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RESEARCH ARTICLE

Impact of the Sustainability Indicators on Agricultural Output in Iraq for the Period (1990–2024)

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Abstract

This study uses an econometric approach to examine how sustainability indicators affect agricultural output in Iraq. Water sustainability, food security sustainability, the agricultural labor force, and virtual water imports are independent variables, and agricultural output is the dependent variable. The analysis uses annual data from 1990 to 2024. The Autoregressive Distributed Lag (ARDL) model is applied to analyze both short- and long-run relationships. Specifically, the results confirm the existence of a long-run equilibrium relationship between sustainability indicators and agricultural output. In the long run, water sustainability positively affects agricultural output, indicating a direct, expected relationship. Furthermore, food security sustainability has a positive, statistically significant impact at the 1% level. In contrast, the agricultural labor force variable shows a negative, statistically insignificant coefficient, which may reflect the prevalence of disguised and seasonal unemployment in the agricultural sector. Meanwhile, virtual water imports have a negative and statistically significant effect, consistent with theoretical expectations. These findings support the hypothesis that sustainability indicators significantly influence agricultural output, although the magnitude and direction of effects vary across dimensions.

Keywords: Agricultural output, Water sustainability, Food security sustainability, Agricultural workforce, Imported virtual water

1. Introduction

Agriculture has been an integral part of Iraq's overall economic structure. It provides food for many people and contributes to food security, in addition to its role in creating job opportunities and advancing economic development. However, this sector faces many challenges that affect agricultural production, the most prominent of which are limited water resources, climate change, rising food demand, and increased reliance on imports. Therefore, the importance of adopting the concept of sustainability in managing agricultural resources has emerged to ensure the continuity of production and achieve sustainable agricultural development. Sustainability indicators are important tools for evaluating the efficient use of natural and economic resources in the agricultural sector, as they help direct agricultural policies towards the optimal use of available resources. These indicators include several basic aspects, such as water sustainability, food security, the agricultural labor force, and the volume of imported virtual water, which influence the performance of the agricultural sector and the level of agricultural output. Water plays an essential role in shaping civilizations and driving human progress, directing the course of social and economic development. However, the current reality is no longer merely an image that reflects in all seriousness the difficulty of the matter and its threat to living conditions. With population growth and industrial expansion, water resources are under increasing pressure, leading to the realization of the urgent need to manage these vital resources sustainably from a functional-integration

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perspective, a key concept in social systems theory. Water sustainability is considered a basis for ensuring the continuity and balance of the social system. This view underscores the importance of coordinating diverse roles and functions within society to protect water resources and ensure equitable distribution. Water sustainability is defined as the ability of the water system to maintain its balance and continuity in providing water resources in a fair and efficient manner, ensuring the fulfillment of current societal needs without compromising the ability of future generations to meet their needs, while enhancing coordination among social and institutional roles to protect water resources and manage them in a sustainable way (Padowski & Jawitz, 2020).

There is a wide range of globally interconnected factors at this level that are likely to have an adverse effect on the creation of sustainable food security through demand in the food system. The effects of growing global per-capita incomes, which equate to increased consumption of meat and processed foods, as well as an increase in urbanization, have had a negative effect on consumer food choice options available at times based upon misinformation about their availability, in addition to decreasing energy usage from employment opportunities in cities (Kearney, 2010).

Sustainability and Food Security are intertwined within the definition of Sustainable Food Systems. These two concepts have been identified through their definitions. "A sustainable food system protects and respects biodiversity and ecosystems; is culturally appropriate, available, equitable, reasonably priced, nutritious, safe and healthy, while utilizing both human and natural resources to its fullest potential". The concept of sustainable food security refers to "the ability of the food system to provide sufficient, safe, and nutritious food for all individuals continuously and over the long term, ensuring the fulfillment of current food needs without compromising the ability of future generations to meet their food needs, while preserving natural and environmental resources" (FAO, 2012). A "sustainable food system", hence providing food security and nutrition for every person without deteriorating the economic, social or environmental resources needed to provide food security and nutrition for all persons in the future (HLPE, 2014). The concept of virtual water refers to the amount of water required to produce a particular commodity. Therefore, exporting or importing any commodity is considered an export or import of the quantities of water necessary for its production. This is a relatively modern concept that emerged in the mid-1990s of the last century (Badiwi & Hammam, 2016).

2. Literature review and hypothesis development

Samuel et al. (2024) research entitled "Economic Development & Environmental Sustainability: A Study using an Economic Model for Selected African Nations" was introduced by Dr. [Author]. This research analyzed how economic development will affect long-term environmental sustainability. Research was conducted in (15) randomly chosen nations across Africa. In this research, a fixed-effects model (FEM) was utilized. To maintain the health and welfare of current and future generations, Dr. [author] encourages all policymakers across Africa to formulate sustainable, environmentally friendly economic policies. Hassan et al. (2024) examined "Environmental Sustainability: The Relationship Between Agriculture, Renewable Energy and Economic Growth in Mitigating Carbon Dioxide Emissions in Somalia," which studied the interrelated environmental relationships among agriculture, renewable energy, agricultural production, and CO2 emissions for the period 1991-2022 in Somalia. This research used a distributed lag (ARDL) model to examine whether these variables affect environmental sustainability. The results indicated a negative correlation between agriculture and renewable energy and CO2 emissions, as well as a positive, indirect effect of agriculture on local investment relative to CO2 emissions. Madlul and AL-Hiyali (1449), entitled "An Economic Study of the Relationship between Environmental Shocks and the Value of Agricultural GDP in Iraq for the Period (2004-2023)," examined five sets of environmental shocks on agricultural GDP in Iraq from 2004 to 2023. To analyze the relationship between environmental shocks and the influencing factors, the Vector Autoregressive (VAR) model, developed as a theoretical framework, was selected. A study by Teeli et al. (2025) on the "Assessing the Impact of Climate on Agricultural Productivity in India" paper has examined how climate change affects long-term agricultural productivity in India, using the Autoregressive Distributed Lag (ARDL) approach. These results underscore the urgent need to adopt climate-resilient agricultural practices and policies to maintain productivity amid rising temperatures and fluctuating rainfall. Kaplan (2025) presented a study entitled Sustainability Challenge in Turkey: An Empirical ARDL Analysis of the Impact of Energy Consumption, Economic Growth, and Agricultural Growth on CO2 Emissions." The goal of the study is to determine the long-term (dynamic) relationship between CO2 emissions and their major sources in Turkey. This empirical study has demonstrated how these factors affect the environment through mechanisms that promote sustainable development. An annual time series of 34 years and an ARDL model were employed to demonstrate that both economic growth and energy consumption significantly contribute to increased CO2 emissions and, therefore, to increased environmental pollution (Skrypchuk et al., 2023). They presented the results of the study titled "Land Footprint: Theory, Methodology and Applied Environmental and Economic Principles in Ukraine," which proposed a set of indicators to assess the environmental impacts of agricultural land use (Georgina, 2024). The main finding of the study is that Agricultural Output has a negative but insignificant contribution to Nigeria's Economic Growth. The ARDL model is a statistical method for investigating the impact of human action and climate change on land use/land cover. This will enable farmers to access the funds needed to purchase seedlings, equipment, and other inputs, thereby enhancing agricultural productivity in Nigeria. Therefore, this recommendation can help overcome the study's limitations. Thus, the recommendations can provide a foundation for further studies on other aspects of agriculture in Nigeria. Bytyqi et al. (2024) presented "Determinants of Economic Growth and Environmental Sustainability: An ARDL Evidence Panel for EU Countries." What was this research project focused on? It explored the factors that affect economic development and how they relate to sustainable development. In addition, it examined whether there is a positive correlation between the two. The researchers analyzed the last 10 years' worth of data for all of the countries that are part of the European Union (2011-2020). Therefore, the study suggests that the Nigerian federal government, to support local farmers, provide concessionary loans to enable them to carry out their agricultural activities. Tawfic and Allami (2025) in "Assessment of Effects of Climatic Change on Land Use/Land Cover in Southern Iraq Using Remote Sensing," which analyzed the effects of human-activity-driven and climatically-induced land-use/land-cover change on the environment within southern Iraqi provinces, specifically Basra, Maysan, and Dhi Qar, to assess how such land-use/land-cover change affects agriculture and increases ambient temperature through contributing to environmental degradation. Al-Shahed (2017) study, titled "An Analytical Study of the Impact of Economic Variables on Egyptian Agricultural GDP," aimed to identify the performance of the Egyptian agricultural sector by examining the growth rate of the sector and the evolution of economic variables affecting total Egyptian agricultural output. The research relied on descriptive and quantitative analyses to examine the key variables affecting agricultural GDP in Egypt. Among its key findings was that the overall average value of the national product and agricultural GDP reached 954.5 billion Egyptian pounds and 117.9 billion Egyptian pounds, respectively, at current prices, and is increasing annually (Al-Mahi et al., 2025). The "Climate Change Effects on Agricultural Crops Production Activities" research problem was presented through an analytical study entitled "An Analytical Study of Climate Change and its Impact on the Production of the Most Important Agricultural Crops in Egypt. It is predicted that increasing the variability of climate conditions would have negative effects on agriculture (declining agricultural productivity, insufficient food to meet the most basic needs of society, and reduced contributions of the agricultural sector to supplying raw materials and manufacturing inputs for other sectors).

Hassan and Shukr (2025) economic analysis was the focus of a "study on An Economic Analysis of the Factors Affecting Agricultural GDP in Iraq for the Period (1990-2022)". The research problem was summarized as the continuous decline in agricultural GDP as a percentage of total GDP, leading to a deterioration of the agricultural sector and its development in the wrong direction. The purpose of this study was to investigate the variables that affect agricultural GDP in Iraq; time-series data were analyzed for the years 1990-2022 (Allehebi, 2025). The authors also conducted a case study on "Green Economy and Sustainable Development." They analyzed how the Green Economy can help countries achieve sustainable development by leveraging clean energy resources. Clean energy resources are key to attracting new foreign investment into renewable energy markets. Renewable energy is one aspect of sustainable development, including economic, social, environmental, and technological aspects. "The study reached a set of conclusions and recommendations", including that the transformation ensures the separation between the use of resources and environmental impacts and economic growth, and a direction towards green sectors. Bouali and Hammaloui (2024) examined water sustainability and its role in enhancing food security in Algeria, focusing on the relationship between water resource management and the efficiency of achieving food security under increasing environmental and climatic challenges. The study highlighted that improving water management is a key factor in supporting agricultural production and ensuring the sustainability of natural resources, especially in water-scarce countries such as Algeria. It also aimed to provide a set of perspectives and solutions to enhance water-use efficiency and improve food security through more sustainable water policies. The importance of the study lies in emphasizing the critical role of water as a determining factor in agricultural development and food security, and in its findings, which can be utilized to develop agricultural and environmental policies in developing countries. The study by Masry et al. (2023) examined agricultural economics in ancient Egypt and its comparison with modern agricultural economics within the framework of the new economy. It focused on highlighting the ancient agricultural system as an integrated system that adapts to the environment and follows the principles of sustainability. The study aimed to clarify the characteristics of agricultural economics in ancient Egypt, compare them with modern practices in the agricultural sector, and emphasize the role of agricultural sustainability in supporting economic development and food security. It also assessed the potential for drawing on historical experience to develop contemporary agricultural policies in developing countries. The importance of the study lies in linking historical experiences with modern applications and in providing an analytical perspective that helps understand the relationship between agricultural sustainability and economic growth, making it an important reference for studies of the evolution of agricultural systems and their impact on economic development.

3. Methodology

The primary data source was secondary data obtained from various sources, including the Food and Agriculture Organization of the United Nations FAO), the Ministry of Agriculture, the Ministry of Water Resources, the Ministry of Planning, and the Central Statistical Organization. To achieve its goals, this study employed a combination of qualitative descriptive analysis, quantitative economic analysis, and econometric analysis to explain various economic characteristics. The Auto Regressive Distributed Lag (ARDL) model was used to identify general trends and assess the impact of sustainability indicators on agricultural output. The variables included the dependent variable, representing agricultural output (AP), and the independent variables: water sustainability (WS), food security sustainability (SFS), agricultural labor force (ALF), and virtual water imports (VWI). The ARDL model examines both short-run and long-run associations between the variables. This model was suitable for time series data, which may vary in their stationarity, after conducting the necessary stationarity tests. This ensured the model's estimation accuracy and the achievement of the research objectives. The study relied on annual time-series data covering the period (1990–2024). Water sustainability refers to the ability of the water system to provide water resources efficiently and continuously without compromising the needs of future generations. Sustainable food security refers to the ability of the food system to provide sufficient and safe food continuously while preserving environmental and economic resources. Virtual water imports refer to the quantities of water embodied in imported agricultural commodities.

4. Results and discussion

4.1. Model description

This model represents the relationship between agricultural GDP and several economic and environmental variables, assuming that water sustainability, food security, agricultural value added, agricultural labor force, and imported virtual water directly affect agricultural sector growth. It also explains the direction and magnitude of each variable's impact on agricultural output.

$$LAPA = B_0 + B_1\, LWS + B_2 LSFS + B_3 LALF + B_4 LVWI \quad (1)$$

Where:
LAPA = Natural logarithm of agricultural output.
LWS = Natural logarithm of water sustainability.
LSFS = Natural logarithm of food security sustainability.
LALF = Natural logarithm of agricultural labor force.
LVWI = Natural logarithm of imported virtual water quantity.

4.1.1. Time series stationary test

4.1.1.1. Unit root test

Table 1 show the economic variables are generally unstable, as confirmed by most studies. There are several well-known methods for determining if a set of time series is stationary. The most widely used techniques include graphical representations, the Augmented Dickey-Fuller (ADF) test, and the Phillips-Perron (PP) test. The ADF was used to test whether the time series of the model variables were stationary at both levels and after first differences, with a constant, a constant and trend, and without either.

In light of the stationarity results, none of the variables reached stationarity at the I(0) level, due to the inherently unstable nature of economic variables. They did reach stationarity at the first difference (at the constant, at the constant and trend, and at the absence of the constant and trend). Therefore, the condition for using the ARDL model was met.

Table 1. Results of the stationarity of variables using the augmented Dickey-Fuller test(ADF).

At level		LAPA	LWS	LSFS	LALF	LVWI
with constant	t-statisc	-1.599	-5.023	-1.115	-0.865	-3.287
	prob.	0.4718	0.0002	0.6983	0.787	0.0234
		no	***	No	no	*
with constant & Trend	t-statisc	-2.582	-3.201	-2.951	-3.283	-3.278
	prob.	0.2900	0.1011	0.1602	0.0862	0.0871
		no	no	no	*	*
without constant & Trend	t-statisc	0.977	1.916	-1.136	0.084	-0.723
	prob.	0.9096	0.9848	0.2277	0.703	0.3956
		no	no	no	no	No
At first Difference		DLAPA	D(LWS)	D(LSFS)	D(LALF)	D(LVWI)
with constant	t-statisc	-6.462	-3.723	-6.319	-4.854	-5.617
	prob.	0.0000	0.0083	0.0000	0.0004	0.0001
		***	***	***	***	***
with constant & Trend	t-statisc	-6.538	-4.691	-6.324	-3.889	-5.519
	prob.	0.0000	0.0035	0.0000	0.0243	0.0004
		***	***	***	*	***
without constant & Trend	t-statisc	-6.141	-3.396	-6.398	-4.894	-5.713
	prob.	0.0000	0.0013	0.0000	0.0000	0.0000
		***	***	***	***	***

* Significant at the 10% significance level,
** Significant at the 5% significance level,
*** Significant at the 1% significance level,
No: Not significant.
Source: Prepared by the researcher based on the statistical software EViews.

Table 2. Results of the Cointegration test using the bounds test.

F-Bounds Test		Null Hypothesis: No levels relationship		
Test Statistic	Value	Signif.	I(0)	I(1)
		Asymptotic: n=1000		
F-statistic	6.468910	10%	2.2	3.09
K	4	5%	2.56	3.49
		2.5%	2.88	3.87
		1%	3.29	4.37

Source: Prepared by the researchers based on the statistical program (Eviews.12).

4.1.1.2. Cointegration tests using the bounds test

Table 2 shows that the calculated F-value is 6.46. When comparing this calculated F-value to both the upper and lower critical values for a 1% level of significance, it is apparent that the calculated F-value is larger than the upper critical value of (4.37) as well as larger than the lower critical value of (3.29). As such, we can reject the null hypothesis (the assertion that within the population of interest there exist no significant long-run relationships amongst the predictor variables and/or response variable(s)) in favor of the alternative hypothesis (the assertion that within the population of interest there exists at least one significant long-run relationship amongst the predictor variables and/or response variable(s).

4.1.2. Estimating the results using ARDL model

Table 3 shows that the value of the coefficient of determination (the explanatory power of the model) reached (0.75), this means that the independent or explanatory variables were able to explain (75%) of the fluctuations or changes in the dependent variable, while the remaining (25%) of the fluctuations in the dependent variable are due to other independent variables that were not included in the estimated model and whose effect was absorbed by the random variable. Table 3, shows that the WS parameter (water sustainability) has a direct relationship and is consistent with economic logic and is significant, meaning that increasing water sustainability by (1%) will increase agricultural output. As for the SFS variable (food security sustainability), its parameter came with a positive sign, consistent with economic logic and significant at the (1%) level, meaning that increasing food security sustainability by (1%) will increase agricultural output, and the VWI variable (imported virtual water quantity) came with a negative sign and is consistent with economic logic, as increasing imports has a negative impact on agricultural output, and it was significant. The error correction coefficient

Table 3. Short term model equation ECM error correction model.

ECM Regression				
Case 2: Restricted Constant and No Trend				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(LAPA(-1))	-0.256156	0.112137	-2.284321	0.0340
D(LWS)	1.793608	0.451970	3.968422	0.0008
D(LWS(-1))	-1.493564	0.459495	-3.250445	0.0042
D(LWS(-2))	-1.454429	0.454938	-3.196984	0.0047
D(LSFS)	3.927292	0.859485	4.569357	0.0002
D(LSFS(-1))	-3.755213	0.822454	-4.565862	0.0002
D(LVWI)	-0.184806	0.097749	-1.890616	0.0740
CointEq(-1)*	-0.605738	0.086510	-7.001966	0.0000
R-squared	0.751524	Mean dependent var	0.187991	
Adjusted R-squared	0.679052	S.D. dependent var	1.072551	
S.E. of regression	0.607624	Akaike info criterion	2.053799	
Sum squared resid	8.860981	Schwarz criterion	2.420233	
Log likelihood	-24.86078	Hannan-Quinn criter.	2.175261	
Durbin-Watson stat	2.238189			

* p-value incompatible with t-Bounds distribution.
Source: Prepared by the researchers based on the statistical program (Eviews.12).

Table 4. Long-run model equation.

Levels Equation				
Case 2: Restricted Constant and No Trend				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
LWS	3.244321	1.351548	2.400447	0.0268
LSFS	3.384555	1.934627	1.749462	0.0963
LALF	-0.252429	0.654405	-0.385738	0.7040
LVWI	-0.016030	0.099279	-0.161461	0.8734
C	-12.68054	11.68941	-1.084789	0.2916

EC = LAPA - (3.2443*LWS + 3.3846*LSFS -0.2524*LALF -0.0160*LVWI -12.6805)
Source: Prepared by the researchers based on the statistical program (Eviews.12).

was negative and significant at the 1% level, with a value of -0.60. This indicates that 60% of the short-term imbalance is corrected in the long term, and that both the necessary and sufficient conditions are met in this model. In other words, it requires approximately 18 months (1/0.60) (1.66 * 12) = 20 months to correct its position towards long-term equilibrium. The agricultural labor force (ALF) was not statistically significant in the short run in the ARDL–ECM model, but became significant in the long run, indicating its structural nature and slow adjustment in the short term.

4.1.3. Long-run equation

Table 4 shows the long-run equation, or cointegration, between the independent and dependent variables. WS parameter, representing water sustainability, the relationship is both statistically positive (at the one percent significance level). indicating a long-term positive relationship between water sustainability and agricultural output in Iraq, consistent with economic logic. The SFS parameter, representing food security sustainability, is also positive, indicating a significant and positive relationship between food security sustainability and agricultural output. The agricultural labor force (ALF) coefficient was negative and statistically insignificant. This can be explained by the presence of surplus labor in the agricultural sector and the low marginal productivity of labor, in which an increase in the number of workers is not accompanied by a proportional increase in efficiency or output. This leads to a weak or statistically unobservable effect within the estimated model. The VWI parameter, representing the quantity of imported virtual water, is negative, meaning that an increase in imports will lead to a decrease in agricultural production due to competition. This may be attributed to the fact that imported virtual water does not represent a direct production input, but is instead linked to food imports and consumption patterns. This reduces its ability to directly affect agricultural output, making its effect statistically insignificant. Thus, all variables

Table 5. Results of Harvy test for detecting the invariance of variance problem Heteroskedasticity test: Harvy.

Null hypothesis: Homoskedasticity			
F-statistic	1.686703	Prob. F(12,19)	0.1492
Obs*R-squared	16.50578	Prob. Chi-Square(12)	0.1692
Scaled explained SS	10.06910	Prob. Chi-Square(12)	0.6099

Source: Prepared by the researchers based on the statistical program (Eviews.12).

Table 6. Results of LM test for detecting the Autocorrelation problem.

Breusch-Godfrey Serial Correlation LM test			
Null hypothesis: No serial correlation at up to 2 lags			
F-statistic	0.941958	Prob. F(2,15)	0.4093
Obs*R-squared	3.139760	Prob. Chi-Square(2)	0.2027

Source: Prepared by the researchers based on the statistical program (Eviews.12).

remained unchanged from the short to the long run, except for the agricultural labor force variable.

4.2. *Diagnostic tests for the model*

4.2.1. *Harvy test*

As shown in Table 5, we have also checked for heteroskedasticity (the violation of the assumption of homoscedasticity known as the Invariance of Variance problem) with the use of a H test. The result is that the P-value was found to be (0.1492), which is larger than the critical alpha level of .05. This implies that the null hypothesis can be accepted; therefore, our models are appropriate and do not show evidence of heteroscedasticity.

4.2.2. *LM test*

Table 6, which shows the detection of the autocorrelation problem using the LM test, indicates that the calculated F-value was (0.94), while the probability value was (0.4093), which is greater than (0.05). This means accepting the null hypothesis that the model does not suffer from autocorrelation.

4.2.3. *Identifying the multicollinearity problem*

The results in Table 7, indicate that each of the VIF scores for all the explanatory variables is less than 10, indicating that multicollinearity does not exist with respect to the explanatory variables. Therefore, the null hypothesis that there is a lack of multicollinearity problems with regard to the explanatory variables can be accepted.

Table 7. Results of VIF test for identifying the multicollinearity problem.

Variance Inflation Factors			
Sample: 1990 2024			
Included observations: 32			
Variable	Coefficient Variance	Uncentered VIF	Centered VIF
LAPA(-1)	0.027437	445.4965	3.973749
LAPA(-2)	0.021624	342.7245	4.996754
LWS	0.326348	458.5439	1.766838
LWS(-1)	0.364142	509.9168	2.032613
LWS(-2)	0.311104	435.6248	1.736828
LWS(-3)	0.379956	529.1773	2.245814
LSFS	1.464319	2248.050	2.529530
LSFS(-1)	2.314488	3545.330	4.157565
LSFS(-2)	1.280503	1954.929	2.486106
LALF	0.154709	724.8192	1.668788
LVWI	0.019481	32.56482	2.414016
LVWI(-1)	0.013754	22.26120	9.018702
C	52.89391	3629.339	NA

Source: Prepared by the researchers based on the statistical program (Eviews.12).

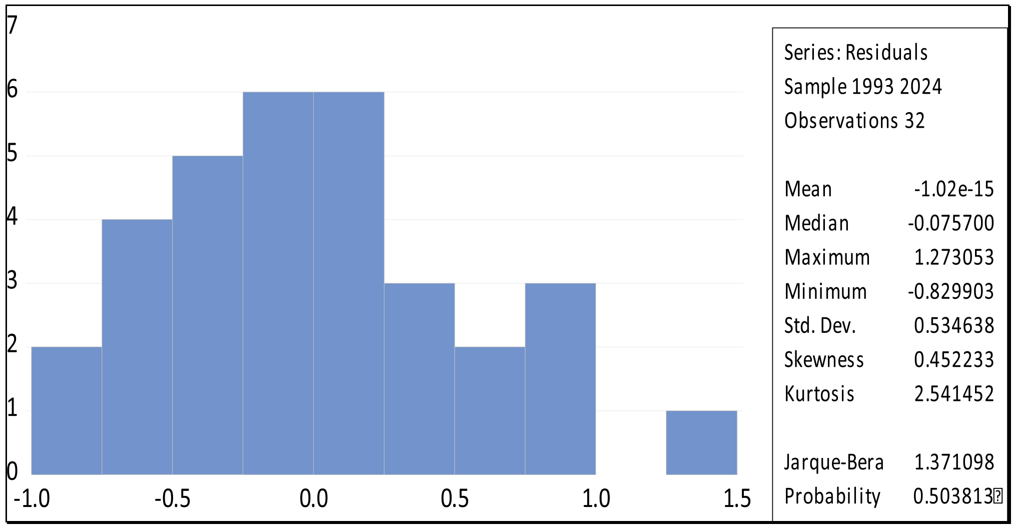

Fig. 1. Normal distribution of residuals using Jarque-Bera test. Source: Prepared by the researchers based on the statistical program (Eviews.12).

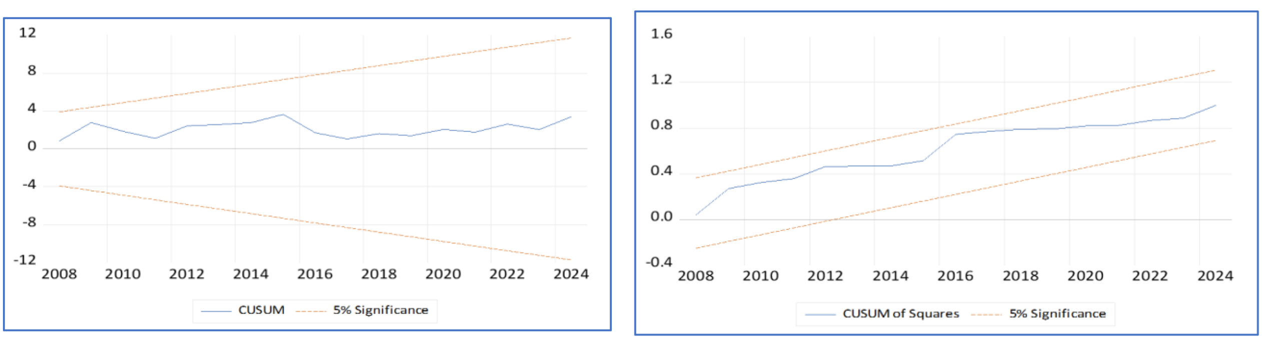

Fig. 2. Cumulative sum of successive remainders CUSUM and cumulative sum of squared successive remainders (CUSUMQ). Source: Prepared by the researchers based on the statistical program (Eviews.12).

4.2.4. Testing the normality

In addition to this, we can see from Fig. 1 that the JB statistic = (1.37), with a corresponding p-value of = (0.50). Therefore, since the p-value is greater than (0.05) we will accept the null hypothesis for the model; which states that the model is acceptable, and that the residuals follow a normal distribution.

4.2.5. Detecting the structural stability of the model" "CUSUM and CUSUMQ tests

The Structural Stability of ARDL Model Parameters is tested with Cumulative Sum of Successive Residuals (CUSUM), the cumulative sum of squared successive residuals (CUSUM), and the cumulative sum of squares of successive residuals (CUSUMQ). From Fig. 2, we see that the CUSUM lies beyond the upper or lower limit at the 5% confidence level. Thus, we conclude that the parameter is structurally stable. The same conclusion is reached from the CUSUMQ plot. This lies within the 5% confidence interval; therefore, it indicates that the parameter exhibits structural stability over time. From these two tests, we conclude that the model parameters used and estimated are structurally stable and consistent, as the short-term parameters are consistent with long-term parameters in the estimated model.

5. Conclusions

The results showed a long-term, positive equilibrium relationship between water sustainability and agricultural output, given the heavy reliance of agricultural activity on water resources. A positive relationship was found between food security and agricultural output, as enhanced local agricultural production improves food security and reduces dependence on imports. A statistically significant positive relationship exists in the long run between the Agricultural Labor Force and Agricultural Output: increasing the number of agricultural workers increases agricultural production. Furthermore, the availability of trained agricultural labor contributes to increased efficiency in production processes and higher output. There is an inverse relationship between the amount of imported virtual water and agricultural output. Low-priced imports will lead to a decline in domestic agricultural production due to their inability to compete, especially in cases of dumping. The model demonstrated econometric soundness and structural stability, enhancing the reliability of the results and their applicability to economic interpretation.

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Conflict of interest

The Authors declare that there is no conflict of interest.

Author contribution

Noor S. Mohammed: Collected the data; Performed the analysis; Wrote the paper.

Basim H. Al-Badri: Conceived and designed the analysis; Supervised the research and provided academic guidance.

Data availability

This data is available from the Ministry of Planning, the Central Statistical Organization https://cosit.gov.iq/ar, Food and Agriculture Organization of the United Nations (FAO) https://www.fao.org/home/ar.

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Authors' declaration

- We therefore declare that all Figures and Tables included in the paper belong to us, and the results have been prepared exclusively by the authors.
- The ethical clearance for this study was granted from the local ethical committee at the University of Baghdad.
- There is no animal study included in the paper.

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