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RESEARCH ARTICLE

Barley Virtual Water Determinants in Iraq: An Econometric Analysis Study for the Period (1990–2023)

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Abstract

The paper aims to analyze the determinants of virtual water use for barley crops in Iraq over the period (1990–2023), in light of increasing water challenges and declining inflows of the Tigris and Euphrates Rivers. The research adopts a descriptive and econometric analytical approach, employing the Autoregressive Distributed Lag (ARDL) model to examine the relationship between imported virtual water quantity (VW) as the dependent variable and a set of independent variables, including agricultural GDP, blue water, the water self-sufficiency ratio, and the degree of agricultural trade openness. The results of the Bounds Test indicate the existence of a long-run equilibrium relationship among the variables. Furthermore, the Error Correction Model (ECM) reveals an effective adjustment mechanism, with an adjustment speed of 72% annually, indicating convergence toward the long-run equilibrium path. The findings also demonstrate significant, albeit varying, effects: agricultural GDP and the water self-sufficiency ratio exhibit an inverse relationship with virtual water imports, whereas trade openness and green water show a positive relationship with virtual water imports. The study recommends adopting water-oriented trade policies that support domestic production and improve the efficient use of available water resources, with the aim of reducing reliance on imports of water-intensive commodities. It also emphasizes the importance of adopting the concept of virtual water as a fundamental basis for formulating agricultural foreign trade policies.

Keywords: Virtual water, Barley crop, ARDL model, Water security, Iraq

1. Introduction

Water is considered one of the most important natural resources and one of the most influential factors in achieving sustainable economic development, particularly in the agricultural sector, which is the largest consumer of water. In light of the steadily increasing demand for water driven by population growth and the expansion of economic activities, water scarcity has become one of the most pressing challenges facing many countries, including Iraq. Iraq has experienced a decline in water inflows from the Tigris and Euphrates rivers, along with fluctuations in rainfall and increasing impacts of climate change (FAO, 2021; Sherif et al., 2023). This situation has intensified competition among different water uses, thereby necessitating the search for more efficient mechanisms for managing water resources (El-Rawy et al., 2023). In this context, the concept of virtual water has emerged as an important analytical tool that reflects the amount of water actually used in the production of agricultural commodities, enabling the reassessment of agricultural and trade policies by identifying crops with high water footprints (Hoekstra et al., 2020). This concept contributes to improving water resource efficiency by reorienting agricultural production or reducing reliance on imports, thereby achieving a balance between water security and food security (Alamri et al., 2020). Barley is considered an important agricultural crop in Iraq due to its essential role in supporting the livestock sector and food security. However, its production is

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associated with varying levels of water consumption, placing it among crops that require analysis within the framework of virtual water (Fader et al., 2010). Nevertheless, there are still few studies that identify the factors influencing the virtual water of this crop in Iraq, and there is also a lack of a clear vision regarding its production efficiency relative to imports within the framework of water resource management (Al-Hamdany & Shahadha, 2025). Accordingly, this study aims to analyze the determinants of virtual water for barley in Iraq over the period (1990–2023), thereby providing a scientific perspective to support policy-makers in agricultural and water policy and enhance the efficiency of water resource management under current environmental and economic conditions.

2. Literature review and hypothesis development

Sartori et al. (2017) presented a study that modeled the future evolution of the virtual water trade network by integrating network models with the gravity model, aiming to predict changes in the characteristics of virtual water flows under different climatic, social, and economic scenarios. The results indicated that the current trajectory of virtual water exports is unsustainable for all countries, and that some importing countries may face indirect water stress due to their reliance on imports from countries that use water unsustainably. Fu et al. (2021) conducted an analysis of virtual water flows and their driving factors in the European Union, employing a multi-regional input–output model and the logarithmic Divisia index. The findings revealed a continuous increase in virtual water flows, with economic factors exerting a positive effect, while virtual water intensity had a negative impact. In the Iraqi context, Al-Amadi (2020) conducted an economic study of the water footprint and virtual water of major food imports in Iraq for the period 2000–2020. The study showed that importing water-intensive crops, such as wheat and rice, from water-abundant countries is more efficient than domestic production under conditions of limited water resources. Similarly, Mohamed (2022) examined the role of virtual water trade in addressing water challenges in the Middle East, confirming that this type of trade is an important tool for supporting food security and alleviating pressure on water resources, while emphasizing the need to adopt policies for water management and efficiency improvement. Kannan and Kumar (2023) analyzed the trends and determinants of virtual water trade in agricultural products in India during 2001–2020. The results demonstrated that GDP and population positively influence virtual water exports, whereas distance has a negative effect. It was also found that free trade agreements do not necessarily promote trade in water-intensive agricultural commodities. Tian et al. (2023) investigated the patterns and determinants of agricultural virtual water imports in China using a panel gravity model and quantile regression. The study found a growing trend in imports, with positive effects from supply and demand factors and water resources in exporting countries, while import prices exerted a negative influence. In Iraq, Adamo et al. (2023) addressed the issue of water scarcity and its implications for food security, recommending the development of a comprehensive water management plan based on virtual water footprint analysis, alongside the enhancement of the use of treated and desalinated water. Wang and Ma (2024) examined the optimal allocation of water resources in the Yellow River Basin from a virtual water perspective, revealing that virtual water constitutes the largest share of total water demand, necessitating the integration of both physical and virtual water into allocation policies. Du (2023) focused on estimating the economic value of virtual water using an irrigation water-productivity maximization approach, highlighting significant regional disparities across agricultural areas in China and emphasizing the importance of improving water-use efficiency. Al-Badri et al. (2023) analyzed the water footprint and virtual water and their impact on food security in Iraq for wheat and rice, showing a high dependence on external water resources and recommending the incorporation of these concepts into agricultural production planning and irrigation water distribution. M. Zhang et al. (2024) explored virtual water flows and their drivers in international trade of agricultural products within the framework of the Regional Comprehensive Economic Partnership (RCEP). The results indicated that the main driving factors include agricultural crops, bilateral economic size, and agricultural human resources. El-Danasouri et al. (2019) conducted an economic study on the water footprint and virtual water trade of major cereal crops in Egypt using descriptive and quantitative economic analysis. The results showed that rice achieved net virtual water exports due to successful irrigation policies, whereas yellow maize and wheat recorded high net virtual water imports, reflecting weaknesses in agricultural and irrigation policies. The study recommended enhancing irrigation efficiency and adopting water footprint and virtual water indicators to improve water resource management and support food security, Ampong et al. (2025) examined trends and determinants of virtual water trade in vegetable production in Ghana, finding that Ghana is a net importer of virtual water, with GDP per capita, population size, and agricultural land availability exerting positive effects, while distance has a negative impact. L. Zhang et al. (2025) analyzed interregional circulation of vegetable trade in China from a virtual water perspective, identifying clear spatial disparities in virtual water flows, with exports concentrated in water-rich regions and urban regions relying heavily on imports. Finally, Igbaroola et al. (2025) conducted a systematic review of the factors influencing virtual water trade in agricultural crops, concluding that economic and social factors—such as population, GDP, and consumption patterns—are among the most influential determinants of the volume and direction of this trade, followed by environmental, technological, and trade policy factors.

3. Methodology

This study relies on annual time-series data covering the period (1990–2023) for a group of major agricultural crops in Iraq, namely wheat, rice, barley, yellow maize, and tomatoes. The data were obtained from official and non-official sources, including the Ministry of Planning/Central Statistical Organization, the Ministry of Agriculture/Planning and Follow-up Department, and the Ministry of Water Resources, in addition to international reports issued by the Food and Agriculture Organization (FAO, 2021) and relevant global databases on water and agriculture (World Bank, 2022). These sources are among the most widely used and reliable databases in economic studies related to virtual water and water security (Hoekstra et al., 2020). The variables include the dependent variable, which represents imported virtual water for barley (billion cubic meters) (LVW), while the independent variables comprise agricultural GDP (AGDP), blue water (BW), green water (GW), domestic water self-sufficiency ratio (DWS), the contribution of agricultural output to GDP (GS), and trade openness (TO).

4. Results and discussion

4.1. Model description

For econometric estimation, modern time-series techniques appropriate for the nature of the data will be employed. The stationarity of the time series will be tested using unit root tests such as the Augmented Dickey-Fuller (ADF) test, given the importance of verifying variable stability prior to econometric estimation. Furthermore, both long-run and short-run relationships among variables will be examined using the Autoregressive Distributed Lag (ARDL) model, which is considered one of the most suitable approaches for datasets with variables integrated of different orders (Nkoro & Uko, 2016; Pesaran et al., 2001). The general model is specified as follows:

$$\begin{aligned}\Delta LVW_t = {} & \alpha_0 + \alpha_1 LVW_{t-1} + \alpha_2 AGDP_{t-1} + \alpha_3 BW_{t-1} \\ & + \alpha_4 GW_{t-1} + \alpha_5 DWS_{t-1} + \alpha_6 GS_{t-1} + \alpha_7 TO_{t-1} \\ & + \sum_{i=1}^{p} \beta_1 \Delta LVW_{t-i} + \sum_{i=0}^{q_1} \beta_2 \Delta AGDP_{t-i} \\ & + \sum_{i=0}^{q_2} \beta_3 \Delta BW_{t-i} + \sum_{i=0}^{q_3} \beta_4 \Delta GW_{t-i} \\ & + \sum_{i=0}^{q_4} \beta_5 \Delta DWS_{t-i} + \sum_{i=0}^{q_5} \beta_6 \Delta GS_{t-i} \\ & + \sum_{i=0}^{q_6} \beta_7 \Delta TO_{t-i} + \varepsilon_t \qquad (1)\end{aligned}$$

Furthermore, the impact of the independent variables on virtual water will be analyzed through statistical significance testing of the estimated parameters, and the results will be interpreted in accordance with the economic theory of virtual water and water trade (Hoekstra et al., 2020). The econometric software package (EViews 10) will be used to conduct the estimation and statistical analysis. In addition, several diagnostic tests will be applied to ensure the reliability of the econometric results, including tests for autocorrelation, heteroskedasticity, and model stability.

4.1.1. Time series stationary test

Unit root test. Based on the adopted econometric methodology, the determinants of virtual water trade for barley in Iraq were analyzed over the period (1990–2023). The results of the Augmented Dickey-Fuller (ADF) unit root tests indicated that most of the variables were non-stationary at their levels, while they became stationary after taking the first difference, I(1), as shown in Table 1.

Cointegration Tests Using the Bounds Test. The variation in the order of integration necessitated the use of the Autoregressive Distributed Lag (ARDL) model. The results of the Bounds Test confirmed the existence of a long-run equilibrium relationship among the variables, where the calculated F-statistic reached (4.56), which is higher than the critical values at the 1% significance level, as shown in Table 2.

This result confirms the existence of a stable structural relationship among the variables over the study period, allowing for the analysis of both the short-run and long-run dynamics.

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

At level		LVW	AGDP	BW	GW	DWS	GS	TO
with constant	t-statisc	–1.797737	–1.436156	–4.440234	–4.440234	–2.274310	–6.358201	–2.442902
	prob.	0.3751	0.5527	0.0013	0.0013	0.1858	0.0000	0.1348
		N0	NO	NO	NO	N0	***	NO
with constant & Trend	t-statisc	–3.291101	–2.888872	–4.339157	–4.339157	–2.288636	–5.936359	2.105304
	prob.	0.0854	0.1787	0.0085	0.0083	0.4281	0.0003	0.0001
		NO	NO	**	**	NO	***	***
without constant & Trend	t-statisc	–0.901839	–0.110513	–0.580562	–0.511562	–0.558108	–1.058768	–2.145805
	prob.	0.3181	0.6381	0.4576	0.0065	0.4677	0.2556	0.0326
		NO	NO	NO	NO	NO	NO	**
At first Difference		D(LVW)	D(AGDP)	D(BW)	D(GW)	D(DWS)	D(GS)	D(TO)
with constant	t-statisc	–5.757687	–6.506519	–6.496748	–6.931	–6.636577	–5.713164	–0.455327
	prob.	0.0000	0.0000	0.0000	0.000	0.0000	0.0000	0.8838
		***	***	***	***	***	***	NO
with constant & Trend	t-statisc	–5.599979	–6.408712	–6.404748	–6.788	-6.580223	–5.696462	–3.561014
	prob.	0.0004	0.0000	0.0000	0.0000	0.0000	0.0003	0.0543
		***	***	***	***	***	***	NO
without constant & Trend	t-statisc	–6.636156	–6.406602	–6.612538	–6.764	–6.744871	–5.463068	–5.517524
	prob.	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
		***	***	***	***	***	***	***

Significant at the 10% level, ** significant at the 5% level, *** significant at the 1% level, no: not significant.
Source: Prepared by the authors based on (EViews10) statistical software outputs.

Table 2. Cointegration test using the bounds test approach.

F-Bounds Test		Null Hypothesis: No levels relationship		
Test Statistic	Value	Signif.	I(0)	I(1)
F-statistic	4.567751	10%	2.08	3
k	5	5%	2.39	3.38
		2.5%	2.7	3.73
		1%	3.06	4.15

Source: Prepared by the authors based on (EViews10) statistical software outputs.

Table 3. Error correction model (ECM).

ARDL Error Correction Regression				
ECM Regression Case 2: Restricted Constant and No Trend				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(BW)	0.000867	0.002451	0.353567	0.7269
D(DWS)	–7.35E-05	0.000143	–0.514156	0.6120
D(GS)	–0.000900	0.000734	–1.226501	0.2324
CointEq(-1)*	–0.720894	0.113537	–6.349439	0.0000
R-squared	0.616248	Mean dependent var		0.000823
Adjusted R-squared	0.576550	S.D. dependent var		0.017900
S.E. of regression	0.011648	Akaike info criterion		–5.954132
Sum squared resid	0.003935	Schwarz criterion		–5.772737
Log likelihood	102.2432	Hannan-Quinn criter.		–5.893098
Durbin-Watson stat	1.998304			

Source: Prepared by the authors based on (EViews10) statistical software outputs.

4.1.2. Estimating the results using ARDL model

Table 3 shows that all coefficients representing the short-run dynamics of imported virtual water for barley are statistically significant at the 1% level. This indicates that past changes in virtual water have a substantial impact on current variations, which is consistent with economic logic, as previous levels of virtual water imports influence current agricultural production capacity.

The error correction term (CointEq (-1)) is negative and statistically significant at the 1% level, with a coefficient value of (–0.720). This suggests that approximately 72% of the short-run disequilibrium is corrected annually, restoring the system toward its

Table 4. Long-run equation.

Levels Equation Case 2: Restricted Constant and No Trend				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
AGDP	–3.24E-07	1.96E-06	–0.164968	0.0704
BW	0.018800	0.007272	2.585135	0.0166
DWS	–0.000666	0.000223	–2.987862	0.0066
GS	–0.003626	0.001407	–2.577076	0.0169
TO	0.000123	6.62E-05	1.855911	0.0763
C	0.076925	0.025668	2.996908	0.0064

EC = VW - (-0.0000*AGDP + 0.0188*BW -0.0007*DWS -0.0036*GS + 0.0001*TO + 0.0769)

Source: Prepared by the authors based on (EViews10) statistical software outputs.

Table 5. LM test for detecting autocorrelation.

Breusch-Godfrey Serial Correlation LM Test:			
F-statistic	0.133539	Prob. F(2,21)	0.8757
Obs*R-squared	0.414424	Prob. Chi-Square(2)	0.8128

Source: Prepared by the authors based on (EViews10) statistical software outputs.

long-run equilibrium path. This reflects an effective adjustment mechanism between short-run fluctuations in imported virtual water for barley and the long-run relationship with other model variables. Moreover, both the necessary and sufficient conditions for model stability are satisfied.

4.1.3. Long-run equation

As shown in Table 4, which presents the estimated long-run equation and the cointegration relationship between the independent variables and the dependent variable, the results are largely consistent with economic theory. The coefficient of AGDP (agricultural GDP) carries a negative sign, amounting to (–0.0000003), indicating an inverse long-run relationship between agricultural GDP and imported virtual water for barley in Iraq. This implies that an increase in agricultural GDP reduces reliance on virtual water imports. The coefficient is statistically significant at the 10% level, with a p-value of (0.0704), suggesting a relatively weak statistical significance despite its theoretical consistency. The coefficient of BW (blue water) is positive and statistically significant at the 1% level, with a value of (0.018). This can be interpreted as reflecting the instability and variability of rainfall-based water resources, which leads to compensatory reliance on imports to offset production shortages. Meanwhile, the coefficient of DWS (domestic water self-sufficiency ratio) is negative and statistically significant at the 1% level, with a value of (–0.00066). This confirms an inverse long-run relationship: higher levels of domestic water self-sufficiency reduce virtual water imports, consistent with the economic logic of strengthening domestic production and reducing external dependence. Similarly, GS (the share of agricultural output in GDP) has a negative and statistically significant coefficient at the 1% level, amounting to (–0.0036). This suggests that enhancing the agricultural sector's role in the national economy reduces the volume of imported virtual water due to improved domestic production capacity.

Finally, TO (trade openness) has a positive and statistically significant coefficient at the 10% level, with a value of (0.00012), indicating a positive long-run relationship between trade openness and imported virtual water. This means that greater trade openness contributes to higher import volumes, including water-intensive commodities.

4.2. Diagnostic tests for the model

4.2.1. Autocorrelation test (LM test)

As shown in Table 5, which examines the presence of autocorrelation using the LM test, the calculated F-statistic is (0.13), while the corresponding probability value is (0.87), which is greater than (0.05). This leads to the acceptance of the null hypothesis, indicating that the model does not suffer from an autocorrelation problem.

4.2.2. Multicollinearity test (Variance inflation factor - VIF)

Table 6 shows that all VIF values are below (10), which provides evidence of the absence of multicollinearity among the explanatory variables. Accordingly, the alternative hypothesis is rejected and the null hypothesis of no multicollinearity is accepted.

The variable (GW), representing green water, was excluded due to its strong correlation with (BW), which arises from the high correlation

Table 6. Variance inflation factor (VIF) test for detecting multicollinearity.

Variance Inflation Factors			
Variable	Coefficient Variance	Uncentered VIF	Centered VIF
VW(-1)	0.023682	9.770512	3.887871
AGDP	1.93E-12	16.40515	5.464192
BW	1.26E-05	15.34113	1.664635
BW(-1)	1.16E-05	13.78136	1.514504
DWS	3.12E-08	46.43878	2.402028
DWS(-1)	3.50E-08	52.37372	2.724221
GS	8.90E-07	15.32580	5.035696
GS(-1)	9.09E-07	15.97591	5.030308
TO	2.14E-09	1.522619	1.230700
C	0.000346	66.75769	NA

Source: Prepared by the authors based on (EViews10) statistical software outputs.

Table 7. Breusch-pagan-godfrey (BPG) test for detecting Heteroskedasticity.

Heteroskedasticity Test: Breusch-Pagan-Godfrey			
F-statistic	2.254407	Prob. F(9,23)	0.0650
Obs*R-squared	15.46694	Prob. Chi-Square(9)	0.0789
Scaled explained SS	7.802416	Prob. Chi-Square(9)	0.5542

Source: Prepared by the authors based on (EViews10) statistical software outputs.

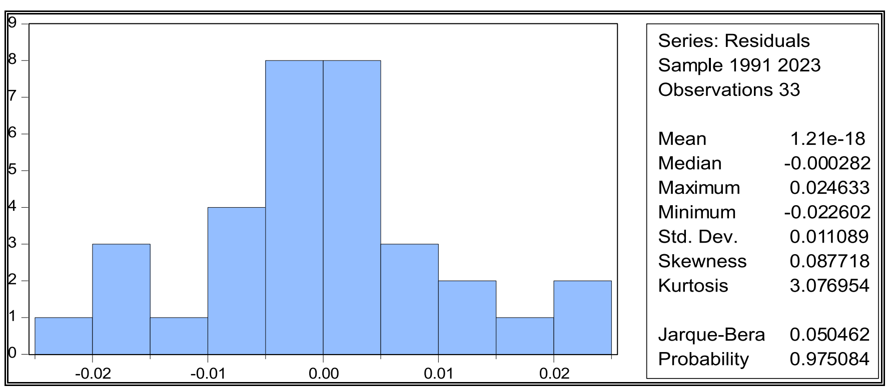

Fig. 1. Normal distribution of residuals using the Jarque-Bera test.
Source: Prepared by the authors based on (EViews10) statistical software outputs.

between the values of these two variables. Therefore, (GW) was removed to avoid the problem of high correlation.

4.2.3. Heteroskedasticity test (Breusch-Pagan-Godfrey)

The results of the Breusch-Pagan-Godfrey test in Table 7 show a probability value of (0.065), which is greater than (0.05). This indicates the acceptance of the null hypothesis and confirms the absence of heteroskedasticity. Accordingly, the model exhibits homoscedastic error variance.

4.2.4. Testing the normality

Fig. 1 shows that the Jarque-Bera (JB) statistic is (0.0504), with a probability value of (0.97), which is greater than (0.05). This indicates the acceptance of the null hypothesis and confirms that the residuals are normally distributed, suggesting a well-specified model.

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

Structural stability of the ARDL model parameters was examined using the cumulative sum of recursive residuals (CUSUM) and the cumulative sum of squares of recursive residuals (CUSUMSQ). Fig. 2 shows that the CUSUM plot remained within the critical bounds at the 5% significance level throughout the study period, with a slight approach toward the lower bound in recent years but without any clear boundary violation. This indicates the absence of structural breaks in the model coefficients. Regarding the CUSUMSQ test, the plot also remained within the critical bounds at the 5% significance level over the

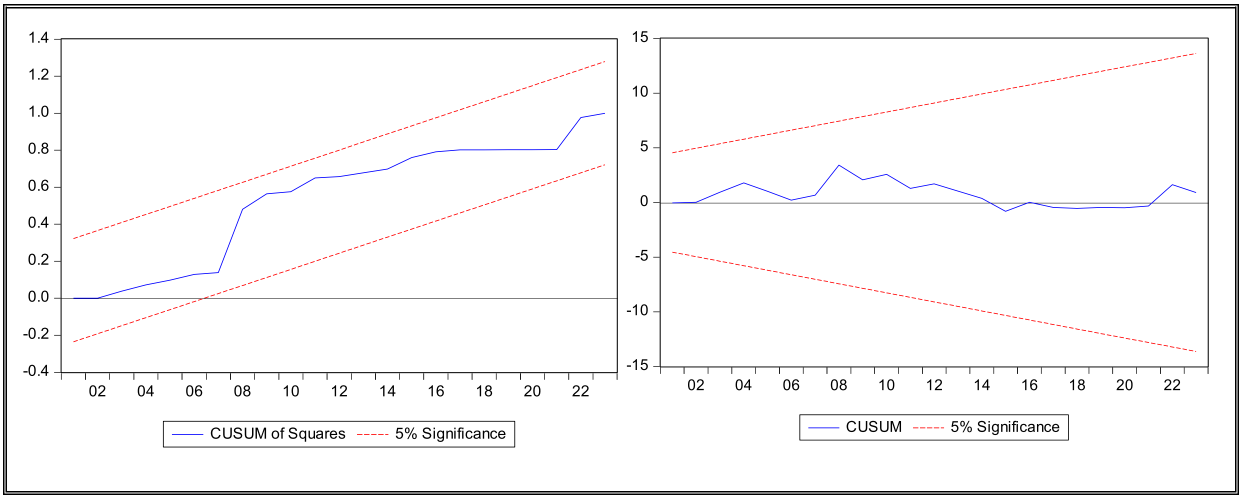

Fig. 2. Cumulative sum of recursive residuals (CUSUM) and cumulative sum of squares of recursive residuals (CUSUMSQ).
Source: Prepared by the authors based on (EViews10) statistical software outputs.

entire study period. Despite a slight upward trend in some years, it did not exceed the critical limits, indicating stable error variance and no sudden structural changes affecting parameter estimates. Based on both tests, it can be concluded that the estimated model parameters are structurally stable and statistically consistent over the study period, and that short-run coefficients are coherent with long-run relationships, thereby enhancing the reliability and robustness of the econometric results and their suitability for economic interpretation.

5. Conclusions

The results of the Bounds Test confirmed the existence of a long-run equilibrium relationship linking virtual water imports with a set of economic and water-related variables in Iraq. The error correction term further indicated a strong capacity of the Iraqi economy to adjust to deviations from the long-run equilibrium path, with an adjustment speed estimated at approximately 72% per annum. The findings also revealed a statistically significant inverse relationship between water self-sufficiency and virtual water imports, suggesting that improvements in water resource management reduce reliance on imports. Conversely, a positive relationship was observed between trade openness and the volume of virtual water imports, reflecting the indirect impact of trade policies on water resource depletion. In addition, an inverse relationship was identified between agricultural GDP growth and virtual water imports; however, the magnitude of this effect was insufficient to achieve full import substitution. Finally, the study concluded that the instability of water resources, particularly green water, necessitates compensating for the barley production gap through external imports.

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Conflict of interest

The Authors declare that there is no conflict of interest.

Author contributions

Muna Jabbar Rahim: Conceived and designed the analysis, Designed the research framework and econometric model (ARDL), Collected the data, Collected data from Ministry of Planning, FAO, and World Bank databases, Contributed data or analysis tools, Used EViews software and statistical tools for analysis, Performed the analysis, Conducted econometric analysis including ADF, ARDL, ECM, and diagnostic tests, and Wrote the paper, Prepared and wrote the manuscript.

Basim H. Al-Badri: Conceived and designed the analysis, Provided guidance in developing the research idea and model design and Other contribution, Provided scientific supervision and final approval of the research.

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Authors' declaration

- We hereby confirm that all the Figures and Tables in the manuscript are ours, and all results were prepared by the authors.
- Ethical Clearance: The Research Was Approved by The Local Ethical Committee in The University of Baghdad.
- No animal studies are present in the manuscript.

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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