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Enhancing food security assessment in border regions: An integrated index and evidence from the Turkistan region of the Republic of Kazakhstan

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ABSTRACT

Food security in border regions depends not only on agricultural production but also on economic, demographic, infrastructural, and investment conditions that shape regional resilience. Existing international frameworks, including the Global Food Security Index (GFSI) and the FAO Resilience Index Measurement and Analysis (RIMA), are not specifically designed for regional assessment in border areas. This study develops and applies the Border Food Security Index (BFSI), using the Turkistan Region of the Republic of Kazakhstan as a case study. The index integrates twenty-five official statistical indicators across five dimensions: Production Resilience, Food Affordability, Demographic Sustainability, Infrastructure and Logistics Capacity, and Investment Resilience. The indicators were normalized using the Min–Max method, aggregated into component indices, and combined through weighted aggregation using official statistics for 2024–2026. The resulting BFSI value is 0.874, indicating a very high level of food security. Production Resilience (0.92) and Infrastructure and Logistics Capacity (0.94) record the highest scores, reflecting the region's strong agricultural base and infrastructure. Food Affordability (0.76) records the lowest score, indicating that household purchasing power and inflation remain the main constraints. The BFSI offers a transparent and reproducible framework for regional monitoring, comparative analysis, and evidence-based policy and can be adapted to other border regions with similar socioeconomic characteristics.

Contribution/Originality: This study develops a composite index for assessing food security in border regions, where economic, demographic, and infrastructure factors interact in ways that are not fully captured by existing international indices. Using official statistics from Kazakhstan, the index provides a practical basis for regional comparison and supports evidence-based policy decisions.

1. INTRODUCTION

Food security has become one of the central challenges of sustainable development and remains a key priority for governments worldwide. In recent years, food systems have been exposed to a combination of economic, environmental, and geopolitical pressures that have increased uncertainty in agricultural production and food supply. Climate change, disruptions in international trade, rising food prices, and pressure on natural resources have highlighted the need for reliable approaches to assessing food security and strengthening the resilience of food

systems (Béné, 2022; Economist Impact, 2022; Food and Agriculture Organization of the United Nations, 2023, 2024; Mkumbukiy, Loghmani-Khouzani, Madani, & Guenther, 2025; Schneider et al., 2023; Ujjwal et al., 2024).

The Food and Agriculture Organization of the United Nations (FAO) defines food security as a situation in which all people have physical, social, and economic access to sufficient, safe, and nutritious food at all times (Food and Agriculture Organization of the United Nations, 2023, 2024). While this definition remains widely accepted, recent research has expanded the concept beyond food availability alone. Current studies increasingly examine the resilience of food systems, emphasizing their ability to withstand external shocks, adapt to changing conditions, and maintain stable food supplies over time (Béné, 2022; Constas, d'Errico, & Pietrelli, 2022; Liang et al., 2025; Mkumbukiy et al., 2025; Schneider et al., 2023; Ujjwal et al., 2024; Xu et al., 2025).

Border regions deserve particular attention in this context. Their development is influenced not only by domestic economic conditions but also by cross-border trade, migration, shared natural resources, and transport connections with neighboring countries. These factors create opportunities for regional development while simultaneously increasing exposure to external risks. Consequently, the conditions affecting food security in border regions often differ from those observed in inland territories and require separate analytical consideration (Ben, Zhang, & Xu, 2025; Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan, 2026a, 2026b; Christyanto & Mayulu, 2021; Donoso Salas, Białogłowska, & Flood, 2025; Gu, Long, & Jiang, 2026; Westerdahl, Pugh, Nordström Källström, & Krautscheid, 2025).

Food security in border regions is also closely linked to broader issues of social and economic development. Household income, employment opportunities, access to food markets, and the quality of infrastructure all influence people's ability to obtain sufficient and affordable food. In many border areas, these factors are shaped by regional inequalities and cross-border economic interactions. For this reason, evaluating food security is not only an agricultural task but also an important issue for social and regional policy.

Kazakhstan provides an appropriate setting for examining these issues. Agriculture remains one of the country's strategic economic sectors, yet considerable differences exist among its regions in terms of natural conditions, production capacity, infrastructure, and demographic characteristics (Government of the Republic of Kazakhstan, 2021, 2023; Ministry of Agriculture of the Republic of Kazakhstan, 2025; Ministry of Water Resources and Irrigation of the Republic of Kazakhstan, 2025). These differences are particularly evident in border regions, where agricultural development is closely connected with cross-border cooperation and the management of shared resources. Assessing food security using only national-level indicators may therefore overlook important regional differences that are relevant for policy decisions.

The Turkistan Region represents a useful case for this study. It is the most populous border region of Kazakhstan and one of the country's leading agricultural producers. The region makes a substantial contribution to national production of vegetables, fruits, greenhouse products, and livestock. At the same time, its food system depends on irrigation infrastructure, water availability within the Syr Darya basin, and economic cooperation with neighboring Uzbekistan (Akimat of the Turkistan Region, 2024; Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan, 2026a; Department of Agriculture of the Turkistan Region, 2025; Republic of Kazakhstan, 2005). These characteristics make the region an appropriate example for examining how different factors jointly influence food security at the regional level.

Despite the growing body of literature on food security, important methodological limitations remain. Existing international assessment tools, including the Global Food Security Index (GFSI) and the FAO Resilience Index Measurement and Analysis (RIMA), were primarily developed for cross-country comparisons or household-level assessments. Although these frameworks provide valuable information, they do not fully capture the specific conditions of border regions, where agricultural production, demographic trends, infrastructure, investment activity, and cross-border interactions jointly determine the resilience of regional food systems (Ben et al., 2025; Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan, 2026a, 2026b;

Christyanto & Mayulu, 2021; Donoso Salas et al., 2025; Economist Impact, 2022; Food and Agriculture Organization of the United Nations, 2023; Gu et al., 2026; Meng & Liu, 2025; Westerdahl et al., 2025).

This study addresses that gap by developing the Border Food Security Index (BFSI), a composite indicator designed to assess food security in border regions. The index combines official regional statistics covering five complementary dimensions: production resilience, food affordability, demographic sustainability, infrastructure and logistics capacity, and investment resilience. The Turkistan Region is used to demonstrate the application of the proposed approach.

Against this background, the study aims to develop the Border Food Security Index (BFSI) and examine its application to the Turkistan Region of Kazakhstan. The specific objectives are to review existing approaches to food security assessment, identify the main factors influencing food security in border regions, develop the methodology for the composite index, apply the index to the selected case study, and discuss its potential use in regional policymaking.

The remainder of the paper is organized as follows. The next section reviews the relevant literature on food security assessment and composite indicators. The methodology section describes the construction of the Border Food Security Index and the data used in the analysis. The following sections present the empirical results, discuss their implications, and conclude with policy recommendations and directions for future research.

2. LITERATURE REVIEW

Food security has attracted increasing attention in recent decades as governments and researchers have sought to understand how food systems respond to economic, environmental, and political change. Although ensuring an adequate food supply remains a central objective, recent studies increasingly view food security as a multidimensional concept that depends on the interaction of production, access, stability, and resilience rather than on agricultural output alone (Béné, 2022; Committee on World Food Security, 2021; Food and Agriculture Organization of the United Nations, 2024; Mkumbukiy et al., 2025; Schneider et al., 2023; Ujjwal et al., 2024).

This broader understanding has influenced the development of approaches used to assess food security. Earlier studies focused mainly on measuring food availability, whereas more recent research considers the performance of the entire food system, including economic conditions, institutional capacity, environmental sustainability, and the ability to respond to external shocks (Mkumbukiy et al., 2025; Schneider et al., 2023; Ujjwal et al., 2024). As a result, resilience has become one of the key concepts in contemporary food security research.

Among the most widely used international assessment tools is the Global Food Security Index (GFSI) developed by Economist Impact (2022). The index combines indicators related to food affordability, availability, quality and safety, and natural resources to compare the overall level of food security across countries (Economist Impact, 2022). Because it relies on a broad set of indicators, the GFSI has become an important reference for international comparisons and policy analysis.

Another widely recognised framework is the Resilience Index Measurement and Analysis (RIMA), developed by the Food and Agriculture Organization of the United Nations (FAO). Unlike the GFSI, RIMA was designed to assess the resilience of households and rural communities to food insecurity. The framework has been applied in many developing countries and provides valuable information on household vulnerability and adaptive capacity (Food and Agriculture Organization of the United Nations, 2023).

Although both approaches are widely accepted, neither was developed to evaluate food security at the regional level within a country. The GFSI is intended for national comparisons and, therefore, cannot adequately reflect differences among individual regions. RIMA focuses on households rather than regional socioeconomic systems. Consequently, both approaches provide only limited support for analysing food security in border regions, where agricultural production, infrastructure, demographic change, investment activity, and cross-border interactions are closely interconnected.

Growing interest in regional food systems has encouraged researchers to develop new analytical approaches that better reflect territorial differences. Studies increasingly show that food security varies not only between countries but also across regions with different economic structures, natural conditions, and levels of infrastructure development (Meng & Liu, 2025; Shon & Miles, 2025; Xu et al., 2025). Regional assessments therefore provide information that is often overlooked in national-level analyses and are more useful for designing place-based development policies.

Particular attention has recently been given to border regions. Their development depends on a combination of domestic and external factors, including international trade, labour mobility, transport corridors, and the management of shared natural resources (Ben et al., 2025; Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan, 2026a, 2026b; Christyanto & Mayulu, 2021; Donoso Salas et al., 2025; Gu et al., 2026; Westerdahl et al., 2025). These characteristics distinguish border regions from inland territories and create additional challenges for maintaining stable food systems. At the same time, they increase the importance of regional monitoring and evidence-based policy decisions.

One methodological response to these challenges has been the growing use of composite indicators. By combining information from several variables into a single measure, composite indices make it possible to evaluate complex socio-economic phenomena that cannot be described by one indicator alone (Nardo, Saisana, Saltelli, & Tarantola, 2005; Saaty, 1980; Saisana, Saltelli, & Tarantola, 2005; Saltelli, 2007). The OECD Handbook on Constructing Composite Indicators provides widely accepted guidance on indicator selection, normalization, weighting, aggregation, and validation. These principles have been adopted in many studies addressing regional development and food security (Nardo et al., 2005).

Researchers have proposed different methods for constructing composite indices, including equal weighting, principal component analysis, entropy-based weighting, and the Analytic Hierarchy Process (Cinelli, Kadziński, Miebs, Gonzalez, & Słowiński, 2022; Corrente, Greco, Słowiński, & Zappalà, 2026; Greco, Ehrgott, & Figueira, 2016; Paruolo, Saisana, & Saltelli, 2013; Pascariu, Kourtit, & Tiganasu, 2020; Saaty, 1987). Each approach has advantages and limitations, and the choice depends on the purpose of the study, data availability, and the characteristics of the phenomenon being measured. In studies that rely primarily on official statistical data and aim to support public decision-making, transparent and easily reproducible methods are often preferred over more complex statistical procedures.

Despite the growing literature on food security and composite indicators, an important gap remains. Most existing indices were designed either for comparisons between countries or for assessing household resilience. Relatively few studies address food security at the level of border regions, where agricultural production, demographic trends, infrastructure, and investment need to be considered simultaneously. In addition, many existing approaches rely on datasets that are not readily available for routine regional monitoring.

For these reasons, there is still a need for an assessment tool that can be applied using official regional statistics while accounting for the specific characteristics of border territories. The Border Food Security Index (BFSI) proposed in this study was developed to address this need by combining five complementary dimensions into a single framework suitable for regional comparison and policy analysis.

3. RESEARCH METHODOLOGY

3.1. Research Design and Conceptual Framework

This study adopts a quantitative research design to develop and test the Border Food Security Index (BFSI) as a tool for assessing food security in border regions. The methodological approach is based on the assumption that food security cannot be adequately evaluated using a single indicator because it is shaped by a combination of agricultural, economic, demographic, infrastructural, and investment-related factors. A composite index therefore provides a more comprehensive assessment than any individual variable considered separately.

The empirical analysis focuses on the Turkistan Region of the Republic of Kazakhstan. This region was selected because of its strategic importance for national agricultural production, extensive irrigated farming, and location along the border with Uzbekistan. These characteristics make it an appropriate case for examining how different dimensions of regional development jointly influence food security.

The construction of the index followed a step-by-step procedure. The process included selecting appropriate indicators, collecting publicly available statistics, transforming the variables to a common scale, calculating the component indices, and combining them into a single composite measure. This sequence was designed to ensure transparency and allow the methodology to be reproduced in future studies.

The conceptual framework of the BFSI is presented in Figure 1.

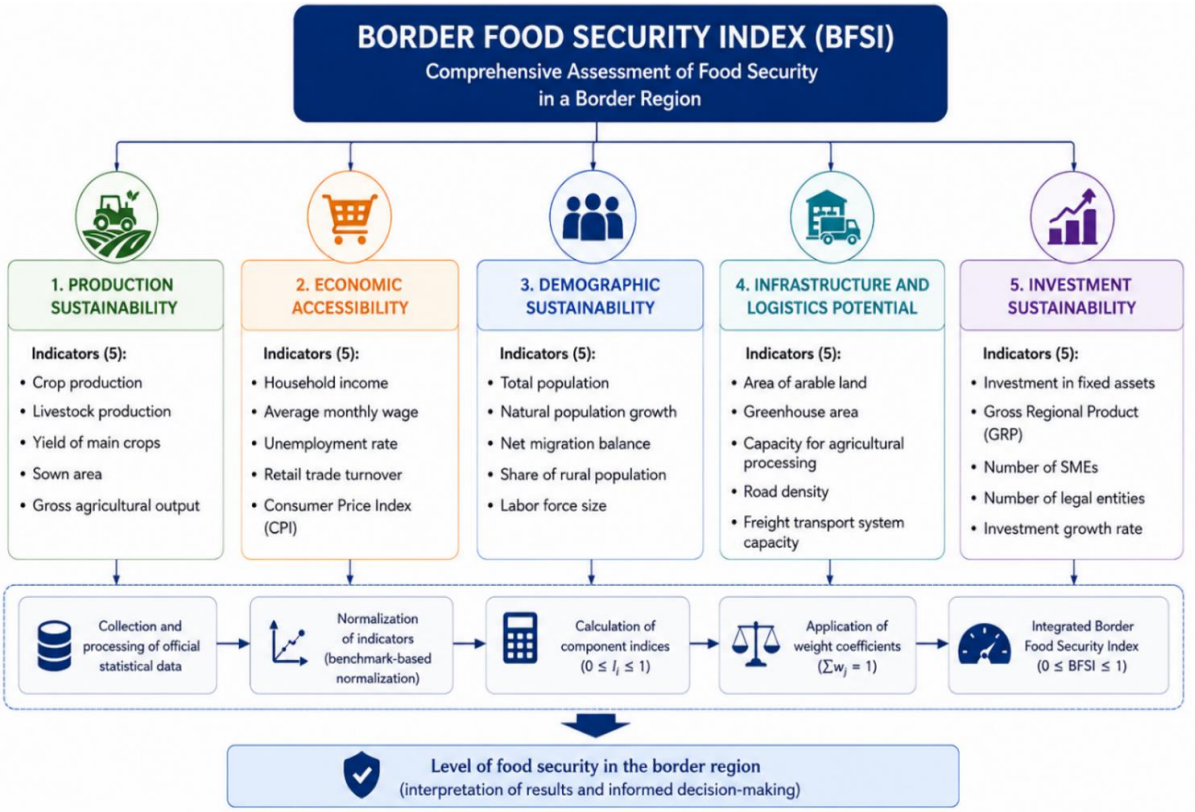

Figure 1. Conceptual framework of the border food security index (BFSI).

The framework groups the selected indicators into five complementary dimensions that together describe the main components of food system resilience. Production Resilience reflects the capacity of the agricultural sector to maintain food production. Food Affordability characterizes the economic accessibility of food for households. Demographic Sustainability considers population characteristics that influence labour availability and long-term regional development. Infrastructure and Logistics Capacity reflects the ability of the region to support the production, storage, processing, and distribution of agricultural products. Investment Resilience captures the investment potential necessary for the long-term development of the regional food system.

Although each dimension represents a different aspect of food security, the dimensions are closely interconnected. Changes in one component may influence the performance of the others. For this reason, the BFSI evaluates food security through an integrated framework rather than through isolated indicators.

3.2. Data Sources

The analysis is based exclusively on official statistical information published by national government institutions and international organizations. The principal sources include the Bureau of National Statistics of the Republic of

Kazakhstan, the Ministry of Agriculture, the Ministry of Water Resources and Irrigation, the Government of the Republic of Kazakhstan, and the Akimat of the Turkistan Region. Additional background information was obtained from reports published by the Food and Agriculture Organization (FAO), the Organisation for Economic Co-operation and Development (OECD), and the World Bank (Akimat of the Turkistan Region, 2024, 2026; Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan, 2025a, 2025b; Department of Agriculture of the Turkistan Region, 2025; Food and Agriculture Organization of the United Nations, 2024; Government of the Republic of Kazakhstan, 2021, 2023; Ministry of Agriculture of the Republic of Kazakhstan, 2025; Ministry of Water Resources and Irrigation of the Republic of Kazakhstan, 2025; Organisation for Economic Co-operation and Development Joint Research Centre of the European Commission, 2008; Republic of Kazakhstan, 2005; Wang et al., 2025; World Bank, 2024).

The use of official statistics was a deliberate methodological choice. First, these data are collected according to uniform national standards, ensuring comparability across regions. Second, they are updated regularly, making the proposed index suitable for continuous monitoring. Finally, publicly available data improve the transparency of the methodology and allow the results to be independently verified and replicated by other researchers.

The empirical analysis uses statistical information covering the period from 2024 to 2026. The dataset includes indicators describing agricultural production, demographic development, household income, employment, investment activity, transport infrastructure, and other factors associated with regional food security.

Before constructing the composite index, all indicators were reviewed for completeness, consistency, and comparability. Because the variables were measured in different units and exhibited substantially different value ranges, they required transformation before aggregation. Several approaches to data transformation were considered during the methodological design. However, the objective of this study was to preserve the relative position of each region while expressing all indicators on a common scale. For this reason, the Min–Max normalization method was selected as the most appropriate approach.

3.3. Selection of Indicators

The selection of indicators was guided by both theoretical considerations and practical data availability. Rather than maximizing the number of variables, the objective was to identify indicators that adequately reflect the multidimensional nature of food security while remaining suitable for routine regional monitoring.

The initial list of potential indicators was compiled through a review of the literature on food security, regional development, and composite indices. Particular attention was given to internationally recognised approaches developed by the FAO, OECD, Economist Impact, and previous studies on food system resilience (Béné, 2022; Constas et al., 2022; Economist Impact, 2022; Food and Agriculture Organization of the United Nations, 2023, 2024; Liang et al., 2025; Meng & Liu, 2025; Mkumbukiy et al., 2025; National Academies of Sciences Engineering and Medicine, 2020; Organisation for Economic Co-operation and Development Joint Research Centre of the European Commission, 2008; Palkovič, 2024; Schneider et al., 2023; Shon & Miles, 2025; Subedi, Godde, Korale-Gedara, Farr, & Fyfe, 2025; Ujjwal et al., 2024; World Bank, 2024; Xu et al., 2025). Each indicator was subsequently evaluated using several criteria, including relevance to regional resilience, availability in official statistics, consistency of measurement, regular publication, and suitability for interregional comparison.

Indicators providing overlapping information or lacking reliable statistical coverage were excluded from further analysis. As a result, twenty-five indicators were selected and organised into five analytical dimensions that form the framework. Table 1 presents the selected indicators, their expected effects, and the corresponding data sources.

Table 1. Indicator system of the border food security index (BFSI).

Component	Indicator	Expected Effect	Data Source
Production Resilience	Gross agricultural output	+	Bureau of National Statistics of the Republic of Kazakhstan (BNS RK)
	Gross crop production	+	BNS RK
	Gross livestock production	+	BNS RK
	Sown area	+	BNS RK
	Yield of major agricultural crops	+	BNS RK
Food Affordability	Average monthly wage	+	BNS RK
	Per capita household income	+	BNS RK
	Unemployment rate	−	BNS RK
	Consumer Price Index (CPI)	−	BNS RK
	Retail trade turnover	+	BNS RK
Demographic Sustainability	Total population	+	BNS RK
	Share of rural population	+	BNS RK
	Natural population growth	+	BNS RK
	Net migration	+	BNS RK
	Economically active population	+	BNS RK
Infrastructure and Logistics Capacity	Irrigated land area	+	Ministry of Water Resources and Irrigation of the Republic of Kazakhstan
	Greenhouse cultivation area	+	Ministry of Agriculture of the Republic of Kazakhstan
	Freight turnover	+	BNS RK
	Volume of agricultural product processing	+	BNS RK
	Transport infrastructure development	+	BNS RK
Investment Resilience	Investment in fixed capital	+	BNS RK
	Gross Regional Product (GRP)	+	BNS RK
	Number of active legal entities	+	BNS RK
	Number of small and medium-sized enterprises (SMEs)	+	BNS RK
	Investment growth rate	+	BNS RK

The final list of indicators was intended to balance methodological completeness with the practical requirement that the index be calculated using publicly available statistical information.

The selected indicators were further classified according to the direction of their expected influence on food security. Variables associated with improvements in regional food security, such as agricultural output, investment, and household income, were treated as benefit indicators. Variables whose increases reflect less favourable conditions, including the unemployment rate and consumer price inflation, were treated as cost indicators. This classification provided the basis for the normalization procedure described in the following section.

3.4. Normalization of Statistical Indicators

The indicators included in the proposed index differ substantially in their units of measurement and numerical ranges. Some variables are expressed as monetary values, whereas others represent demographic characteristics, production volumes, or percentages. Direct aggregation of these variables would therefore distort the final results, as indicators with larger numerical values would exert a disproportionate influence on the composite index.

To ensure comparability, all variables were transformed to a common scale using the Min–Max normalization method. This approach is widely applied in the construction of composite indices because it preserves the relative positions of observations while expressing every indicator within the interval from 0 to 1 (Nardo et al., 2005). In

addition, the normalized values remain easy to interpret, which is particularly important when the results are intended to support regional policy decisions.

The indicators were divided into two groups according to the expected direction of their influence on food security. Indicators whose higher values contribute to stronger food security were classified as benefit indicators, whereas indicators whose increasing values reflect less favourable conditions were classified as cost indicators.

For benefit indicators, normalization was performed using the following equation.

$$I_i = \frac{X_i - X_{min}}{X_{max} - X_{min}}$$

Where:

I_i — normalized value of indicator i.

X_i — is the observed value.

X_{min} — is the minimum observed value among the regions.

X_{max} — is the maximum observed value among the regions.

For cost indicators, the following transformation was applied.

$$I_i = \frac{X_{max} - X_i}{X_{max} - X_{min}}$$

Where:

Using different equations for benefit and cost indicators ensures that higher normalized values always correspond to better food security performance, regardless of the original direction of the indicator.

Alternative normalization techniques are available in the literature, including logarithmic transformation and z-score standardization. These methods may be appropriate for studies focused on statistical modelling or highly skewed data. However, the objective of the present study was to construct a transparent and reproducible composite index that could be readily replicated using publicly available official statistics. For this reason, the Min–Max normalization method was selected because it preserves the relative position of observations while transforming all indicators to a common scale. Table 2 classifies the selected variables as benefit or cost indicators and provides representative examples.

Table 2. Classification of border food security index (BFSI) indicators.

Indicator Type	Description	Examples
Benefit indicators (Stimulants)	An increase in the indicator improves the level of food security.	Gross agricultural output, investment, crop yield, household income
Cost indicators (Destimulants)	An increase in the indicator reduces the level of food security.	Unemployment rate, Consumer Price Index (CPI)

3.5. Calculation of Component Indices

After normalization, the indicators were aggregated into five component indices corresponding to the principal dimensions of the proposed index.

Each component was calculated as the arithmetic mean of its normalized indicators.

where:

$$C_j = \frac{\sum_{i=1}^{n} I_i}{n}$$

C_j — is the value of the component index.

I_i — is the normalized value of indicator i.

n— is the number of indicators included in the component.

The use of the arithmetic mean reflects the assumption that all indicators within a given dimension contribute equally to the characteristic being measured. Since the selected variables describe complementary aspects of the same dimension, and no empirical evidence was available to justify assigning different importance to individual indicators,

equal weighting within each component was considered appropriate. This approach also improves the transparency of the methodology and facilitates interpretation of the component scores. Rather than relying exclusively on the overall composite index, the five component indices allow individual dimensions of regional resilience to be examined separately, making it possible to identify both strengths and potential weaknesses within the regional food system.

3.6. Weighting Scheme

The final Index was obtained by combining the five component indices using predetermined weights.

Assigning weights is one of the most important stages in constructing a composite index because it determines the relative contribution of each dimension to the final assessment. Different weighting techniques have been proposed in previous studies, including equal weighting, principal component analysis (PCA), the analytic hierarchy process (AHP), entropy-based weighting, and other multicriteria decision-making approaches (Cinelli et al., 2022; Corrente et al., 2026; Greco et al., 2016; Paruolo et al., 2013; Pascariu et al., 2020; Saaty, 1987).

Each method has particular advantages, depending on the objectives of the analysis and the characteristics of the available data. Statistical approaches, such as PCA or entropy weighting, derive weights directly from the structure of the dataset, whereas AHP relies on expert judgment. Although these methods are widely recognised, they also increase methodological complexity and may reduce the transparency of the resulting index.

The present study follows an expert-informed weighting approach. This decision was guided by two considerations. First, the objective was to develop an index that can be readily applied using official regional statistics without requiring complex statistical procedures. Second, the proposed weighting scheme reflects the relative importance of the five dimensions within the regional food system, as identified in the literature and supported by the characteristics of border regions in Kazakhstan. Production Resilience received the highest weight because stable agricultural production forms the basis of regional food security. Food Affordability and Infrastructure and Logistics Capacity were assigned equal weights because of their direct influence on access to food and the functioning of regional supply systems. Demographic Sustainability and Investment Resilience received slightly lower weights, reflecting their indirect but important contributions to long-term food security. Table 3 presents the weight assigned to each BFSI component and explains the rationale for the weighting scheme.

Table 3. Weighting Scheme of the Border Food Security Index (BFSI).

Component	Weight	Rationale
Production Resilience	0.30	Determines the physical availability of food within the region.
Food Affordability	0.20	Reflects the purchasing power of the population.
Demographic Sustainability	0.15	Represents the availability and sustainability of human resources.
Infrastructure and Logistics Capacity	0.20	Determines the efficiency of food storage, processing, and transportation.
Investment Resilience	0.15	Reflects the long-term development potential of the regional agri-food system.

To illustrate the calculation procedure, an example of the weighted aggregation is presented in Table 4.

Table 4. Example of border food security index (BFSI) calculation.

Component	Index Value	Weight	Weighted Contribution
Production Resilience Index (PRI)	0.92	0.30	0.276
Food Affordability Index (FAI)	0.76	0.20	0.152
Demographic Sustainability Index (DSI)	0.88	0.15	0.132
Infrastructure and Logistics Capacity Index (ILI)	0.94	0.20	0.188
Investment Resilience Index (IRI)	0.84	0.15	0.126
Border Food Security Index (BFSI)	0.874	1.00	0.874

3.7. Interpretation of the Border Food Security Index

To facilitate the interpretation of the calculated values, the Index was classified into five performance levels, ranging from *Critically Low* to *Very High*. This classification provides a common framework for comparing food security performance and simplifies interpretation of the composite index for policymakers and researchers. Table 5 presents the five BFSI performance levels and provides an interpretation of each level.

Table 5. Interpretation of border food security index (BFSI) values.

BFSI Value	Food Security Level	Interpretation
0.00–0.20	Critically Low	The regional food system is unable to ensure a stable food supply for the population.
0.21–0.40	Low	The region exhibits a high dependence on external factors and faces substantial structural constraints.
0.41–0.60	Moderate	Basic food needs are generally satisfied; however, significant vulnerabilities remain.
0.61–0.80	High	The regional food system demonstrates stable and sustainable performance.
0.81–1.00	Very High	All major dimensions of regional food security exhibit a high degree of resilience.

The proposed classification should be regarded as a practical interpretive scale rather than a rigid statistical threshold. Its primary purpose is to distinguish among different levels of regional food security and to support comparative assessments across border regions. Because the index is based on normalized indicators, its interpretation remains consistent when the methodology is applied to other regions using the same calculation procedure.

3.8. Validation of the Border Food Security Index

Validation is an essential stage in the development of any composite indicator because it demonstrates whether the proposed methodology is logically consistent, transparent, and suitable for practical application. In the present study, validation of the framework focuses on three aspects: methodological consistency, reproducibility, and practical applicability.

Methodological consistency was ensured by following a clearly defined sequence of analytical steps, beginning with the selection of indicators and ending with the calculation of the composite index. Each stage of the procedure is explicitly described, allowing other researchers to reproduce the calculations using the same statistical sources and methodological assumptions.

Reproducibility is supported by the exclusive use of government statistics published by government institutions. Since the selected indicators are collected according to national statistical standards and updated regularly, the proposed index can be recalculated for subsequent years or applied to other border regions of Kazakhstan without modifying the underlying methodology.

The practical applicability of the index was examined through its application to the Turkistan Region. The resulting component scores correspond well with the region's documented socioeconomic characteristics. Production Resilience and Infrastructure and Logistics Capacity received the highest values, reflecting the region's strong agricultural base and developed irrigation infrastructure. Food Affordability recorded the lowest score, indicating that inflation and purchasing power remain the principal constraints affecting regional food security. This consistency between the calculated results and official regional statistics provides additional support for the practical usefulness of the proposed methodology.

The primary objective of the proposed methodology was to develop a transparent and reproducible framework based on official regional statistics. Future studies may extend the validation process by comparing alternative weighting schemes and conducting additional robustness analyses.

Overall, the proposed index provides a transparent and reproducible approach to assessing food security in border regions. While additional statistical validation may further strengthen the methodology, the current approach offers a practical tool for regional monitoring, comparative analysis, and evidence-based policymaking.

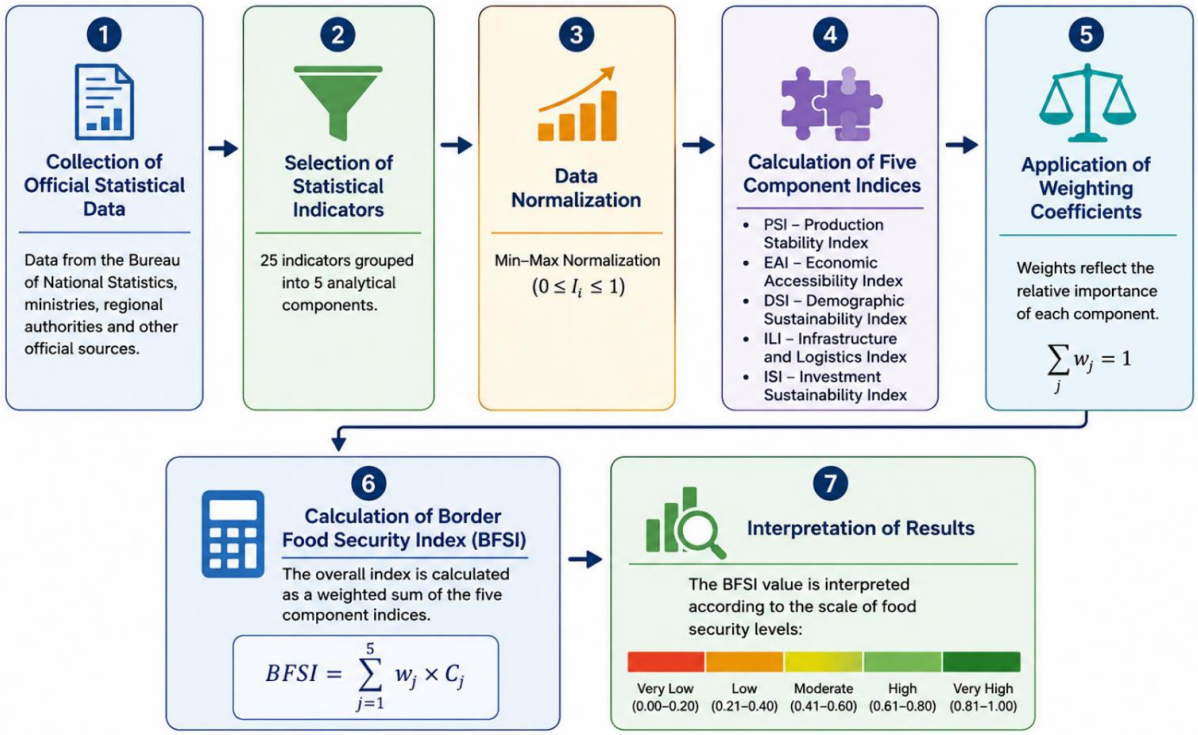

Figure 2. Algorithm for calculating the border food security index (BFSI).

Figure 2 summarises the sequence of analytical steps used to construct the index. The procedure begins with data collection and indicator selection, followed by normalization, calculation of the component indices, weighted aggregation, and interpretation of the final composite index. Presenting the methodology in this form improves transparency and facilitates its application in future studies.

4. RESULTS

4.1. Current State of Food Security in the Turkistan Region

Publicly available statistics indicate that the Turkistan Region plays a central role in Kazakhstan's agricultural sector and makes a substantial contribution to the country's food supply. The region benefits from favourable climatic conditions, extensive irrigated agriculture, and continuing public investment, all of which support stable agricultural production and strengthen the regional food system (Ministry of Agriculture of the Republic of Kazakhstan, 2025; Ministry of Water Resources and Irrigation of the Republic of Kazakhstan, 2025; Wang et al., 2025).

By 1 May 2026, the region's population had reached 2.147 million people, with almost three-quarters of residents living in rural areas. This demographic structure provides an important labour base for agricultural production. At the same time, the continuing negative migration balance (-13,180 people) suggests that retaining skilled workers remains a challenge for the region's long-term development (Republic of Kazakhstan, 2005; Wang et al., 2025).

Economic indicators also show generally positive dynamics. During the first quarter of 2026, the average monthly nominal wage reached KZT 332,640, while average per capita household income increased to KZT 134,176. The unemployment rate remained relatively low at 4.6%. Nevertheless, consumer prices continued to rise, with the Consumer Price Index reaching 104.8% compared with December 2025. This suggests that improvements in household income have been partly offset by inflationary pressure, reducing gains in purchasing power (Republic of Kazakhstan, 2005; Wang et al., 2025). Agriculture continues to be the foundation of the regional economy. Between

January and May 2026, gross agricultural output totalled KZT 255.2 billion, representing annual growth of 10.9%. During the same period, investment in fixed capital exceeded KZT 614 billion, more than 50% higher than in the previous year. These trends indicate the continued expansion of both agricultural production and investment activity (Akimat of the Turkistan Region, 2026; Republic of Kazakhstan, 2005; Wang et al., 2025). Entrepreneurial activity also remains strong. By June 2026, the region had 18,743 active legal entities, including more than 18,000 small enterprises. The continuing growth of small and medium-sized enterprises reflects increasing business activity and strengthens the economic foundation supporting food security performance (Republic of Kazakhstan, 2005; Wang et al., 2025). Taken together, these indicators suggest that the Turkistan Region possesses favourable conditions for maintaining a high level of food security. At the same time, inflation and continued outward migration remain the principal socio-economic challenges that may affect its future resilience.

4.2. Analysis of the Border Food Security Index Components

The Border Food Security Index makes it possible to evaluate not only the overall level of food security but also the contribution of each component to the final assessment. Examining the component indices separately provides a clearer understanding of the strengths and weaknesses of the regional food system and helps identify areas where policy intervention may have the greatest impact.

4.3. Production Resilience Index (PRI)

The Production Resilience Index achieved the highest value among the production-related dimensions, reaching 0.92. This result reflects the strong agricultural performance of the Turkistan Region, supported by high levels of crop and livestock production, extensive cultivated land, and favourable agricultural conditions (Akimat of the Turkistan Region, 2026; Republic of Kazakhstan, 2005).

The high score indicates that the region has a stable production base capable of supporting the domestic food supply. This finding is consistent with official statistics showing continued growth in agricultural output and confirms the strategic role of the Turkistan Region within Kazakhstan's agri-food system. At the same time, strong production capacity alone does not guarantee overall food security, as food availability must also be supported by affordable prices, efficient infrastructure, and sustainable regional development.

4.4. Food Affordability Index (FAI)

Among the five component indices, Food Affordability recorded the lowest value (0.76).

Although household incomes have continued to increase in recent years, rising consumer prices have reduced the positive effect of income growth on purchasing power. Average wages in the Turkistan Region also remain below those observed in several economically stronger regions of Kazakhstan (Republic of Kazakhstan, 2005; Wang et al., 2025). From a policy perspective, this result is particularly important. It suggests that improving agricultural production alone is unlikely to strengthen regional food security unless economic access to food also improves. Measures aimed at increasing real household income, maintaining price stability, and supporting vulnerable population groups may therefore have a substantial impact on the overall level of food security.

4.5. Demographic Sustainability Index (DSI)

The Demographic Sustainability Index reached 0.88, indicating favourable demographic conditions for the long-term development of the regional food system.

The region has the largest population among Kazakhstan's border regions and a high proportion of rural residents, providing an important labour resource for agriculture (Republic of Kazakhstan, 2005; Wang et al., 2025). Positive natural population growth further supports the long-term sustainability of agricultural production.

At the same time, the continuing negative migration balance remains an important concern. Although it does not currently reduce the overall level of food security, continued outward migration may gradually weaken the regional labour force and reduce the capacity for future agricultural development.

4.6. Infrastructure and Logistics Capacity Index (ILI)

The Infrastructure and Logistics Capacity Index achieved the highest score of all five components, reaching 0.94.

This result reflects the region's extensive irrigation systems, large greenhouse sector, and continued investment in transport and logistics infrastructure (Akimat of the Turkistan Region, 2024; Department of Agriculture of the Turkistan Region, 2025; Republic of Kazakhstan, 2005). Efficient infrastructure improves the movement, storage, and processing of agricultural products, reducing losses and supporting stable food distribution.

The high value of this component demonstrates that infrastructure is one of the principal competitive advantages of the Turkistan Region and makes a substantial contribution to the resilience of the regional food system.

4.7. Investment Resilience Index (IRI)

The Investment Resilience Index was estimated at 0.84, indicating favourable conditions for continued development of agriculture and related industries.

Recent growth in fixed capital investment, together with expanding business activity and increasing numbers of small and medium-sized enterprises, reflects growing confidence in the regional economy (Republic of Kazakhstan, 2005; Wang et al., 2025). Continued investment supports technological modernisation, infrastructure development, and improvements in agricultural productivity, all of which strengthen the food system's long-term resilience. Table 6 presents the values of the five component indices used in the integrated assessment.

Table 6. Component values of the border food security index (BFSI).

Component	Index Value
Production Resilience Index (PRI)	0.92
Food Affordability Index (FAI)	0.76
Demographic Sustainability Index (DSI)	0.88
Infrastructure and Logistics Capacity Index (ILI)	0.94
Investment Resilience Index (IRI)	0.84

Figure 3 illustrates the component structure of the BFSI and shows the relative performance of its five dimensions.

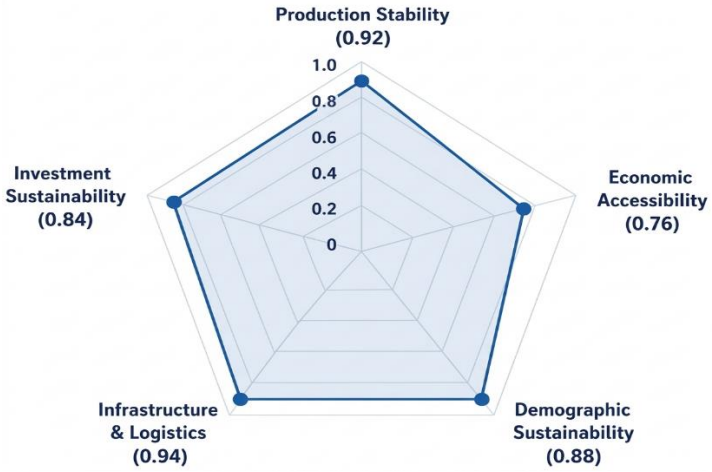

Figure 3. Component structure of the border food security index (BFSI): Radar chart of the component index values.

4.8. Integrated Assessment of Food Security in the Turkistan Region Using the Border Food Security Index (BFSI)

The five component indices were combined to obtain an overall assessment of food security in the Turkistan Region. The calculation followed the methodological procedure described in the previous section, including indicator normalization, estimation of the component indices, and weighted aggregation. Table 7 presents the weighted calculation of the overall BFSI for the Turkistan Region.

Table 7. Calculation of the border food security index (BFSI) for the Turkistan region.

Component	Index Value	Weight	Contribution to BFSI
Production Resilience Index (PRI)	0.92	0.30	0.276
Food Affordability Index (FAI)	0.76	0.20	0.152
Demographic Sustainability Index (DSI)	0.88	0.15	0.132
Infrastructure and Logistics Capacity Index (ILI)	0.94	0.20	0.188
Investment Resilience Index (IRI)	0.84	0.15	0.126
Border Food Security Index (BFSI)	0.874	1.00	0.874

The overall Border Food Security Index reached 0.874, placing the Turkistan Region in the category of Very High Food Security, according to the interpretation scale presented in the methodology.

This result reflects the combined effect of several favourable characteristics rather than the exceptional performance of a single indicator. High agricultural production, developed irrigation infrastructure, continued investment activity, and favourable demographic conditions together create a stable foundation for the regional food system. The relatively balanced distribution of component scores also suggests that regional food security depends on the interaction of several mutually reinforcing dimensions rather than on production capacity alone.

Nevertheless, the analysis also highlights important differences among the individual components. While Production Resilience and Infrastructure and Logistics Capacity achieved very high values, Food Affordability remained the weakest dimension of the index. This imbalance indicates that economic access to food continues to represent the principal constraint on further improvements in regional food security.

From a policy perspective, these findings suggest that future improvements are likely to depend less on expanding agricultural production and more on strengthening household purchasing power, reducing inflationary pressures, and improving the economic accessibility of food. Such measures would complement the region's existing production capacity and contribute to a more balanced and resilient food system.

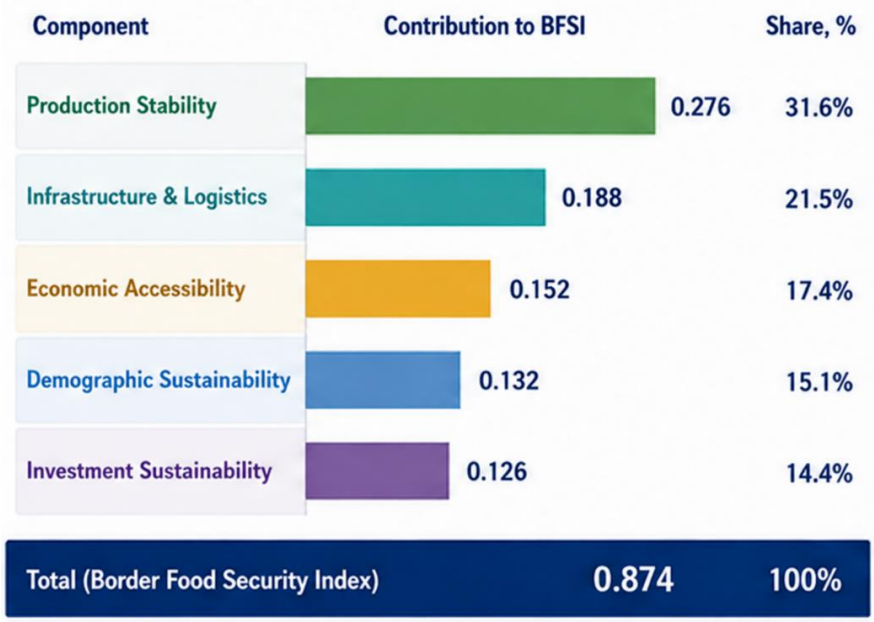

Figure 4. Contribution of the Component Indices to the Overall Border Food Security Index (BFSI).

Figure 4 illustrates the contribution of each component index to the overall BFSI value. Production Resilience makes the largest contribution, accounting for 0.276, or 31.6% of the total index. Infrastructure and Logistics Capacity ranks second, with a contribution of 0.188 (21.5%), followed by Food Affordability at 0.152 (17.4%). Demographic Sustainability and Investment Resilience contribute 0.132 (15.1%) and 0.126 (14.4%), respectively. Together, these five components generate an overall BFSI value of 0.874, indicating that the region's strong production base and infrastructure are the principal drivers of food security.

4.9. Interpretation of the Border Food Security Index Results

The application of the Border Food Security Index demonstrates the advantages of evaluating food security through a multidimensional framework rather than relying on individual production or economic indicators. Although agricultural production remains an essential element of food security, the results show that regional resilience depends on the combined influence of production capacity, household access to food, demographic conditions, infrastructure, and investment activity.

The findings are broadly consistent with previous studies, emphasising that food security should be viewed as a multidimensional phenomenon influenced by economic, institutional, and infrastructural factors in addition to agricultural production (Constas et al., 2022; Liang et al., 2025; Meng & Liu, 2025; Mkumbukiy et al., 2025; Palkovič, 2024; Schneider et al., 2023; Shon & Miles, 2025; Subedi et al., 2025; Ujjwal et al., 2024; Xu et al., 2025). However, unlike existing international indices such as the Global Food Security Index (GFSI) and the FAO Resilience Index Measurement and Analysis (RIMA), the proposed Border Food Security Index evaluates these dimensions at the regional level using official statistical information. This provides a perspective that is particularly relevant for border territories, where regional conditions may differ substantially from national averages.

The results indicate that the Turkistan Region possesses considerable production and infrastructure advantages, supported by sustained investment and favourable demographic characteristics. These strengths explain the high overall BFSI value. At the same time, the comparatively lower Food Affordability Index suggests that economic access to food remains the principal factor limiting further improvement. Consequently, policies aimed at increasing household purchasing power and maintaining price stability are likely to have a greater impact on future food security than further expansion of agricultural production alone.

Overall, the Border Food Security Index provides a more detailed assessment than a single composite score. Examining the individual component indices enables policymakers to identify priority areas for intervention and design measures that address specific weaknesses within regional food systems, rather than applying uniform policy solutions across all regions.

5. DISCUSSION

5.1. Scientific Contribution of the Border Food Security Index (BFSI)

The development of the Border Food Security Index extends existing approaches to food security assessment by focusing on the regional level rather than on national- or household-level analysis. While international indices have made an important contribution to measuring food security, relatively little attention has been given to the specific characteristics of border regions, where agricultural production, infrastructure, demographic processes, and cross-border interactions jointly influence regional resilience. The findings of this study suggest that evaluating these dimensions separately provides a more complete understanding of regional food security than relying on agricultural production indicators alone. In the case of the Turkistan Region, strong production capacity is accompanied by favourable infrastructure and investment conditions, yet economic access to food remains comparatively weaker. This illustrates that high agricultural output does not automatically guarantee equally strong performance across all dimensions of food security. The proposed index therefore contributes to the growing literature that conceptualizes

food security as a multidimensional phenomenon shaped by interactions among economic, social, demographic, and institutional factors, rather than agricultural production alone.

5.2. Comparison with Existing Approaches

The Border Food Security Index shares several conceptual features with internationally recognised assessment frameworks, particularly the Global Food Security Index (GFSI) and the FAO Resilience Index Measurement and Analysis (RIMA). All three approaches recognise that food security depends on multiple dimensions rather than on food production alone.

However, important differences remain.

The GFSI was designed primarily to compare countries and therefore provides limited information about differences within individual regions. RIMA focuses mainly on household resilience and vulnerability, making it especially useful for community-level studies. By contrast, the Border Food Security Index was developed specifically for regional analysis and uses official statistical information routinely collected by government agencies.

This distinction is particularly important for countries such as Kazakhstan, where neighbouring regions may differ considerably in agricultural specialization, infrastructure, demographic structure, and cross-border economic activity. A regional assessment, therefore, provides information that cannot be obtained from national-level indices alone. Table 8 compares the GFSI, RIMA, and BFSI in terms of their unit of analysis, primary objective, data sources, consideration of border-specific characteristics, and applicability to regional policymaking.

Table 8. Comparison of the border food security index (BFSI) with existing international food security indices.

Criterion	Global food security index (GFSI)	Resilience index measurement and analysis (RIMA)	Border food security index (BFSI)
Unit of analysis	Country	Household	Region
Primary objective	International comparison of food security	Assessment of household resilience to food insecurity	Monitoring and assessment of regional food security
Use of official statistical data	Partial	Partial	Comprehensive
Consideration of border-specific characteristics	No	No	Yes
Applicability to regional policymaking	Limited	Limited	High

Source: Compiled by the authors based on the methodologies of the Global Food Security Index (GFSI), the FAO Resilience Index Measurement and Analysis (RIMA) framework, and the findings of the present study.

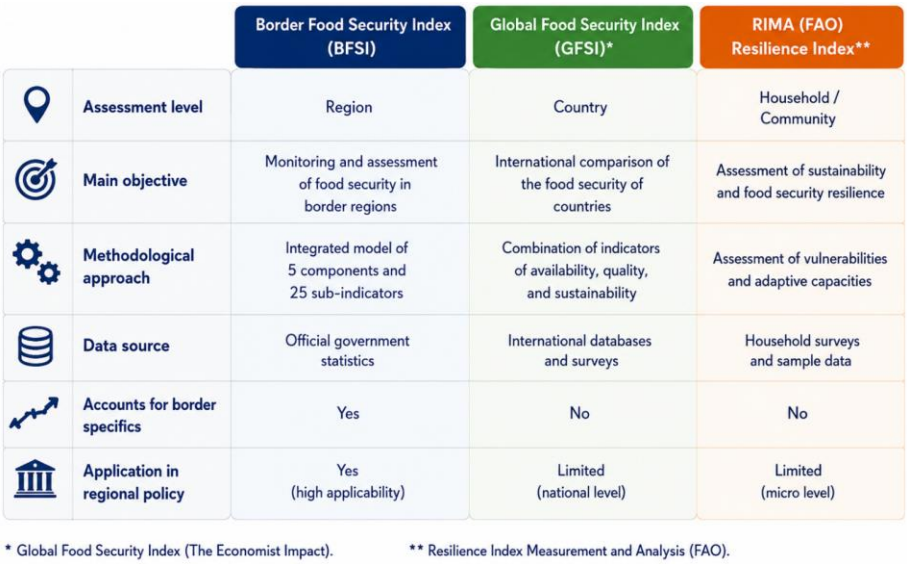

Figure 5. Comparison of the Border Food Security Index (BFSI) with the Global Food Security Index (GFSI) and the Resilience Index Measurement and Analysis (RIMA).

Figure 5 compares the proposed Border Food Security Index with the Global Food Security Index and the FAO Resilience Index Measurement and Analysis framework. The comparison shows that the GFSI primarily assesses food security at the national level, whereas RIMA focuses on households and communities. In contrast, the BFSI evaluates food security at the regional level using official statistical indicators and explicitly incorporates the specific characteristics of border regions. Consequently, the BFSI provides greater applicability to regional monitoring, development planning, and evidence-based policymaking.

5.3. Interpretation of the Findings

The empirical results demonstrate that the Turkistan Region currently possesses favourable conditions for maintaining a high level of food security. High agricultural productivity, well-developed irrigation systems, and continuing investment activity form a stable foundation for regional food production.

Nevertheless, the component analysis also demonstrates that regional food security cannot be evaluated solely on the basis of production indicators. Although the Production Resilience and Infrastructure and Logistics Capacity components achieved very high scores, Food Affordability remained comparatively lower. This finding indicates that economic access to food continues to represent one of the principal challenges despite favourable production conditions.

The results support previous studies arguing that food security should be viewed as a multidimensional concept influenced simultaneously by agricultural, economic, demographic, and institutional factors. The proposed Border Food Security Index makes these relationships more visible by presenting both the overall level of food security and the contribution of each individual dimension.

5.4. Practical Implications

The proposed Border Food Security Index has several practical applications for regional planning and public administration.

First, the methodology can support regular monitoring of food security across Kazakhstan's border regions using official statistical information. Second, the index's component structure enables policymakers to identify which dimensions require the greatest attention, rather than relying exclusively on the overall composite score.

The findings also suggest that future policy should place greater emphasis on improving food affordability alongside continued support for agricultural production. Measures aimed at increasing household purchasing power, reducing inflationary pressures, and strengthening regional labour markets may complement existing agricultural policies and contribute to a more balanced model of regional food security.

Beyond Kazakhstan, the proposed methodology may also be adapted for application in other border regions where official statistical information is available and food security is influenced by similar combinations of agricultural, demographic, and economic factors.

5.5. Limitations and Future Research

Like any composite indicator, the Border Food Security Index has several limitations that should be considered when interpreting the results.

The empirical analysis presented in this study is based on a single border region. Although the Turkistan Region provides an appropriate case study, further applications in other regions would allow broader comparison and provide additional evidence regarding the usefulness of the methodology.

The index also relies exclusively on official statistical information. This improves transparency and reproducibility but does not capture qualitative aspects of food security, including institutional performance, consumer behaviour, dietary diversity, or governance quality.

Future research may further develop the methodology by incorporating additional indicators related to environmental sustainability, climate resilience, digitalisation, and cross-border cooperation. Comparative analyses involving several border regions would also make it possible to evaluate regional differences more comprehensively and further strengthen the practical value of the Border Food Security Index.

6. CONCLUSION

This study developed and applied the proposed index, a composite indicator designed to assess food security in border regions using official regional statistics. The proposed methodology integrates five complementary dimensions Production Resilience, Food Affordability, Demographic Sustainability, Infrastructure and Logistics Capacity, and Investment Resilience into a single analytical framework suitable for regional assessment.

The empirical application to the Turkistan Region demonstrates that the region currently maintains a very high level of food security, with an overall BFSI value of 0.874. The strongest performance was observed in Production Resilience and Infrastructure and Logistics Capacity, reflecting the region's well-developed agricultural sector and transport infrastructure. At the same time, Food Affordability emerged as the weakest component, indicating that economic access to food remains the principal challenge despite favourable production conditions.

The results show that food security cannot be evaluated solely through agricultural production indicators. Economic conditions, demographic characteristics, infrastructure, and investment also play important roles in determining the resilience of regional food systems. Assessing these dimensions together provides a more comprehensive understanding of food systems and helps identify areas where public policy can be most effective.

From a practical perspective, the Border Food Security Index offers a transparent and reproducible tool that can support regional monitoring, comparative analysis, and evidence-based decision-making. Because the methodology relies on official statistical information, it can be updated regularly and adapted for application in other border regions of Kazakhstan and in countries facing similar regional development challenges.

Future research may extend the proposed framework by applying the index to additional regions, incorporating environmental and climate-related indicators, and comparing alternative approaches to weighting and validation. Such developments would further enhance the methodology's analytical value and contribute to a broader understanding of food security in border territories.

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Appendix A. Example of the border food security index (BFSI) calculation.

To improve the transparency and reproducibility of the proposed methodology, this Appendix A presents a complete example of the calculation procedure for one statistical indicator included in the Border Food Security Index (BFSI). The same computational procedure was applied to all remaining indicators.

Step 1. Selection of the indicator

As an example, the indicator Average Monthly Nominal Wage included in the Economic Accessibility Index (EAI) was selected.

According to the Bureau of National Statistics of the Republic of Kazakhstan, the average monthly nominal wage in Turkistan Region in the first quarter of 2026 amounted to 332,640 KZT. The minimum value among the regions of Kazakhstan was recorded in the North Kazakhstan Region (326,664 KZT), whereas the maximum value was observed in the Mangystau Region (659,801 KZT).

Table A1 presents the source data used to demonstrate the normalization of the average monthly nominal wage indicator, including the observed value for the Turkistan Region and the minimum and maximum regional values.

Table A1. Example of source data.

Indicator	Turkistan Region	Minimum	Maximum
Average monthly nominal wage (KZT)	332,640	326,664	659,801

Step 2. Normalization

Normalization of stimulant indicators was performed using the Min–Max procedure.

$$I_i = \frac{X_i - X_{min}}{X_{max} - X_{min}}$$

Substituting the official statistical values.

$$I = \frac{332640 - 326664}{659801 - 326664} = 0.018$$

Thus, the normalized value of the indicator equals.

$I = 0.018$

Table A2 presents the input parameters used in the Min–Max normalization procedure and the resulting normalized value of 0.018 for the average monthly nominal wage indicator.

Table A2. Example of normalization procedure.

Parameter	Value
Region	Turkistan
Observed value	332640
Minimum	326664
Maximum	659801
Normalized value	0.018

Step 3. Component Index Calculation

After normalization, all indicators belonging to the Economic Accessibility component were aggregated using the arithmetic mean.

$$EAI = \frac{\sum_{i=1}^{5} I_i}{5}$$

The same computational procedure was applied to all remaining indicators included in the Border Food Security Index.

Step 4. Final Border Food Security Index

After normalization of all indicators and calculation of the five component indices, the overall Border Food Security Index was obtained using the weighted aggregation procedure described in Section 3.6.

The same computational sequence was applied to all twenty-five indicators included in the proposed methodology. Consequently, the resulting Border Food Security Index represents an integrated quantitative assessment of the overall level of food security in the analyzed border region.

The statistical data used in this study were obtained from publicly available official sources cited in the References.