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Modeling the Short-Run and Long-Run Effects of Water Stress on Food Security in Iran: ARDL Approach

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Highlights

- **Water stress reduces food security.**
- **Financial credit extended to agriculture improves food security.**
- **Electricity access increases food security.**
- **Income inequality reduces food security.**
- **The ECM indicates a rapid convergence toward the long-run equilibrium.**

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Abstract

Providing food and proper nutrition is a prerequisite for development and health of society and is an important factor in establishing conditions of stability, prosperity, peace and security. Therefore, among the priorities of development goals, achieving food security is of particular importance and has always been emphasized by policymakers. Accordingly, this study investigates the extent to which water stress influences food security in Iran. Using an Autoregressive Distributed Lag (ARDL) model over the period 1990–2023, our results reveal that water stress has a significant and negative impact on food security. Among the primary challenges to food security, water stress notably reduces agricultural yields—especially in irrigated regions. Diminished supply resulting from water scarcity drives up prices and lowers economic access to food. It also restricts the production of diverse and nutritious crops, thereby compromising dietary quality. Further model estimates indicate that energy security and agricultural credit positively and significantly enhance food security, whereas income inequality (measured by the Gini coefficient) exerts a significant negative effect. The error-correction coefficient suggests that approximately 72% of per-period disequilibrium is corrected in the subsequent period, indicating a robust and speedily adjusting return toward long-run equilibrium.

1. Introduction

Today, challenges such as increasing hunger in the world, the lack of balance in people's daily diets, and the destruction of the environment and natural resources have made food security one of the most important issues for human societies. In other words, ensuring food security is one of the main conditions for achieving national security, increasing productivity, and human health, so countries strive to achieve a desirable degree of it (Ecker & Breisinger 2012; Shukri & Arani 2018; Upton et al. 2016).

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Food security encompasses an array of factors ranging from food availability, accessibility, utilization, to food stability, being traditionally used to assess whether people are able to attain food. The attainment of food security on a sustainable basis entails a wide variety of factors. In line with World Food Summit principles, food security is attained through everyone having at all times physical and economic accessibility to enough, safe, wholesome food meeting dietary needs for an active life. (Poczta-Wajda et al. 2020; Stephens, et al 2018).

Food security is essential to health, learning, and productivity. Indeed, food security is the backbone of a developed nation and a fundamental feature of intellectual, psychological, and physical well-being of the people. This has particular relevance in developing countries like Iran. Food security entails adequate food availability at the macro-level, with fair distribution to enable access to food for everyone.

United Nations projections indicate that the world's population will rise to approximately 9.7 billion by 2050. (UN, 2023). This population increase will create major challenges in terms of food supply. Also, according to the 2023 FAO report, 735 million people in the world faced hunger in 2022 – almost one in 10 people – an increase of 122 million compared to 2019 (before the pandemic). If present trends continue, the global number of hungry people is expected to surpass 840 million by 2030.

According to the FAO report, in the year 2020, the percentage of the total population in Iran who are malnourished is 5.5 percent. On the other hand, the percentage of the total population who are food insecure is 2.8 percent. However, the percentage of the total population who are moderately food insecure is 2.37 percent. It can be assumed that despite all the initiatives taken to eliminate hunger in the world, food insecurity can be considered one of the toughest issues in the world. Additionally, it is a common problem in developing countries (Allee et al. 2021; Horn et al. 2022).

Water is a fundamental input for agriculture and a cornerstone of the food supply chain and food security. Due to the life-giving nature of this element, water scarcity directly and indirectly affects many aspects of human life and has created issues such as water control, storage and supply, types of distribution, transmission, productivity, water resource management and protection. Many researchers consider reduced access to water resources to be prone to tension, violent conflict, and social unrest. (Hsiang, et al. 2013; Burke, et al. 2009). Due to the high sensitivity of this element and the vital dependence of organisms on it, in areas where the amount of water is low compared to the needs of the organism or where the actors cannot access the water they need for any reason, the possibility of water stress for obtaining this vital element will be very high. Water stress is defined as the difficulty in finding fresh water resources for use due to depletion of resources. Water stress reduces agricultural yields, reduces food production, and increases food prices (Upton et al.2016).

Furthermore, water stress limits the cultivation of diverse and nutritious crops, thereby reducing the quality of the diet. In areas of severe water stress, these effects often cause forced migration, unemployment, and social instability. Empirical studies also show that increasing water stress is associated with increased malnutrition, reduced crop production, reduced access to healthy food, and reduced food security (Kompas et al. 2024; Ban et al. 2025; UN-Water 2024; Jensen et al. 2024; World Resources Institute 2024; UNESCO 2023; Earth.Org 2023; FAO 2023).

In this regard, various factors cause water stress. These factors include global warming, overuse of pesticides and chemical fertilizers, illegal discharge of sewage into rivers, population growth, infiltration of soil contamination into groundwater, surface water pollution, climate change, drought, flash floods, overuse of water, conflicts, destruction of infrastructure due to natural disasters, and poor water management.

In studies like Ban et al. (2015) on climate change and socio-economic factors, Xu et al. (2016) on economic growth, Gharakhana et al. (2022) on irregular rainfall and drying up of key water sources, such as rivers, and groundwater overuse, as well as the study by Ban et al. (2025) on climate and socio-economic changes, various factors affecting water stress have been discussed.

Water stress has been widely recognized as a growing concern in Iran (Chakoshi, 2009). In recent decades, national water withdrawals have persistently exceeded the standard water-stress threshold of 25% of renewable freshwater resources, in some years by almost a factor of four. The water in the country's lakes is decreasing; the water in rivers and groundwater tables is declining; and the declining trend in access to the country's water has led to the intensification of inter-regional and inter-sectoral conflicts over water (in Isfahan and between Isfahan and Yazd). Of the total water consumed in the country, on average, 90 percent is consumed in the agricultural sector, 7 percent in the urban-domestic sector, and 3 percent in industry. Water stress has reduced agricultural production and reduced the country's food security (Afrakhteh & Hajipour, 2024). Iran has about 1% of the world's population, but only about 0.3% of the planet's renewable freshwater resources. The World Bank's 2000 annual report predicted a significant decline in Iran's annual rainfall by 2050. (Afzali et al., 2020).

Several determinants of food security are often explored in many empirical studies. For example, Asaki et al. (2024) investigated the determinant effects of marital status, household income, access to credit, and household size. Ditta et al. (2023) narrowed their focus down to temperature and population growth, while Adesete et al. (2023) considered climate change and food prices. Affoh et al. (2022) looked into rainfall, whereas Fusco (2022) included cereal production, population growth, rainfall, and temperature. Ceesay & Ndiaye (2022) also tackled population growth. Domguia et al. (2023), put emphasis on the importance of energy, and Zakari et al. (2022) emphasized energy security. Similarly, Candelise et al. (2021) discussed access to electricity, while Huseynov (2019) explored food imports, exchange rate, inflation, climate change, and urban population growth. Mahrous (2019) took a look at cereal cultivation, rainfall, population growth, and temperature. Kumar et al. (2017) analyzed cereal production, credit facilities, and heat. Akerele (2011), included variables such as food costs, age and gender of the head of the household, agricultural income, household size, and the educational attainment of the head of the household and the mother. Recently, Ziaabadi (2025) investigated environmental footprint, agricultural value added, per capita income, grain yield, and energy consumption. Ghorbani et al. (2025) considered per capita income, foreign direct investment, trade freedom, population growth, and inflation. Haji Rahimi et al. (2024) focused on cultivated area, rainfall, and chemical fertilizer usage, whereas Heydari et al. (2020) investigated GDP, price increase, and urbanization.

Fotros, et al (2018) of war, GDP per capita, share of rural population, ratio of arable land area to total land area, rate of use of agricultural machinery per hectare, population size are mentioned as factors affecting food security.

But no study has been conducted on the impact of water stress on food security in Iran. In this regard, this issue is innovative and important. Given the importance of the issue, the main question of this study is: What is the impact of water stress on food security in Iran?

Considering the research question, the following hypothesis has been formulated:

-Water stress has a significant impact on food security in Iran

This article is organized into six sections. Following the introduction, Section 2 presents the literature review, while Section 3 outlines the research background. Section 4 describes the econometric model, data, and research methodology. Section 5 provides the empirical discussion, while Section 6 concludes the study by making some policy recommendations.

2. Literature Review

Security is a complex concept that is not easily defined. Security is freedom from danger or fear. Security is a condition in which an individual is protected by the community against the dangers, threats, and harms of social life. Economic security is a new and important face of security in the contemporary world. Economic security is a situation in which production units can plan long-term without worrying about environmental risks (Kaunert,2011). Food security constitutes a key component of economic security, as it reflects both the reliable availability of staple foods and the stability of food prices at national and international levels. In line with the widely used FAO definition, food security is achieved when all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and preferences for an active and healthy life. (FAO, 2019).

Accordingly, food security has four main components, including availability; meaning the availability of food through production or import management; access; meaning access to food according to the economic and physical capabilities of households or communities; Utilization refers to the health of food and its productivity with respect to the nutritional and biological quality of food, and to the sustainability of quality food production and, ultimately, Stability, which is the ability to access it at all times (FAO, 2011). To achieve food security goals, all four dimensions must be met simultaneously. Each of the aforementioned dimensions is influenced by multiple factors that are rooted in various social, economic, political, environmental, and even medical issues (Hurni, et al. 2015). Therefore, food security is a multifaceted concept that links public health, agriculture, economics, and nutrition.

In this regard, water stress is a key factor affecting food security. Water stress is the difficulty in finding fresh water sources for use due to resource depletion. Water stress and its effects can be exacerbated by pollution of available water sources and also during periods of drought. Water stress is caused by the overuse of water resources, significantly outstripping the available renewable water resources. Many researchers warn that reduced access to water resources could lead to violent conflicts and civil unrest (Hsiang et al. 2013; Burke et al. 2009).
Water stress leads to reduced crop yields, especially in areas dependent on irrigation. Reduced production due to water scarcity may increase food prices and limit economic access to food. In addition, water stress limits the range of nutrient-rich crops available and reduces the quality of the diet. Areas experiencing high water stress are also at risk of forced migration, increased unemployment, social unrest, and further erosion of food security.

3. Research Background

Palatnik et al. (2025) evaluate controlled-environment agriculture (CEA) as a resource-saving alternative to traditional farming in Mediterranean countries. They report that greater availability of non-conventional water sources is linked to higher domestic cereal production in the northern Mediterranean, and that desalination, wastewater reuse, and CEA are positively associated with food security and macroeconomic outcomes. The results of the study Warsame, et al (2025) in Somalia between 1985 and 2017 showed that rainfall and energy consumption play an important role in increasing food production in the short and long term.

Ban, et al (2025), studied the impact of climate change and socio-economic changes on food security in the northwest region of China. The results showed that the problem of water scarcity could worsen in the 21st century, mainly due to the increase in water demand.

Yusuf et al. (2025) conducted a comprehensive assessment of Saudi Arabia's agricultural landscape in the context of Vision 2030. Their findings highlight the importance of water-saving technologies, such as hydroponics and greenhouse farming, for the period 2021–2025.

Perez et al. (2024) demonstrate that, if pursued in isolation, transitioning toward sustainable groundwater management may constrain food production and trade, thereby raising food prices and increasing the number of people vulnerable to hunger. They further emphasize that coordinated measures across food and water systems, including improving the productive use of rainfall and strengthening investment in agricultural research and development, can mitigate the food-security risks associated with reliance on unsustainable groundwater use.

Asaki, et al (2024) in a study in Ghana explained that water, energy and food insecurity are important challenges that affect both the economy and households, especially in developing countries. The results of this study showed Marital status, household income, access to credit, and household size are critical determinants of household food security.

Ditta et al. (2023) report that temperature and population growth exhibit different time-profile effects on food security: over the long horizon, temperature is associated with improvements in food security, whereas population growth is associated with deterioration. In the short run, both variables are linked to weaker food security across the sampled developing economies.

Dias et al. (2023) investigate interactions within the water–energy–food (WEF) system for a watershed in southern Brazil. Their results suggest that maintaining the current trajectory would considerably raise future water demand. Scenario-based simulations further show that shifting part of hydroelectric generation toward solar power, implementing watershed-management measures, or combining both strategies can lower projected demand by roughly 9–25% relative to the baseline.

Rahman et al. (2023) emphasize integrated water resources management (IWRM) as a policy-relevant factor in reducing food insecurity. They argue that deficiencies in water governance and management increase exposure to food insecurity, whereas effective IWRM policies can strengthen sustainable access to water resources and support food production.

Adesete et al. (2023), focusing on sub-Saharan Africa, find that climate change indicators and food prices are negatively associated with food security, while income and food supply show positive and statistically significant relationships with food security.

Affoh et al. (2022) document that rainfall improves food access over the longer term in sub-Saharan Africa. Similarly, Fusco et al. (2022) find for African countries that cereal production, population growth, and rainfall are positively related to food security, whereas temperature is negatively related.

Ceesay & Ndiaye (2022), using data for Gambia (1971–2020), find that food security improves with agricultural performance but deteriorates with rainfall variability; population growth is significantly negative in the short run and only weakly negative in the long run. Candelise et al. (2021) report a positive association between electricity access and food security.

For Azerbaijan (1991–2018), Huseynov (2019) shows that food imports, exchange rates, inflation, climate factors, and urban population growth undermine food-security dynamics.

Mahrous et al. (2019) find for East Africa (2000–2014) that cereal-cultivated area and rainfall support food security, whereas population growth and temperature reduce it.

Kumar, et al (2017) in a study in India showed that cereal production and credit facilities had a positive and significant effect, and heat had a negative and significant effect on food security in India.

Narain (2016) found in northern India that water scarcity exacerbates tensions between urban and semi-urban communities, including farmers. Renaud & Wirkus (2012) linked water insecurity to increased human insecurity and displacement

A substantial body of research has examined food security and water stress, yet the empirical evidence on how water stress affects food security in Iran remains limited. This study addresses this gap by providing country-specific estimates for Iran, offering a novel and policy-relevant contribution.

4. Econometric Model Specification, Data and Research Methodology

This study draws upon theoretical frameworks and empirical findings—such as those of Candelise et al. (2021) and Kumar et al. (2017)—to assess the impact of water stress on food security using a modified regression model specified as follows:

$$\mathrm{FSI1}_t = C + \beta_1 \mathrm{LELECCONPC}_t + \beta_2\ \mathrm{LGINI}_t + \beta_3 LOPEN + \beta_4\ \mathrm{LSTRESS}_t + \beta_5 \mathrm{LFSICREDIT}_t + U_t \quad (1)$$

Table 1. Definition of research variables

Variable	symbol	source	Description
Food Security Index	FSI1	FAO	derived from the prevalence of moderate and severe food insecurity (as reported by the FAO), expressed as a percentage of the population (0–100%). Since the focus is on food security rather than insecurity, this variable is logit-transformed and reversed—higher values correspond to . better food security—using the formula $Logit\ (p) = ln\left(\frac{p}{p-1}\right)$ Here, p represents a probability, meaning it lies strictly between 0 and 1 (0 < p < 1), and ln denotes the natural logarithm, with e as its base. This transformation maps values from the bounded interval [0, 1] to the entire real line (−∞, +∞), making the data more appropriate for regression modelling and statistical analysis. Additionally, the negative form of this transformation was applied when constructing the food security index to uphold the inverse relationship between food insecurity and food security. In this model, the food security index is calculated as follows :

			$$FSI1 = ln\left(\frac{\text{PSFINSECU}}{\text{PSFINSECU} - 1}\right)$$
Logarithm of electricity access (percentage of the population)	LELECCONPC	World Bank databases	serving as a proxy for energy security. It reflects individuals' reliable daily energy access for cooking, food storage, health, and overall well-being, and is a critical indicator of energy infrastructure
Logarithm of the Gini coefficient,	LGINI	the World Bank and UNDP.	representing income or wealth inequality, which can influence food purchasing power and access to services.
Logarithm of financial credit extended to agriculture	LFSICREDIT	Data were sourced from FAO credit databases covering over 130 countries.	This encompasses loans and advances provided by banking institutions to farmers, rural households, cooperatives, and agri-related businesses (excluding direct government subsidies), reflecting the extent of financial support available to the agricultural sector.
Logarithm of the degree of economic openness	LOPEN	UN Comtrade	defined as the sum of exports and imports divided by GDP, indicating a country's level of engagement with global trade
Logarithm of water stress, measured by	LSTRESS	World Bank databases	the ratio of annual freshwater withdrawal by key sectors (agriculture, forestry, fisheries, industry, electricity, and services) to total renewable freshwater resources, after environmental demands are met. Higher values indicate more severe water scarcity.

***Source**: Prepared by the researcher*

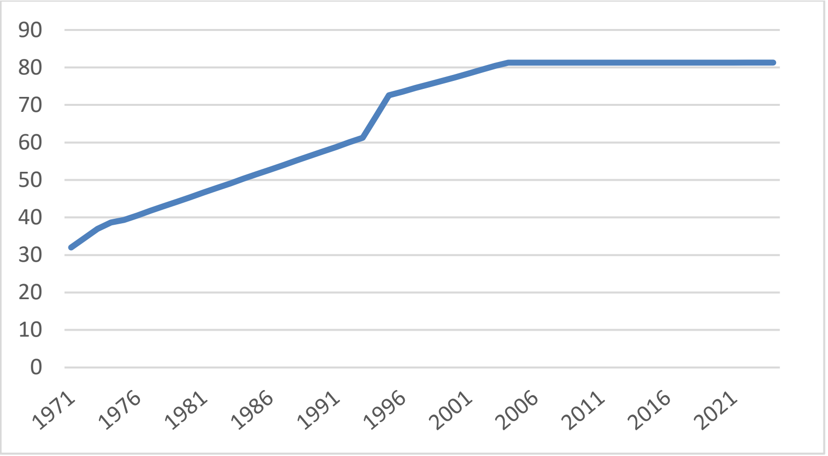

Figure 1. Iran's Water Stress %
Source: *: FAO,n.d (2026)*

Iran's water stress—measured as freshwater withdrawals relative to internal renewable water resources—appears to rise from about 39% in 1975 to ~81% from the early 2000s onward, suggesting that Iran has been withdrawing over 80% of its renewable supply annually in recent decades. Adding to the concern, Iran has experienced consecutive drought years in recent times, with rainfall down by around 40-43% in some major regions, more intense heatwaves (temperatures regularly exceeding 40-50 °C in parts), erratic precipitation, and reservoirs reaching historic low storage levels. These climate trends intensify the risks associated with high water withdrawal—leaving little buffer for demand spikes, droughts, or further climate shocks.

Table 2. Summary Statistics for the Study Variables

Variable	Mean	Median	Std. Dev.	Variance
FSI	-2.7539	-2.7876	0.1720	0.0296
LELECCONP	7.6106	7.6827	0.4356	0.1897
LGINI	3.6959	3.7658	0.1019	0.0104
LSTRESS	4.3861	4.3166	0.8389	0.7037
LFSICREDIT	11.1674	10.8633	0.9821	0.9645
LOPEN	-0.5508	-0.4954	0.2542	0.0646

Source: *Research findings*

Table 2 summarizes the statistical summary of the variables for 1990–2023. The Food Security Index (FSI) has been moving in a rather stable pattern with low variability. Similarly, changes in both electricity consumption per capita (LELECCONP) and the Gini coefficient (LGINI) reflect moderate dispersions over time. Water stress (LSTRESS) shows the highest variability, reflecting fluctuations in national water-resource pressure. Agricultural credit (LFSICREDIT) and trade openness (LOPEN) show a more moderate variation over the period at hand.

5. Model Evaluation

The analysis proceeds as follows. The Autoregressive Distributed Lag (ARDL) framework is employed to estimate the relationship between food security and its key determinants. As established by Pesaran, Shin, and Smith (2001), the ARDL approach is appropriate for time-series models in which regressors are integrated of order zero or one, I(0) and I(1), provided that none is I(2). A further advantage of this framework is its ability to produce reliable long-run estimates in relatively small samples. The optimal lag structure is selected using standard information criteria, including AIC, SBC/BIC, and HQ, and the specification that minimizes the selected criterion is retained. Long-run association among the variables is then examined using the ARDL bounds-testing procedure. Once cointegration is confirmed, the model is expressed in an error-correction form to capture short-run adjustments and the speed at which deviations from the long-run equilibrium are corrected.

Before estimating the ARDL model, the order of integration of each series is assessed to ensure that none is integrated of order two. Accordingly, the Augmented Dickey–Fuller (ADF) unit-root test is applied, and the results are summarized in Table 2.

Table 3. Results of the ADF Unit-Root Test

Variable	ADF-Statistic (Level)	p-value (Level)	ADF-Statistic (First Difference)	p-value (First Difference)	Stationarity
FSI1	–2.68	0.249	–4.58	0.004	I(1)
LSTRESS	–0.52	0.977	–5.62	0.000	I(1)
LFSICREDIT	–4.55	0.009	—	—	I(0)
LOPEN	–2.14	0.499	–5.71	0.000	I(1)
LGINI	–2.73	0.230	–2.82	0.0664	I(1)
LELECCONPC	–0.27	0.981	–7.53	0.000	I(1)

Source: *Research finding*

The ADF results for 1990–2023 (Table 3) indicate that, with the exception of agricultural credit and electricity consumption (used here as a proxy for energy access), all variables are non-stationary in levels but become stationary after first differencing, implying integration of order one, I(1). By contrast, agricultural credit and electricity consumption are stationary in levels, I(0). This combination of I(0) and I(1) variables supports the suitability of the ARDL framework for the subsequent estimation. The estimated short-run dynamics and the associated error-correction term are reported in Table 4.

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and I(1) variables supports the suitability of the ARDL framework for the subsequent estimation. The estimated short-run dynamics and the associated error-correction term are reported in Table 4.

Table 4. Results of the Short-Run Model Estimation ARDL(1, 0, 2, 0, 1, 0)

Variables	Coefficients	t-Statistic	Prob.*
FSI1(-1)	0.247733	2.037457	0.0596
LELECCONPC	0.417031	4.026849	0.0011
LGINI	-1.127576	-3.196318	0.0060
LGINI(-1)	0.066867	0.133460	0.8956
LGINI(-2)	0.840056	1.720563	0.1059
LSTRESS	-0.574377	-7.036473	0.0000
LFSICREDIT	0.184656	2.754637	0.0147
LFSICREDIT(-1)	-0.155333	-2.306393	0.0358
LOPEN	-0.046804	-0.415786	0.6835
C	-2.380783	-1.838036	0.0859
R-squared	0.974420	F-statistic	63.48965
Durbin-Watson stat	2.373111	Prob(F-statistic)	0.000000

Source: *Research findings*

Table 4 presents the short-run ARDL estimation results, which highlight several key relationships: The results show that energy security, agricultural credit and food security index in the previous period have a positive and significant effect, and water stress and the Gini coefficient as an indicator of income inequality have a negative and significant effect on food security. Economic openness does not have a significant effect on food security. The coefficient of determination (R-squared) indicates that Approximately 97% of the variation in the dependent variable is explained by the model’s regressors. Approximately 97% of the variation in the dependent variable is explained by the model’s regressors. To assess the robustness of the specification and the reliability of the estimated parameters, several diagnostic checks were performed, including tests for residual normality, heteroskedasticity, and serial correlation. The diagnostic test outcomes are reported in Table 5.

Table 5. Summary of Diagnostic Test Results

Test Name	Test Statistic (p-value)	Interpretation
Normality Test (Jarque-Bera)	JB = 3.34 (p = 0.187)	Residuals are normally distributed (fail to reject normality).
Autocorrelation Test (LM Test)	F(1,14) = 0.96 (p = 0.34)	No significant serial correlation (p > 0.05).
Heteroskedasticity Test (ARCH)	F(1,29) = 0.002 (p = 0.96); Chi-Square(1) = 0.002 (p = 0.95)	No evidence of heteroskedasticity (p > 0.05 for both tests).

Long-run Relationship Test (Bounds Test)	F(K = 5) = 6.53	The F-statistic exceeds the 1% critical bound (~5.76): long-run relationship confirmed.

Source: *Research findings*

Classic diagnostic assessments confirm that the model's assumptions hold: no serial correlation, correct functional form, residuals follow a normal distribution, and variance is homoscedastic.

Given these validations and the established long-run linkage, the model was further estimated in a long-run framework; results are provided in Table 6.

Table6. Error Correction Model (ECM) Estimation Results ARDL(1, 0, 2, 0, 1, 0)

Variables	Coefficients	t-Statistic	Prob.
C	-2.692733	-7.809773	0.0000
D(GINI)	-0.027621	-4.097408	0.0010
D(GINI(-1))	-0.020247	-2.650669	0.0182
D(LFSICREDIT)	0.191410	5.208711	0.0001
CointEq(-1)*	-0.722464	-7.808669	0.0000

Source: *Research findings*

To examine the adjustment of short-run disequilibria toward long-run equilibrium, an Error Correction Model (ECM) was employed. The key parameter of interest in the ECM is the coefficient of the lagged error correction term, ECM (–1). This coefficient represents the proportion of the previous period's disequilibrium that is corrected in the current period. Our estimates indicate that approximately 72 percent of any short-run imbalance is adjusted in each period, indicating a robust and timely convergence toward the long-run equilibrium. In other words, the system exhibits a stable tendency to return to its long-term path with substantial speed.

Table 7. ARDL Long Run Estimation Results ARDL (1, 2, 2, 2, 2, 2, 2)

C	-2.692733	0.857273	-3.141046	0.0067
FSI1(-1)	-0.722464	0.147240	4.906713	0.0002
LELECCONPC	0.396202	0.112148	3.532849	0.0030
GINI(-1)	-0.005806	0.004944	-1.174328	0.2586
LSTRESS	-0.567951	0.110649	-5.132900	0.0001
LFSICREDIT(-1)	0.025549	0.027328	0.934898	0.3646
LOPEN	-0.023122	0.112124	-0.206220	0.8394
D(GINI)	-0.027621	0.009417	-2.933129	0.0103
D(GINI(-1))	-0.020247	0.011733	-1.725630	0.1049
D(LFSICREDIT)	0.191410	0.072205	2.650933	0.0182

Source: *Research findings*

Result of long run form in Table 7 illustrates the negative and highly significant (-0.722) value of the error correction term .This result idicates that there is a stable long-term equilibrium relationship between these two variables. While electricity consumption has a positive and statistically significant influence on long-term food security, increasing water stress significantly decreases food security; therefore, increased pressure on freshwater resources will significantly decrease the availability and affordability of food. The effects of income inequality, agricultural credit, and trade openness on long-term food security are not statistically significant. In the short term, increases in income inequality will decrease food security, while agricultural credit significantly increases food security due to the immediate liquidity effects on production and access to food resources.

Table8. Bounds Test

F- Bounds Test		t-Bounds Test
F-statistic = 7.621914	k=5	t-statistic= -4.906713

Source: *Research findings*

Table 8 reports the results of the ARDL bounds test. The findings support the existence of a long-run cointegration relationship among the variables. Specifically, the calculated F-statistic (7.621914) exceeds the upper critical bound, leading to rejection of the null hypothesis of no levels relationship. Consistent with this evidence, the t-statistic on the error-correction term (–4.91) is more negative than the 1% lower-bound critical value, indicating a statistically significant adjustment toward the long-run equilibrium. Overall, the bounds and error-correction results provide robust evidence of stable long-run cointegration within the ARDL framework.

6. Discussion

The results showed that water stress has a significant negative impact on food security. In other words, a one percent increase in water stress, on average, ceteris paribus, food security has decreased by 0.57 percent. Water stress is recognized as one of the fundamental challenges in the field of food security, and numerous studies have examined this relationship, including studies by Kompas et al (2024), UNESCO et al (2023), Earth.Org (2023), and FAO (2023). Water stress leads to reduced crop yields, especially in areas dependent on irrigation. Reduced supply of agricultural products due to water shortages can lead to increased prices and reduced economic access to food. Water stress limits the production of diverse and nutritious crops, thereby reducing the quality of the diet. Areas with high water stress cause forced migration, unemployment and social unrest, and reduce food security.

Agricultural credit has a positive and significant effect on food security. In other words, a one percent increase in agricultural credit, on average, ceteris paribus, food security has increased by 0.18 percent. The link between agricultural credit provision and food security has been widely explored in the literature, including the studies of Gul, et al (2023), Farooq, et al (2023), Khan, et al. (2024) Dicle (2023).

Agricultural credit can quickly provide farmers with the liquidity they need, which leads to increased production, improved access to inputs, and thus increased food security. Access to credit in the agricultural sector plays an important role in increasing production, productivity, and crop diversification, which in turn leads to improved food security.Therefore, policymakers should pay special attention to developing and facilitating access to agricultural credit in order to strengthen food security in their communities. (Rusmawati, et al (2023); Gbolagade Adeola et al. (2019)).

Energy access, used here as a proxy for energy security, exerts a positive and statistically significant effect on food security. The estimated elasticity indicates that 1% increase in electricity access is associated with an average increase of approximately 0.41% in food security, ceteris paribus. This result underscores the role of electricity as a foundational infrastructure that supports food security, particularly in developing countries. Expanded electricity access can strengthen multiple dimensions of food security, including availability, access, utilization, and stability, through channels such as improved agricultural productivity, enhanced storage and processing capacity, and more efficient distribution and market functioning. Similar positive effects of electricity access on food security have been documented in previous studies (Candelise et al., 2021; Gebrehiwot & Hassen, 2022).

Electricity enables the use of refrigeration and cold storage, which reduces food spoilage, reduces post-harvest waste, and increases food shelf life. Electrification of rural areas, especially in the agricultural sector, enables the use of irrigation systems, processing equipment, and machinery, which increases productivity. Electricity enables households to prepare and store a wider variety of food, which leads to improved nutritional status, especially among children. Electricity enables income-generating activities such as agricultural processing, drying, packaging and selling, which increases income and thus the ability to buy better food. The evidence presented here corroborates earlier studies of Taghizadeh-Hesary, et al (2019), Zakari, et al (2022), Balali, et al (2020). Taghizadeh-Hesary, et al(2019) in a study explained that there is a relationship between energy and food security through energy price fluctuations. Energy security is effective for food security. Taghizadeh-Hesary, et al (2019) explained in a study that there is a relationship between energy and food security through energy price fluctuations. Energy security affects food security.The results of the study Zakari, et al (2022) in African countries showed that improving energy security improves food security. Because food production and distribution are energy-intensive, and energy is essential to achieving food security and zero hunger.

The degree of economic openness does not have a significant effect on food security. More open economies tend to have greater access to resources, technology, and global markets. Economic openness can, on the one hand, improve food security by increasing foreign exchange earnings and access to imported food; but on the other hand, excessive dependence on food imports or international price shocks may increase vulnerability to food insecurity (Winters et al., 2004; Marson, et al., 2022; Dollar & Kraay, 2004; Gnedeka & Wonyra, 2023).

Income inequality, proxied by the Gini coefficient, exerts a statistically significant and negative effect on food security. In other words, a one percent increase in income inequality, on average, ceteris paribus, food security has decreased by 1.12 percent. In societies with high inequality, low-income groups have less financial ability to purchase nutritious food, leading to increased food insecurity among these groups.

Inequality can cause food-related investments and services (such as stores, markets, and public refrigerators) to be unfairly distributed across regions, limiting access to food for some groups. Low-income groups in unequal societies are more vulnerable to economic (e.g., food price increases) and environmental (e.g., drought) shocks, which can threaten their food security. The results of this study are consistent with those of Chong-En, et al (2022), Kakizhanova, et al (2024), Fitawek, & Hendriks (2024) insecurity.

The results of the study Hossain et al (2020) showed that high income inequality is associated with reduced food access and increased risk of malnutrition. The results of the study Martin et al (2025) also showed that increasing income inequality increases the likelihood of food insecurity.

The food security index in the previous period had a positive and significant effect on food security in the current period. In other words, one percent increase in food security in a previous period, on average, ceteris paribus, food security has increased by 0.24% percent. This means that if the level of food security was high in the past period, there is a high probability that this situation will continue in the current period. This phenomenon is known in the economic literature as "path dependence in food security".(Mahoney (2000); Pierson(2000); Nord & Coleman (2018)).

7. Conclusion and Policy Recommendation

In today’s world, environmental crises—especially water-related ones—dominate both national and international discourse. On one hand, population growth has intensified demand for water; on the other, climate change has exacerbated droughts and disrupted precipitation patterns, further compounded by environmental pollution reducing accessible water sources. Given Iran’s escalating water crisis and projections that it will worsen, effective management of its scarce water resources is paramount for future development and policymaking.

This study sought to evaluate the Modeling the Long-Run and Short-Run Effects of Water Stress on Food Security in Iran. Using a Autoregressive Distributed Lag (ARDL) model over the period 1990–2023, the results revealed a significant negative effect of water stress on food security. Specifically, a one percent increase in water stress, on average, ceteris paribus, food security has decreased by 0.57 percent .These findings affirm the hypothesis of a meaningful effect of water stress on food security. Water stress emerges as a foundational challenge in food security, as supported by Kompas et al. (2024); UNESCO (2023); Earth.Org (2023); FAO (2023).

The need for food security is one of the important challenges and needs of human society. Humans, as the main pillar of the economy, have needs, the most important of which is the need for food security and healthy nutrition. On the other hand, food security plays a decisive role in health, learning, and increasing efficiency. Food security is a fundamental pillar of socioeconomic development and an important determinant of population health and well-being. This is particularly relevant for developing countries such as Iran.

Policy Recommendations

Given the significant impact of water stress on food security, water recycling, virtual water trading, irrigation system modernization, greenhouse expansion, and integrated water management are recommended.

One way to combat water stress is to recycle water. In the European Union, the reuse of treated wastewater in agriculture has significantly reduced freshwater withdrawals and increased the resilience of food production in water-stressed areas (Pistocchi et al., 2018). Also, in Mediterranean countries, the use of treated wastewater for irrigation in different climate scenarios has improved water use efficiency and reduced the risk of food production fluctuations (Areosa et al., 2024) .A study in Asia also showed that storing and reusing surface water and runoff for supplemental irrigation significantly improved household food security while increasing agricultural profitability (Nega et al., 2022) .This empirical evidence reinforces the need to develop infrastructure related to water recycling and sustainable resource management to mitigate the effects of water stress.

Virtual water trade is often discussed as a strategy for coping with water stress in water-scarce economies. In this context, it refers to reallocating production and trade so that water-intensive goods are imported, while domestic production focuses more on commodities with relatively low water requirements. In this regard, two methods can be considered: importing water-intensive goods; and producing these goods in water-rich areas with joint investment by water-scarce countries. In China, analysis of provincial panel data showed that virtual water imports from water-rich areas played an important role in reducing the effects of domestic water stress and enhancing food security (Wu et al., 2025) .One research in the MENA region also implied that targeted imports of water-rich crops for water-scarce countries, especially in drought years, helped maintain production levels and stabilize food markets. (Lee et al., 2019)

Zimmer & Renault, (2003), showed that trade in water-intensive products from water-rich to water-scarce regions can effectively reduce pressure on domestic water resources and food insecurity. This evidence suggests that strategies such as importing water-intensive goods and joint ventures in cross-border cultivation can be effective tools for countries with limited water resources.

Modernizing the irrigation system can also be a good solution to dealing with water stress. Irrigation system modernization includes pressurized irrigation, concreting irrigation canals to prevent water loss (evaporation, penetration into lower layers, etc.), renovation of water networks and canals, and storing water in ponds and reservoirs to prevent water waste in the agricultural sector. Modern irrigation systems significantly increase crop yield and water efficiency. (Ndoro et al., 2025; Tadese, 2025). Panel data analysis in China shows that the development of economical irrigation and technology-based systems reduces water consumption and significantly increases food production, especially in areas with high water stress (Yang et al., 2021). Perry (2012), reports that drip and other high-efficiency irrigation methods can yield significant water savings by increasing irrigation efficiency, commonly by 50–80%.

Integrated water management, especially in the agricultural sector, plays a fundamental role in food production and water security. Therefore, it is necessary for the Ministries of Agriculture and the Ministry of Water Resources to establish coordinated and integrated water management and work to create water security. These measures include raising public awareness, efficient management, coordinating organizations, establishing links between information systems on water and food insecurity, creating governance within each system and between systems, improving public health, and protecting the environment and ecosystem.

Therefore, it is essential that not only the Ministries of Energy and Agricultural Jihad, but also all relevant organizations (such as the Iranian Radio and Television Organization) ensure water security by creating a culture in society and developing efficient management among officials. A UN report on the Arab region shows that institutional coordination between the water, energy and agriculture sectors can help reduce food vulnerability, especially in dryland countries (UN-ESCWA, 2017).

In order to increase food security, diversification in cultivation, the use of new technologies, and the promotion of organic and indigenous agriculture are recommended, as are investing in research and infrastructure in the agricultural sector, establishing business support funds in the agricultural sector, identifying and introducing new agricultural jobs in the world, especially service jobs, marketing agricultural products, and paying attention to the models of successful farmers. Panel data analysis in Maghreb countries showed that agricultural investment, improved productivity and increased acreage increased food security (Guerrache et al., 2024). Also, FAO and WFP studies show that developing agricultural infrastructure, education and extension, and upgrading agricultural technologies are key factors in reducing malnutrition, increasing food production, and improving access to healthy food (FAO, 2019, FAO, 2020). This empirical evidence directly supports recommendations based on crop diversification, increasing productivity, promoting organic farming, and strengthening government support.

Given the positive and significant impact of energy security on food security, optimal use of energy resources, utilization of renewable energy resources, energy diversification, increased investment in the energy sector, and increased energy efficiency are recommended in creating food security. The findings of the Althani, 2025, study indiated that increasing the share of renewable energy has strengthened the accessibility and sustainability of food security. In this regard, the government has formulated the necessary plans to advance the transition toward renewable energy systems in development plans in accordance with global policies in the country. Studies have shown that the development of new energy sources can significantly increase the security of the country's energy system. (Razmjoo, et al, 2021, Aghaei Marzebalia, & Arasteh, 2022).

Research limitations

- Due to the absence of long-term, spatially disaggregated data on food security and water stress at the provincial or regional level, the analysis is conducted at the national scale. This aggregation smooths over substantial climatic, hydrologic, and economic heterogeneity across regions and may not be fully indicative of spatial variations in the outcomes of food security.

- Indicators such as the Global Food Security Index (GFSI), which provide a more multidimensional view of food security, have not been reported for Iran and do not have sufficient time coverage. Therefore, it was not possible to use them in this study.

Broader Significance

These recommendations are vital not only for bolstering food security but also for addressing the broader consequences of Iran’s water crisis—which includes land subsidence, widespread environmental degradation, and escalating social unrest. Comprehensive reform in water management policies is essential to safeguard food stability and national resilience.

Author Contributions

Conceptualization, investigation, formal analysis, and writing of the original draft: Azadmehr Kharam and Parvaneh Salatin; Supervision and methodological guidance: Parvaneh Salatin Scientific consultation: Azadmehr Kahram. All authors have read and approved the final version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

Data Availability Statement

The data supporting the findings of this study are publicly available from the Food and Agriculture Organization of the United Nations (FAO) Statistics database (https://www.fao.org/statistics/en/) and the World Bank World Development Indicators (https://databank.worldbank.org/source/world-development-indicators). Energy-related data used in this study are drawn from publicly available sources, including the World Bank World Development Indicators and, where applicable, international energy databases such as the International Energy Agency (IEA) (https://www.iea.org/), Our World in Data (https://ourworldindata.org/energy), Ember (https://ember-climate.org/), and the Energy Institute Statistical Review of World Energy (https://www.energyinst.org/statistical-review).

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