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Effects of Agricultural Inputs and Climate Variability on Crop Production: Evidence from Azerbaijan Using ARDL Approach

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Abstract: This research investigates the long-term relationship between agricultural inputs, climate change, and agricultural output in Azerbaijan, with a particular focus on the effects of irrigation and agricultural supplies (IAS), investment in fixed capital, and climate conditions on agricultural output. Using annual data from 2002 to 2021, the study employs the Autoregressive Distributed Lag (ARDL) bounds testing approach to examine cointegration among the variables. The results confirm a statistically significant long-run equilibrium relationship between the Crop Production Index (CPI) and its key determinants, including irrigation and agricultural supplies, investment in agricultural fixed capital (INAG), and average annual rainfall (AAR). The ARDL F-statistic exceeds the upper critical bounds at both the 5% and 1% significance levels, providing strong evidence of cointegration. Robustness checks based on long-run coefficient estimates show that a 1% increase in IAS leads to a 1.319% increase in CPI, while a 1% increase in INAG results in a 0.038% rise in CPI. Conversely, AAR has a statistically significant negative impact, with a 1% increase in rainfall corresponding to a 0.115% decline in crop production, likely reflecting climatic irregularities. These findings underscore the critical importance of sustained capital investment and efficient input supply in enhancing crop productivity, while highlighting the risks posed by environmental variability for sustainable agricultural development in Azerbaijan.

Keywords: Crop production; Agricultural supply chain; Irrigation; Investment; Climate; Autoregressive Distributed Lag; Cointegration analysis; Azerbaijan

1 Introduction

Climate change is expected to significantly undermine the stability of crop production systems, while projections indicate that water availability will become increasingly constrained by 2050. In this context, the adoption of advanced water conservation measures and improvements in irrigation efficiency will be pivotal in sustaining an adequate water supply for agricultural productivity [1]. On a global scale, approximately 11% of croplands and 10% of grasslands are susceptible to diminished water availability, potentially leading to a decline in their productive capacity. Regions including Africa and parts of Asia are anticipated to be especially susceptible to the adverse effects of declining water availability and its associated impact on agricultural productivity [2]. The 2015 Paris Climate Conference (COP21) underscored the importance of agricultural sustainability by prioritizing sustainable crop production and the enhancement of food security. Emphasis was placed on advancing climate-resilient agricultural systems, optimizing resource use efficiency, and implementing sustainable land and water management practices to address the challenges posed by climate change [3]. Effective decision-making to address climate change and to advance the economic development of the agricultural sector necessitates the integration of multiple analytical frameworks to evaluate anticipated risks and benefits. These frameworks should incorporate considerations of governance mechanisms, ethical dimensions, issues of equity, comprehensive economic assessments, and the diverse responses to risk and uncertainty across stakeholder groups [4].

Agriculture occupies a central role in Azerbaijan's non-oil economic development, contributing substantially to national food security and promoting the growth of export-driven production through increased financial allocation and strategic investment. In Azerbaijan's economy, agriculture ranks as the third-largest sector following oil and construction. The agricultural sector, along with its associated processing industries, supplies approximately 75% of the population's demand for consumer goods, highlighting its critical role in ensuring domestic food availability and supporting overall economic stability [5]. Between 2014 and 2019, Azerbaijan experienced favorable trends in the consumption of essential food products. In 2019, the country was ranked 53rd among 113 countries in the Global Food Security Index (GFSI), with a score of 64.8 out of 100. The GFSI assesses food security based on dimensions including accessibility, availability, quality, and safety, underscoring Azerbaijan's advancements in these areas [6]. In Azerbaijan, irrigation holds strategic significance for agricultural productivity, given the country's limited and unevenly distributed land resources. A substantial portion of cultivable land lies in arid zones, making effective irrigation systems essential for sustaining crop production [7]. The area of agricultural land equipped with modern pivot irrigation systems in Azerbaijan has expanded from 80,000 to 120,000 hectares. Promoting the use of advanced irrigation technologies constitutes a central policy direction of the Ministry of Agriculture. In alignment with this strategy, the Agricultural Subsidy Council has endorsed incentive mechanisms, including a 60% increase in subsidies for farms adopting such systems. These support measures are expected to continue in the coming period [8].

The aim of this study is to examine the long-term impact of the agricultural supply chain and climate-related factors on crop production in Azerbaijan, with particular emphasis on the roles of irrigation, agricultural investment, and annual rainfall. Understanding the intricate relationships within the agricultural supply chain, particularly irrigation, and their impact on crop production is vital for designing precise and effective policy interventions. A comprehensive examination of these connections offers critical insights into enhancing resource efficiency and boosting agricultural productivity. This study aims to elucidate these interactions in order to guide the formulation of strategies that support sustainable agricultural development in Azerbaijan.

2 Literature Review

Agricultural supply chains are essential systems that span the entire journey from production to consumption, integrating the movement of goods and information exchange. These interconnected processes are fundamental to maximizing agricultural income, reducing expenditures, and supporting global food security. Bhatia and Bhat [9] developed an integrated mathematical and conceptual framework, employing linear programming techniques to optimize the production and distribution processes of perishable agricultural crops. Their model is designed to enhance farm revenue while minimizing associated costs by incorporating variables such as historical resource availability, market prices, crop selection, investment levels, and timing. This approach facilitates efficient planning across all stages from cultivation to harvest. In their study focused on agricultural supply chains and food security, Sjah and Zainuri [10] conceptualized the supply chain as a network encompassing all stakeholders engaged in the production and delivery of goods or services, extending from initial suppliers to end consumers. In addition to the physical movement of products, the supply chain also involves a financial flow from consumers to producers and a two-way information flow that facilitates the coordination of production and distribution activities. Pourmehdi and Kheiralipour [11] assessed the environmental impacts of dryland and irrigated wheat production systems through a life cycle assessment, introducing a novel "input-to-total-output" efficiency index based on data collected from 100 farms. Their findings indicated that dryland wheat production exhibited greater environmental impacts and lower input efficiency relative to irrigated systems, with nitrogen identified as the primary contributor to multiple environmental indicators.

Optimizing crop production is vital for ensuring global food security, especially in countries heavily reliant on agriculture that confront various challenges. Investigating the determinants of agricultural output is fundamental to formulating effective strategies aimed at improving resilience and productivity. Chopra [12] examined both long- and short-term dynamics between crop production and critical inputs such as land use, agricultural water consumption, and gross irrigated area in India over the period from 1981 to 2018, employing the Autoregressive Distributed Lag (ARDL) bounds testing methodology. The results demonstrated a significant long-run association, with crop production positively affected by land use and irrigated area, while the error correction model validated the system's capacity to converge toward equilibrium over time. Warsame et al. [13] analyzed the influence of rainfall, temperature, and CO_2 emissions on Somalia's crop production from 1985 to 2016, finding that rainfall exerts a mixed effect, with positive long-term and negative short-term impacts, temperature consistently reduces production, and CO_2 emissions have no significant effect, emphasizing the urgent need for targeted climate adaptation and mitigation policies to strengthen agricultural resilience.

Laghari et al. [14] investigated the impact of agricultural land on food and crop production in China from 1990 to 2021, incorporating environmental sustainability as a moderating variable and employing the ARDL bounds testing approach. Their results demonstrated significant long- and short-term relationships, while robustness checks using fully modified ordinary least squares (FMOLS) and dynamic ordinary least squares (DOLS) confirmed the consistency of the long-run ARDL estimates, thereby reinforcing the validity and reliability of the primary findings. Yadav and Goyari [15] empirically examined the impact of financial development on crop productivity in India using time-series data from 1980 to 2020 and the ARDL bounds testing methodology. Their findings confirm a long-run equilibrium relationship, with financial development exerting a strong positive influence on crop productivity, supported by evidence of bidirectional causality and consistent results across various estimation techniques. Consistent findings have emerged from studies conducted in multiple countries with comparable agricultural supply and production structures, utilizing similar methodological frameworks. This convergence of results underscores the reliability of the applied metrics and reveals shared trends in the determinants of agricultural productivity and supply chain performance across different regional settings [16–18].

This study examines agricultural output in Azerbaijan, concentrating specifically on the roles of irrigation and agricultural inputs. A comprehensive review of the theoretical framework and extant empirical literature highlights a significant gap in research addressing these factors within the Azerbaijani context. Recognizing the continued importance of this topic, the present research aims to contribute original insights and methodological innovations that advance scholarly understanding in this field.

3 Data and Methodology

This research explores the interrelationship between the agricultural supply chain, environmental factors, and crop production dynamics in Azerbaijan. Specifically, it assesses the influence of irrigation and agricultural supplies (IAS), investment in agricultural fixed capital (INAG), and average annual rainfall (AAR) on the Crop Production Index (CPI). The empirical analysis spans the period from 2002 to 2021. The dependent variable, CPI, is obtained from the World Bank [19, 20], while data for the explanatory variables are derived from the official records of the State Statistical Committee of the Republic of Azerbaijan (SSCRA) [21]. All variables are annual and measured in consistent national-level units to ensure data comparability.

Figure 1 demonstrates a consistent upward trajectory in Azerbaijan's CPI, which appears to correspond with the steady increase in expenditures on IAS, as well as the overall upward, though variable, trend in investment in agricultural fixed capital between 2002 and 2021. IAS displays a stable growth pattern, whereas INAG fluctuates, likely reflecting shifts in economic conditions or agricultural policy decisions. In contrast, AAR exhibits significant volatility, highlighting the ongoing impact of environmental variability on agricultural output.

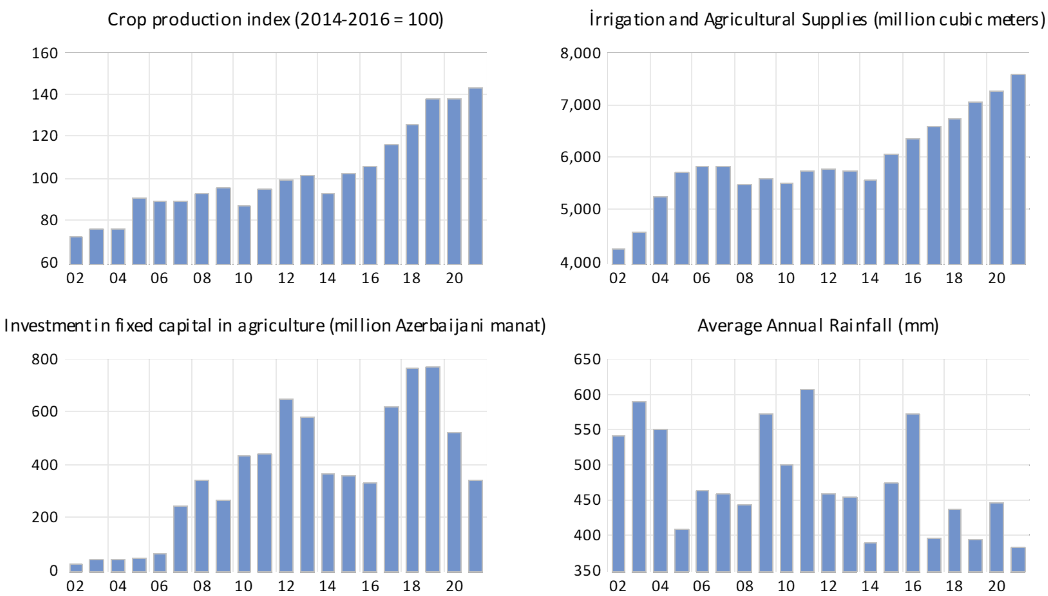

Figure 1. Trends in agricultural inputs, investment, rainfall, and crop production in Azerbaijan (2002–2021)

The data in this study reflects the most recent statistics, so a general depiction of the GDP deflator is necessary for overall context. The graph illustrates (Figure 2) that Azerbaijan's GDP deflator, which captures changes in the general price level relative to a base year, has shown an upward trend from 2002 to 2021, indicating a general increase in inflation over this period. Temporary declines observed around 2009 and 2020 suggest periods of slower price growth, likely associated with global economic disruptions or domestic economic adjustments.

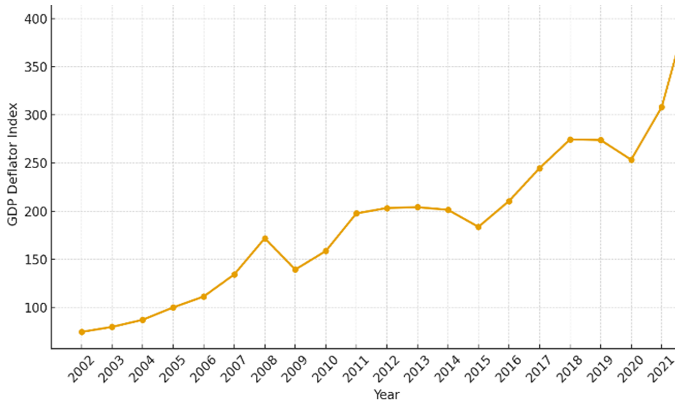

Figure 2. Changes in Azerbaijan's GDP deflator, indicating inflation trends (2002–2021) [20]

The descriptive statistics presented in Table 1 for Azerbaijan's agricultural sector over the period 2002 to 2021 indicate an average CPI of approximately 100.95, accompanied by considerable variability as reflected by a standard deviation of 20.82 and a range spanning from 71.76 to 142.51. The Jarque-Bera test probabilities for all examined variables including CPI, INAG, IAS, and AAR exceed the 0.05 threshold, indicating that the data for each variable follow a normal distribution. This assumption of normality supports the appropriateness and reliability of subsequent statistical analyses investigating the interrelationships among these key agricultural factors.

Table 1. Descriptive statistics of the variables

Statistic	CPI	INAG	IAS	AAR
Mean	100.948	359.315	5919.06	475.68
Median	94.965	348.65	5759.1	457.95
Maximum	142.51	769.5	7575	605.8
Minimum	71.76	18.5	4248	381.1
Std. Dev.	20.81716	241.4419	821.9297	71.77508
Skewness	0.729462	0.087846	0.148776	0.418788
Kurtosis	2.564553	2.016128	2.938652	1.91797
Jarque-Bera	1.931728	0.832393	0.076917	1.560268

The line graph in Figure 3 illustrates the temporal trends of the natural logarithms of CPI, INAG, IAS, and AAR, capturing their evolution within Azerbaijan's agricultural sector. IAS demonstrate a steady upward trajectory, indicative of continuous growth in input provision. In contrast, the natural logarithms of crop production index (L_CPI), investment in agricultural fixed capital (L_INAG), and average annual rainfall (L_AAR) exhibit greater variability, reflecting fluctuating patterns in crop output, agricultural investment, and climatic conditions over the observed period.

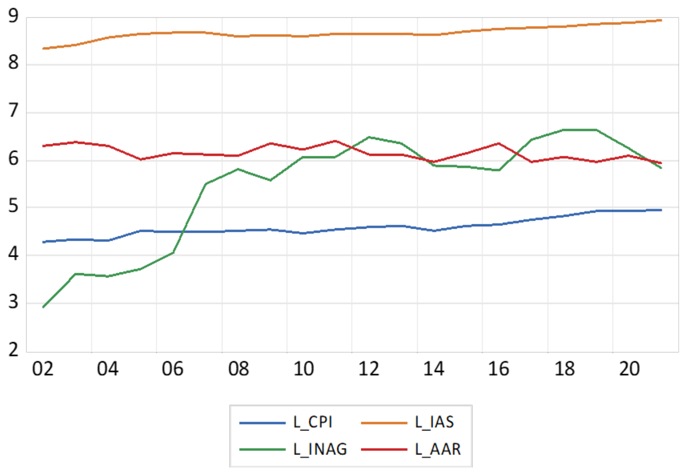

Figure 3. Logarithmic trends of the variables

To evaluate the time series properties of the variables, the Augmented Dickey-Fuller (ADF) [22] unit root test was applied to determine the order of integration and ensure the suitability of subsequent econometric techniques. Upon confirming the stationarity structure of the data, the ARDL [23] bounds testing approach was employed to assess the existence of a long-run cointegration relationship between the variables. The ARDL model F-Bound test is particularly suitable for small sample sizes and mixed levels of integration, i.e., I(0) and I(1). The general specification of the ARDL model applied within the context of this study can be expressed as follows:

$$\begin{gathered}\Delta \ln\left(\mathrm{CPI_t}\right) = \alpha_0 + \sum_{i=1}^{p} \beta_i \Delta \ln\left(\mathrm{CPI_{t-i}}\right) + \sum_{j=0}^{q} \gamma_j \Delta \ln\left(\mathrm{IAS_{t-j}}\right) + \\ \sum_{\{k=0\}}^{r} \delta_k \Delta \ln\left(\mathrm{INAG_{t-k}}\right) + \sum_{m=0}^{s} \theta_m \Delta \ln\left(\mathrm{AAF_{t-m}}\right) + \phi_1 \ln\left(\mathrm{CPI_{t-1}}\right) \\ + \phi_2 \ln\left(\mathrm{IAS_{t-1}}\right) + \phi_3 \ln\left(\mathrm{INAG_{t-1}}\right) + \phi_4 \ln\left(\mathrm{AAF_{t-1}}\right) + \varepsilon_t\end{gathered} \tag{1}$$

This methodological framework ensures a comprehensive analysis of both the dynamic short-run behavior and the equilibrium long-run relationship between agricultural input availability and crop output in Azerbaijan.

4 Results and Discussion

The Unit Root Test results in Table 2 show that at the original level, only L_AAR is stationary, with a significant ADF statistic (-3.989) and p-value ($0.028 < 0.05$), while L_CPI, L_IAS, and L_INAG are non-stationary. After taking the first difference, all these variables become stationary, with significant ADF statistics and p-values below 0.05, indicating they are integrated of order one, I(1). This mix of I(0) and I(1) variables confirms the suitability of the ARDL model, which can handle a combination of stationary and first-differenced variables for estimating both short-run and long-run relationships without the risk of spurious regression.

Table 2. Unit root test

Trend and Intercept Variables	Level ADF Test Statistic	First Difference ADF Test Statistic
L_CPI	-2.100 (0.513)	-5.317 (0.002)*
L_IAS	-2.277 (0.424)	-4.201 (0.022)*
L_INAG	-1.158 (0.890)	-3.723 (0.047)*
L_AAR	-3.989 (0.028)*	-

Note: *Significant at 5% level.

Table 3 displays the results of the ARDL F-Bounds test, employed to assess the existence of a long-run relationship among the variables. The computed F-statistic of 18.813 surpasses the upper critical bound value of 4.66 at the 1% significance level. Consequently, the null hypothesis of no cointegration is rejected, confirming a statistically significant long-run equilibrium relationship. These results establish the presence of a stable long-run association between the CPI and the independent variables in Azerbaijan.

Table 3. F-Bounds test

Test Statistic	Value	Signif.	I(0)	I(1)
F-statistic	18.813	10%	2.37	3.20
k	3	5%	2.79	3.67
		1%	3.65	4.66

The diagnostic test results of the ARDL model (see Table 4), confirm the robustness and reliability of the model. The ECM regression shows a highly significant error correction term, cointEq(–1), with a t-statistic of -11.878 and a p-value below 0.05, indicating a strong adjustment mechanism toward long-run equilibrium. The Breusch-Godfrey Serial Correlation LM Test reveals no evidence of autocorrelation, while the Breusch-Pagan-Godfrey test indicates the absence of heteroskedasticity, confirming that the model's residuals maintain constant variance. These findings collectively validate the adequacy of the ARDL model for capturing the dynamic relationship among the variables.

The CUSUM and CUSUM of Squares plots displayed in Figure 4 remain within the 5% significance boundaries, indicating parameter stability of the ARDL model over the examined period. This provides evidence of the model's structural stability, implying that the estimated relationship between the CPI and other independent variables in Azerbaijan remains consistent across the sample timeframe.

Table 4. Diagnostic tests for ARDL model

Variable	Coefficient	Std. Error	*t*-Statistic	*p*-Value
ECM Regression				
CointEq(-1)	-1.392	0.117	-11.878	0.000
Breusch-Pagan-Godfrey Heteroskedasticity Test				
F-statistic	0.987	Prob. F(9,8)	0.512	
Obs*R-squared	9.470	Prob. Chi-Square (9)	0.512	
Scaled Explained SS	1.049	Prob. Chi-Square (9)	0.999	
Breusch-Godfrey Serial Correlation LM Test				
F-statistic	0.137	Prob. F(2, 6)	0.874	
Obs*R-squared	0.787	Prob. Chi-Square (2)	0.674	

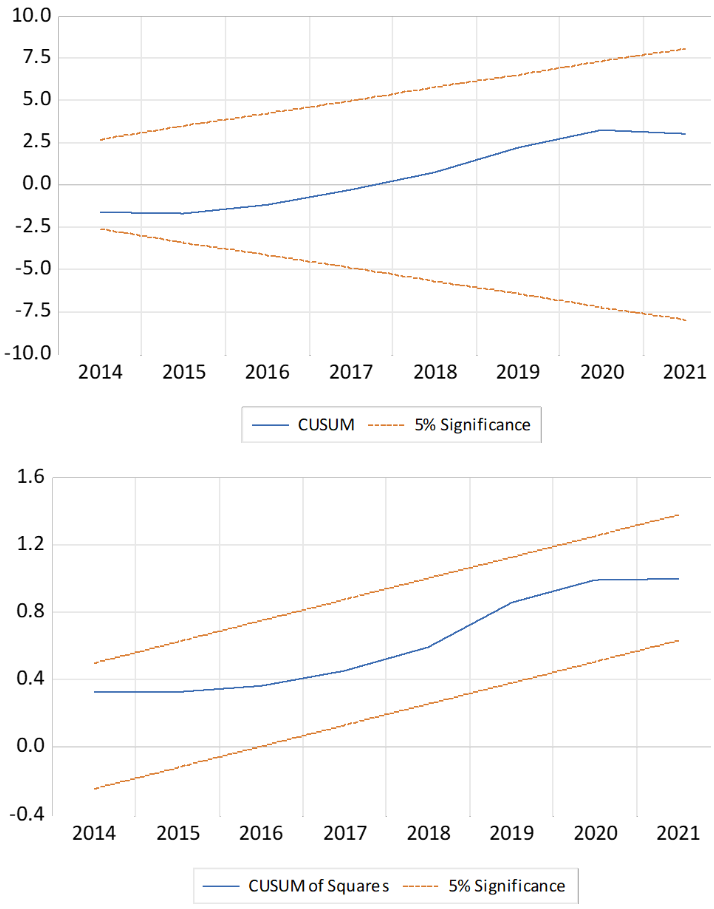

Figure 4. Stability tests of the ARDL model parameters using CUSUM and CUSUM of squares

Table 5 indicates that, in the long run, both INAG and IAS exert statistically significant and positive effects on crop production in Azerbaijan. Specifically, a 1% increase in INAG is associated with a 0.038% rise in the CPI, while a 1% increase in IAS corresponds to a notably larger 1.319% increase in CPI. In contrast, AAR shows a significant negative effect, as a 1% rise in AAR leads to a 0.115% decline in CPI, implying that excessive or erratic rainfall may adversely affect agricultural productivity. These results suggest a robust long-term equilibrium relationship and emphasize the importance of consistent investment and input provision, alongside the challenges posed by climatic variability.

Table 5. Long-run coefficient estimates from the ARDL model

Variable	Coefficient	Std. Error	*t*-Statistic	Probability
L_INAG	0.038	0.008	4.746	0.001
L_IAS	1.319	0.065	20.089	0.000
L_AAR	-0.115	0.038	-2.970	0.017
C (Constant)	-6.382	0.683	-9.344	0.000

The empirical evidence from this study confirms a statistically robust and economically meaningful long-run relationship between irrigation and agricultural supplies and crop production in Azerbaijan. The ARDL bounds test confirms cointegration, and the results reveal a statistically significant long-term equilibrium association between the CPI and its determinants. Investments in agricultural fixed capital and supplies positively contribute to increases in crop production, whereas AAR negatively affects CPI, likely due to unpredictable climatic patterns. This underscores the necessity of sustained capital investment and effective input management, alongside the challenges posed by environmental variability.

These results echo the broader regional and international research literature. Samatar [24], in the context of Somalia, found that employment in agriculture, capital formation, and arable land significantly influence agricultural productivity, emphasizing the need for investment-led and climate-resilient strategies. Although rainfall showed a positive impact, its statistical insignificance in Somalia's case supports the argument for more controlled water management, such as irrigation systems, particularly under increasingly variable climatic conditions. Similarly, Gulaliyev et al. [25] highlighted the weaknesses in Azerbaijan's agricultural sustainability, particularly in its economic and environmental dimensions. These structural shortcomings suggest that improvements in agricultural supplies could not only boost output but also enhance sustainability and reduce rural–urban disparities in welfare. Furthermore, Huseynov et al. [26] found that fixed capital investment is pivotal for sustaining long-term agricultural output growth, with short-term gains driven by government expenditure. These findings complement the current study, implying that improvements in agricultural supply, especially if driven by capital investment and effective public policy, can have far-reaching impacts on sectoral productivity.

The policy implications of these results are significant. Given the high elasticity coefficient and explanatory power of the variables in the ARDL model, policymakers should intensify efforts to upgrade irrigation networks, expand capital investment, expand access to modern agricultural inputs, and ensure efficient distribution mechanisms. These strategies would not only enhance yield stability but also support long-term food security in the face of climate variability. Moreover, precision agriculture and the adoption of water-saving technologies could amplify these benefits, making crop production more resilient and sustainable. Future research should aim to broaden the analytical scope by incorporating additional explanatory variables such as agricultural mechanization, climatic indices, land-use changes, and market infrastructure. This would allow for a more nuanced understanding of the multifactorial dynamics influencing crop production. Despite its limitations, this study provides a strong empirical foundation for evidence-based policymaking to support Azerbaijan's agricultural modernization agenda.

5 Conclusion

The empirical results confirm the existence of a long-term equilibrium relationship between crop production and key determinants, including irrigation and agricultural inputs, capital investment, and average annual rainfall in Azerbaijan. The ARDL bounds test, with a computed F-statistic of 18.813, strongly rejects the null hypothesis of no cointegration, indicating a stable and sustained association among the variables. The estimated levels equation further reinforces this finding by revealing statistically significant and meaningful effects of irrigation infrastructure, input provision, capital allocation, and climatic conditions on crop output. The model's explanatory power underscores the critical influence of these factors on agricultural productivity. The higher elasticity of irrigation supply compared to that of capital investment underscores the central role of water availability in Azerbaijan's crop production. Efficient irrigation directly boosts yields, while capital investment has a more indirect effect, consistent with agronomic and resource-based theories emphasizing the immediate impact of water infrastructure in water-scarce or climate-sensitive contexts. These findings offer solid empirical evidence to support policy initiatives focused on improving input efficiency and fostering long-term sustainable development in the agri-food sector.

Author Contributions

Conceptualization, M.G. and R.H.; methodology, M.G.; software, R.H.; validation, F.G., A.A., and A.N.; formal analysis, F.G.; investigation, M.G. and R.H.; resources, R.H.; data curation, M.G.; writing—original draft preparation, M.G and R.H..; writing—review and editing, F.G., A.A., and A.N.; visualization, R.H.; supervision, M.G.; project administration, M.G. and R.H.; funding acquisition, A.A. and A.N. All authors have read and agreed to the published version of the manuscript.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] I. Faisal and S. Parveen, "Food security in the face of climate change, population growth and resource constraints," in *IOP Conference Series: Earth and Environmental Science*, vol. 6, no. 51. Copenhagen, Denmark, 2009. https://doi.org/10.1088/1755-1307/6/51/512001

[2] N. Fitton, P. Alexander, N. Arnell, B. Bajzelj, K. Calvin, J. Doelman, J. S. Gerber, P. Havlik, T. Hasegawa, M. Herrero, and et al., "The vulnerabilities of agricultural land and food production to future water scarcity," *Glob. Environ. Change*, vol. 58, p. 101944, 2019. https://doi.org/10.1016/j.gloenvcha.2019.101944

[3] United Nations Framework Convention on Climate Change, "Adoption of the Paris agreement: Report of the conference of the parties on its twenty-first session, held in Paris from 30 November to 13 December 2015," 2015. https://unfccc.int/resource/docs/2015/cop21/eng/10a01.pdf

[4] M. Sivakumar, "Climate change, agriculture adaptation, and sustainability," in *Climate Resilience and Environmental Sustainability Approaches: Global Lessons and Local Challenges*. Singapore: Springer Singapore, 2021, pp. 87–109. https://doi.org/10.1007/978-981-16-0902-2_6

[5] R. Mustafayeva, Y. Abbasova, and R. Qambarova, "Economic assessment of agriculture development and prospective directions of agrarian reforms in the Republic of Azerbaijan," *Sci. Pap. Ser. Manag. Econ. Eng. Agric. Rural Dev.*, vol. 21, no. 1, pp. 525–536, 2021.

[6] Food and Agriculture Organization of the United Nations, "Comprehensive analysis of the disaster risk reduction system for the agricultural sector in Azerbaijan," 2022. https://openknowledge.fao.org/server/api/core/bitstreams/ae677d2f-053a-46a2-9c69-984c695e1491/content

[7] Ministry of Agriculture of the Republic of Azerbaijan, "Technology and Innovation," 2025. https://www.agro.gov.az/en/technology-and-innovation

[8] T. Firudin, "Agriculture total area of farms with modern irrigation systems in Azerbaijan announced," 2025. https://fed.az/az/aqrar/azerbaycanda-muasir-suvarma-sistemli-teserrufatlarin-umumi-sahesi-aciqlanib-225656

[9] M. Bhatia and G. M. J. Bhat, "Agriculture supply chain management—An operational perspective," *Braz. J. Oper. Prod. Manag.*, vol. 17, no. 4, pp. 1–18, 2020. https://doi.org/10.14488/BJOPM.2020.043

[10] T. Sjah and Z. Zainuri, "Agricultural supply chain and food security," in *Zero Hunger*. Cham: Springer International Publishing, 2020, pp. 79–88. https://doi.org/10.1007/978-3-319-95675-6_82

[11] K. Pourmehdi and K. Kheiralipour, "Compression of input to total output index and environmental impacts of dryland and irrigated wheat production systems," *Ecol. Indic.*, vol. 148, p. 110048, 2023. https://doi.org/10.1016/j.ecolind.2023.110048

[12] R. R. Chopra, "Sustainability assessment of crops' production in India: Empirical evidence from ARDL-ECM approach," *J. Agribus. Dev. Emerg. Econ.*, vol. 13, no. 3, pp. 468–489, 2023. https://doi.org/10.1108/JADEE-06-2021-0153

[13] A. A. Warsame, I. A. Sheik-Ali, A. O. Ali, and S. A. Sarkodie, "Climate change and crop production nexus in Somalia: An empirical evidence from ARDL technique," *Environ. Sci. Pollut. Res.*, vol. 28, no. 16, pp. 19 838–19 850, 2021. https://doi.org/10.1007/s11356-020-11739-3

[14] F. Laghari, F. Ahmed, B. Ansari, and P. J. Silveira Ferreira, "Agricultural land, sustainable food and crop productivity: An empirical analysis on environmental sustainability as a moderator from the economy of China," *Sustain.*, vol. 17, no. 5, p. 1980, 2025. https://doi.org/10.3390/su17051980

[15] I. S. Yadav and P. Goyari, "The effects of financial development on crop productivity: ARDL evidence from Indian agriculture," *J. Financ. Econ. Policy*, vol. 17, no. 4, pp. 530–558, 2024. https://doi.org/10.1108/JFEP-05-2023-0126

[16] A. Okunola, "Effect of land allocation on agricultural productivity in Nigeria using ARDL approach to cointegration," *J. Land Rural Stud.*, vol. 11, no. 2, pp. 115–130, 2023. https://doi.org/10.1177/23210249231155800

[17] N. F. Marwan, M. F. A. A. Che Harun, A. Alias, and R. K. Suppiah, "Nexus between climate change, technological inputs, energy consumption and cereal production in India: An ARDL approach," *Environ. Behav. Proc. J.*, vol. 9, no. SI20, pp. 3–10, 2024. https://doi.org/10.21834/e-bpj.v9iSI20.6085

[18] I. B. Gurbuz and I. Kadioglu, "Grain production in Turkey and its environmental drivers using ARDL in the age of climate change," *Sustainability*, vol. 16, no. 1, p. 264, 2023. https://doi.org/10.3390/su16010264

[19] World Bank, "Crop production index (2014–2016 = 100)—Azerbaijan," 2025. https://data.worldbank.org/indicator/AG.PRD.CROP.XD?locations=AZ

[20] World Bank, "GDP deflator: Linked series (base year varies by country)—Azerbaijan," 2025. https://data.worldbank.org/indicator/NY.GDP.DEFL.ZS.AD?locations=az

[21] The State Statistical Committee of the Republic of Azerbaijan, "Environmental Protection," 2025. https://www.stat.gov.az/source/environment/?lang=en

[22] D. A. Dickey and W. A. Fuller, “Distribution of the estimators for autoregressive time series with a unit root,” *J. Am. Stat. Assoc.*, vol. 74, no. 366, pp. 427–431, 1979. https://doi.org/10.2307/2286348

[23] M. H. Pesaran, Y. Shin, and R. J. Smith, “Bounds testing approaches to the analysis of level relationships,” *J. Appl. Econ.*, vol. 16, no. 3, pp. 289–326, 2001. https://doi.org/10.1002/jae.616

[24] E. H. Samatar, “Assessing the determinants of agricultural productivity in Somalia: An application of an ARDL model,” *Asian J. Agric. Rural Dev.*, vol. 13, no. 3, pp. 154–162, 2023. https://doi.org/10.22004/ag.econ.342408

[25] M. G. Gulaliyev, S. T. Abasova, E. R. Samedova, L. A. Hamidova, S. I. Valiyeva, and L. R. Serttash, “Assessment of agricultural sustainability (Azerbaijan case),” *Bulg. J. Agric. Sci.*, vol. 25, no. Suppl.2, pp. 80–89, 2019.

[26] M. Huseynov, E. Salahov, and R. Niftaliyeva, “Impact of short- and long-term factors on the growth of gross agricultural products in Azerbaijan: ARDL analysis,” *Agric. Resour. Econ. Int. Sci. E-J.*, vol. 10, no. 3, pp. 303–326, 2024. https://doi.org/10.51599/are.2024.10.03.12