to expand the grain industry and strengthen food security. (Wang and Wang, 2022; Liu et al.,2022; Huang and Pan, 2022). By using financial and policy support to promote the transformation and upgrading of food production and food industry in each province (city) within the economic belt to form green and large-scale development, provinces (cities) within the economic belt should break the inter-provincial barriers and form a unified cognition (Guang et al., 2022; He et al.,2022), grasp the opportunity to rapidly build a modern agricultural development system within the economic belt, and promote food security from quantity security to quality security, ecological security, and social benefit security in multiple dimensions.

6.1.3. Optimize regional cooperation, accelerate utilization efficiency

The Yangtze River Economic Belt is located in three major regions of China, with developed transportation network. The provinces (cities) in the economic belt should adopt the aggregation effect and diffusion effect (Yang, 2022; Wang, 2019), Promote the circulation of grain technology and talents in the region, build a transportation system for grain circulation, and create a golden waterway and three-dimensional transportation network (Ye, 2018; Peng and Yu, 2022), promote the efficiency of grain circulation and reduce the regional gap in grain development within the economic belt. Through regional cooperation within the economic belt (Tang et al., 2019; Zhang, 2016), the grain industry is rationally laid out to promote the complementarity of food development within the Yangtze River economic belt from east to west, from river to sea, and from production areas to outside, to improve food security in the entire Yangtze River economic belt, and to promote the coordinated and sustainable development of the Yangtze River economic belt as a new region for the implementation of China's new round of reform and opening-up transformation.

6.3. Limitations of the study

Agriculture, a critical ecosystem, maintains close ties with food production and environmental conservation. Implementing prudent, scientific food security policies is key to enabling agricultural sustainability while mitigating overexploitation and pollution impacts. Moreover, national and regional food security plays a vital role in maintaining global equilibrium and stability of provision. With escalating climate disruptions and natural disasters, the importance of food security intensifies. Skillfully addressing these challenges and securing supply have become integral to a nation's response to calamitous events and unpredictable transformations.

In working to build a sustainable food security assessment framework suited to the Yangtze River Economic Belt, the specter of incomplete data emerges. This predicament engenders a dearth of relevant data in certain geographical realms or temporal junctures, thereby impinging upon the veracity and comprehensiveness of the appraisals. Albeit the adoption of the TOPSIS model for analysis is a salutary endeavor, it is not without its constraints. Henceforth, prospective investigations may contemplate amalgamating other sophisticated multi-criteria decision-making methodologies, thereby conferring enhanced scientificality and veracity upon the appraisal structure. Although the scope of this paper focuses chiefly on food security, future research horizons call for an expanded view granting due weight to sustainability dimensions like agricultural ecology, environmental conservation, and socioeconomic advancement. Integrating these diverse facets harmoniously will enable a more comprehensive, panoramic assessment framework.

Author contributions

Conceptualization, CUIW and HZ; methodology, HZ and XC; Software, XC; validation, HZ and XC;formal analysis, HZ and XC; investigation, XC; resources, HZ and XC; data curation, HZ and XC; writing—original draft preparation, XC; writing—review & editing, CUIW, JFL and HZ; visualization, HZ , XC and JL; supervision, HZ and JFL; All authors have read and agreed to the published version of the manuscript.

Conflict of interest

The authors declare no conflict of interest.

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