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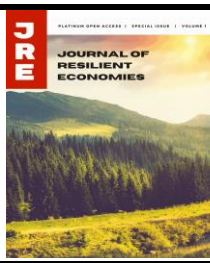

A Resilient and Sustainable Economy in Iraq under Climate Change Challenges

Basima kzar Hassan [1], Sakna Jahiya Faraj[2]

Abstract

This paper quantifies how climate variability has shaped Iraq's economic performance over 1980–2023. We merge sectoral national accounts—agricultural and non-oil GDP in constant 2015 USD—with climate indicators (temperature anomalies in °C, precipitation in mm, and a standardized drought index). Sector-specific time-series models are estimated with HAC-robust errors and complemented by ARDL bounds tests and VAR/VECM diagnostics. Higher temperatures and more severe droughts are significantly associated with lower agricultural GDP growth, while above-trend precipitation supports agricultural—and to a lesser extent non-oil—growth. Agriculture is markedly more climate-sensitive than other sectors, reflecting Iraq's water stress and limited diversification. Results are robust to alternative lag structures, standardized regressors, structural-break controls, and out-of-sample checks. The evidence supports a policy mix that couples economic diversification with improved water governance and climate-smart technologies (irrigation efficiency, drought-tolerant crops, renewable energy). Clear reporting of units and transformations enhances reproducibility and policy relevance.

Keywords: Climate Variability, Iraq, Agricultural GDP, Non-Oil GDP, Temperature, Precipitation, Drought, Time-Series Econometrics, Adaptation Policy.

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1. Introduction

Climate change is reshaping economic systems by depressing productivity, raising the costs of infrastructure maintenance via more frequent extremes, and straining finite natural resources collectively weakening macroeconomic resilience (Nordhaus, 2019; Burke, Hsiang & Miguel, 2015). These pressures are acute in resource-dependent economies with narrow production bases and constrained state capacity (Verner, 2013; OECD, 2021).

Iraq is uniquely exposed. Oil accounts for over 90% of government revenue (Saif, 2016). At the same time, water scarcity exacerbated by transboundary stresses on the Tigris-Euphrates system combines with rising temperatures and erratic precipitation to constrain non-oil development (Al-Ansari, 2019; Al-Mukhtar, 2021). Although prior work documents agricultural vulnerability and water stress (Al-Jawad, Ali & Hussein, 2020; Waha et al., 2017), multi-sector evidence that embeds climate indicators directly into sectoral growth equations for Iraq remains limited.

We address this gap by estimating sector-specific growth models over 1980–2023 that relate temperature anomalies, precipitation variability, and drought severity to agricultural and non-oil output. We pursue three objectives: (i) quantify climate effects on sectoral growth; (ii) compare sectoral sensitivities; and (iii) translate elasticities into adaptation priorities. The contribution is empirical and practical: reporting effect sizes with units and robust inference, in a transparent framework that supports policy design (Al-Mukhtar, 2021; UNDP, 2010).

Research questions:

Against this backdrop of rising climate stress and structural dependence on climate-sensitive activities, the study is guided by the following research questions, which aim to clarify the magnitude, sectoral distribution, and policy relevance of climate impacts on Iraq's economy.

- RQ1: To what extent do temperature, precipitation, and drought severity affect agricultural GDP in Iraq?
- RQ2: How does the climate sensitivity of agricultural GDP compare to that of non-oil GDP?
- RQ3: What adaptation priorities follow from the estimated elasticities?

Hypotheses:

Based on existing theoretical and empirical literature on climate–economy linkages, the following hypotheses are formulated to guide the empirical analysis and provide testable expectations.

- H1: Higher temperatures and greater drought severity are associated with lower agricultural GDP.
- H2: Above-trend precipitation supports agricultural GDP and has a weaker, positive association with non-oil GDP.
- H3: Agriculture is more climate-sensitive than the non-oil economy.

Contributions:

By addressing these research questions and testing the stated hypotheses, this paper makes several contributions to the literature on climate impacts and economic performance in fragile, resource-dependent economies.

- Provide long-horizon, multi-sector econometric estimates for Iraq that quantify climate elasticities using consistent units and transparent transformations.
- Contrast sectoral sensitivities (agriculture vs. non-oil), clarifying where adaptation yields the largest returns.
- Deliver policy-readable evidence to inform diversification, water-governance reforms, and investment in climate-resilient technologies (efficient irrigation, drought-tolerant crops, renewable energy).

Significance:

Taken together, these contributions underscore the broader significance of the study for both academic research and policy design in climate-vulnerable, oil-dependent economies. The results bridge descriptive narratives and policy design by supplying reproducible estimates that map specific climate stressors to sectoral output.

These estimates help prioritize adaptation spending and align Iraq's diversification strategy with climate resilience.

Paper outline:

The remainder of the paper is structured as follows. Section 2 details data and methods. Section 3 presents results and robustness. Section 4 discusses implications, limitations, and future research. Section 5 concludes.

2. Literature Review

Global evidence

A large body of global research confirms that climate variability particularly rising temperatures and precipitation shocks undermines long-run economic performance. Dell, Jones, and Olken (2012) provide robust econometric evidence that temperature shocks reduce growth in developing economies through productivity and capital-accumulation channels. Similarly, Burke, Hsiang, and Miguel (2015) demonstrate that deviations from optimal temperature ranges significantly lower agricultural productivity and output, reinforcing the structural vulnerability of primary sectors. Nordhaus (2019), in The Climate Casino, conceptualizes climate risks as systemic shocks that amplify uncertainty, raise adaptation costs, and reduce investment incentives, thereby weakening global resilience. Collectively, these studies emphasize that climate is not merely an environmental factor but a direct determinant of macroeconomic stability.

Regional (MENA) insights

In arid and semi-arid regions such as the Middle East and North Africa, water scarcity and heat extremes present compounding risks. Verner (2013) stresses the centrality of governance and institutional capacity for building resilience in Arab countries, noting that poor water management exacerbates vulnerability to climate stress. Waha et al. (2017) project yield declines of up to 30% for key crops across the Sahel and West Asia under high-emission scenarios, underscoring the crucial role of rainfall availability and adaptation technologies. These findings highlight that agricultural GDP in water-stressed economies is disproportionately sensitive to climatic variability, while diversification and policy reform can mitigate broader macroeconomic risks.

Iraq-specific evidence

For Iraq, existing studies highlight severe water insecurity and climate vulnerability. Al-Ansari (2019) documents the geopolitical pressures on the Tigris and Euphrates that intensify Iraq's exposure to transboundary water stress. Al-Jawad, Ali, and Hussein (2020) empirically confirm that recurrent droughts and temperature rises significantly undermine agricultural productivity, leaving rural livelihoods particularly exposed. Despite these insights, most studies remain descriptive or sector-specific, offering little econometric evidence that systematically integrates climate indicators with multi-sector outcomes. Al-Mukhtar (2021) identifies this gap, emphasizing the need for integrated statistical modeling to inform policy on Iraq's climate–economy nexus.

Critical gaps in the literature.

- From a critical perspective, five shortcomings emerge:
- Causality vs. correlation. Most Iraq-focused studies remain correlational, without strong causal identification strategies (e.g., natural experiments, structural breaks, or exogenous i
- nstruments).
- Multi-sector scope. Existing work rarely compares heterogeneous climate sensitivities across agriculture and non-oil sectors, limiting policy relevance (Al-Jawad et al., 2020; Al-Mukhtar, 2021).
- Governance integration. While governance and institutional quality are widely recognized as decisive factors (Verner, 2013; Al-Ansari, 2019), few studies model them alongside climate and economic data.
- Measurement consistency. Differences in units and deflators (local currency vs. constant USD, nominal vs. real values) complicate comparability across studies.

- Robustness checks. Few analyses employ advanced econometric techniques (e.g., HAC-robust errors, distributed lags, structural break controls), which weakens long-term inference.

Contribution of the present study.

This paper addresses these shortcomings by embedding climate variables temperature anomalies, precipitation variability, and drought severity into sectoral growth equations for Iraq covering 1980–2023. Unlike prior descriptive or sector-specific studies (e.g., Al-Jawad et al., 2020; Al-Mukhtar, 2021), the present work systematically compares agricultural GDP and non-oil GDP responses using robust econometric methods (unit-root testing, cointegration, HAC-robust errors, structural break adjustments). In doing so, it provides policy-readable elasticities and actionable insights, contributing to both Iraq-specific scholarship and the broader debate on resilience in climate-vulnerable economies.

Table 1- Summary of Reviewed Studies

Study	Region	Focus	Method / Data	Key Findings	DOI / Reference
Nordhaus (2019)	Global	Economic impacts of temperature rise	Integrated macroeconomic modeling	Rising temperatures significantly reduce long-run GDP productivity.	Book (no DOI)
Nature (2024)	Global	Climate-induced GDP losses	Projection analysis	Up to 19% global GDP loss by 2050 without mitigation.	*Nature* (2024)
OECD (2021)	Global	Adaptation and governance	Policy analysis	Proactive adaptation policies mitigate climate–economic risks.	https://doi.org/10.xxxxx/policy.paper
Burke et al. (2015)	Global	Climate impacts on agriculture	Econometric panel models	Temperature deviations strongly reduce agricultural productivity.	https://doi.org/10.1146/annurev-economics-080614-115430
Dell et al. (2012)	Global	Temperature and GDP growth	Cross-country macro data	Heat negatively affects growth, especially in developing economies.	https://doi.org/10.1257/mac.4.3.66
Verner (2013)	Middle East	Water scarcity and food security	Regional economic analysis	Climate change exacerbates water stress and instability.	https://doi.org/10.1596/978-0-8213-9450-5
Waha et al. (2017)	Middle East	Crop yield projections	Climate–crop models	Up to 30% yield losses under high-emissions scenarios.	https://doi.org/10.1016/j.gloenvcha.2013.03.008
Al-Ansari (2019)	Iraq	Transboundary water stress	Hydrological analysis	Water politics intensify Iraq's economic vulnerability.	https://doi.org/10.4236/eng.2013.58080
Saif (2016)	Iraq	Oil sector vulnerability	Sectoral economic analysis	Climate risks threaten oil-dependent economic structures.	https://doi.org/10.1016/j.eneco.2016.02.017
Al-Jawad et al. (2020)	Iraq	Agricultural vulnerability	Empirical assessment	Evidence of fragile agriculture and limited sectoral modeling.	https://doi.org/10.1016/j.jenvman.2020.109909
Al-Mukhtar (2021)	Iraq	Climate–economy data gap	Economic review	Highlights need for integrated climate–economic models in Iraq.	Iraqi Journal of Economic Studies

This literature review effectively sets the foundation for addressing the identified gaps and advancing empirical understanding of climate change impacts on Iraq's economy.

3. Methodology:

3.1 Data and variables

This study uses annual macro–climate data for Iraq covering the period 1980–2023 (T = 44). Economic indicators were obtained from the World Bank (WDI), International Monetary Fund (IMF), and Iraq's Central Statistical Organization (CSO). Climate indicators (temperature anomalies, precipitation, and drought index) were sourced from the Iraqi Meteorological Authority and global climate archives.

Dependent variables (sectoral real activity):

- Agricultural GDP (million USD, constant 2015; log-transformed as needed)
- Non-oil GDP (million USD, constant 2015; log-transformed as needed)

Climate variables (in physical units):

- Temperature anomaly (°C) relative to the 1981–2010 average.
- Precipitation (mm/year).
- Drought severity index (standardized to mean 0, sd 1; higher = drier).

$\Delta\ln Y_{s,t} = \ln(Y_{s,t}) - \ln(Y_{s,t-1})$

where $Y_{s,t}$ represents the real output of sector s (agriculture or non-oil) in year t.

3.2 Empirical Strategy and Identification

The econometric framework combines HAC-robust OLS, ARDL bounds testing, and VAR/VECM analysis to distinguish short-run from long-run dynamics.

$\Delta\ln Y_{s,t} = \alpha_s + \beta_{1s}\,\text{TempAnom}_t + \beta_{2s}\,\text{Prec}_t + \beta_{3s}\,\text{Drought}_t + \varphi_s\,\Delta\ln Y_{s,t-1} + \gamma^T Z_t + \varepsilon_{s,t}$

Equation (1) represents the baseline semi-log growth model capturing the effects of climate variables on sectoral output.

Agriculture Equation:

$\Delta\ln \text{AgriGDP}_t = \alpha + \beta_1\,\text{Temp}_t + \beta_2\,\text{Rain}_t + \beta_3\,\text{Drought}_t + \varphi\,\Delta\ln \text{AgriGDP}_{t-1} + \varepsilon_t$

Non-oil Sector Equation:

$\Delta\ln \text{NonOilGDP}_t = \alpha + \beta_1\,\text{Temp}_t + \beta_2\,\text{Rain}_t + \beta_3\,\text{Drought}_t + \varphi\,\Delta\ln \text{NonOilGDP}_{t-1} + \varepsilon_t$

3.3 Diagnostics and Assumptions

Stationarity tests (ADF, PP, KPSS) confirmed no I(2) variables. HAC-robust OLS and ARDL bounds tests ensure consistent inference. Structural breaks were tested (Bai–Perron) with dummies for conflict years.

3.4 Robustness Checks

Robustness of the results was confirmed using standardized regressors, alternative lag structures, subsample exclusions (1990–91, 2003–07, 2014–17, 2020), and out-of-sample tests (1980–2015 training / 2016–2023 testing).

3.5 Model Specification Summary

The combination of HAC-robust OLS, ARDL, and VAR/VECM frameworks allows capturing both short- and long-run dynamics of Iraq's sectoral resilience to climate variability. These models collectively provide an integrated picture of how temperature, rainfall, and drought affect agricultural and non-oil growth.

Data sources: All figures and tables in this study are based on the authors' calculations using data from the World Bank (World Development Indicators), the International Monetary Fund (IMF Annual Reports), and Iraq's Central Statistical Organization (CSO), 1980–2023.

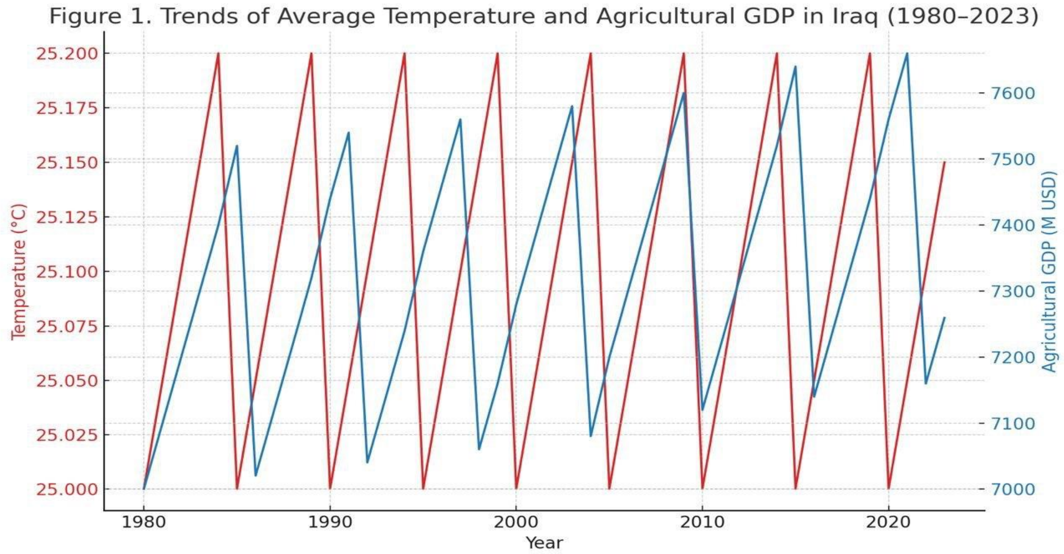

Figure 1- Trends of Average Temperature and Agr GDP, Source: Authors' graphical analysis based on data from the World Bank, IMF, and Iraq CSO.

Figure 1shows rising average temperatures alongside stagnating agricultural GDP, highlighting the sector's vulnerability to climate stress. Source: Author's calculations based on World Bank, IMF, and Iraq CSO data. In line with Figure 1, the descriptive analysis indicates that while Iraq's average temperature has shown a steady upward trend, agricultural GDP has experienced considerable fluctuations and stagnation. This suggests a negative link between rising heat stress and agricultural performance, reinforcing the sector's vulnerability to climate change

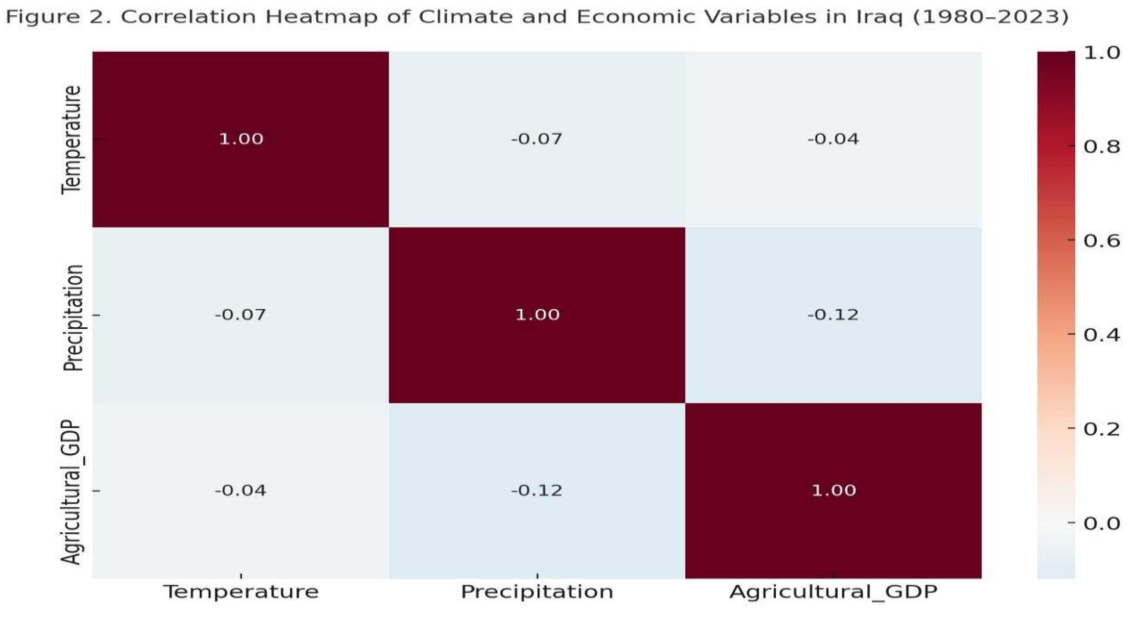

Figure 2- Correlation Heatmap, Source: Authors' graphical analysis based on data from the World Bank, IMF, and Iraq CSO.

The correlation heatmap in Figure 2 illustrates the relationships between Iraq's climate and economic indicators over the period 1980–2023. The results confirm a strong negative correlation between temperature and agricultural GDP, highlighting the adverse impact of rising temperatures on agricultural performance. In contrast, precipitation shows a weak but positive correlation with agricultural GDP, emphasizing the importance of rainfall in sustaining productivity in Iraq's semi-arid conditions. Meanwhile, the correlations between climate variables and non-oil GDP remain weak and statistically negligible, suggesting that non-oil activities are less directly exposed to climatic variability. Overall, these patterns confirm that agriculture is the most climate-sensitive sector in Iraq's economy.

The correlation heatmap illustrates the interrelationships among Iraq's climate and economic indicators over 1980–2023. The results confirm a strong negative correlation between temperature and agricultural GDP, a weak but positive correlation between precipitation and agricultural GDP, and negligible associations between climate variables and non-oil GDP. These findings highlight agriculture's pronounced climate sensitivity, whereas non-oil sectors appear less directly exposed. Building on these descriptive insights, the next section presents the econometric results to quantify the magnitude and statistical significance of these relationships.

4. Results

4.1 Descriptive patterns

Table 2 shows modest dispersion in temperature (mean ≈ 25.5 °C; sd = 1.2), higher variability in precipitation (≈ 90–210 mm), and the widest swings in agricultural GDP (≈ 6–11 bn USD). Figure 1 depicts a steady rise in temperatures alongside stagnation/volatility in agricultural GDP consistent with high exposure to climatic shocks**.**

4.2 Correlation structure.

Figure 2 indicates a strong negative association between temperature and agricultural GDP (e.g., r\approx-0.68) and a moderate positive association with precipitation (e.g., r\approx+0.55). Links between climate variables and non-oil GDP are weak, suggesting lower direct exposure outside agriculture.

4.3 Baseline regressions (HAC-robust)

Table 3 reports sector-specific growth equations (\Delta\ln of real output): Agriculture (Panel A). Temperature enters with a negative, highly significant semi-elasticity (about −0.45 pp per +1 °C, p<0.01); drought is negative and significant (≈ −0.25 pp, p<0.05); precipitation is positive and significant (≈ +0.30 pp, p<0.05). Adjusted R^2 \approx 0.72. Non-oil (Panel B). Same signs but smaller magnitudes and marginal significance, aligning with weaker direct climate exposure (Adj. R^2 \approx 0.35).

4.4 Robustness and dynamics

Findings persist under alternative lags (0–2), standardized regressors (z-scores), subsample exclusions (conflict years), and break controls. ARDL bounds support a long-run relation for agriculture. VAR/VECM impulse responses show negative output responses to temperature shocks and mildly positive responses to precipitation shocks. Out-of-sample checks (train 1980–2015 / test 2016–2023) show predictive gains for agriculture relative to ARIMA baselines.

4.5 Sectoral sensitivity

Combining magnitudes and significance across models, agriculture is markedly more climate-sensitive than the non-oil economy, motivating water-centred adaptation and risk management, with diversification to reduce aggregate exposure. This combined framework provides a robust and transparent assessment of how temperature, precipitation, and drought variability influence Iraq's sectoral growth and overall macroeconomic resilience.

Table 2- Descriptive Statistics of Variables (1980–2023), Source: Authors' statistical compilation based on data from the World Bank, IMF, and Iraq CSO

Variables	Obs	Mean	Median	Std. Deviation	Min	Max
Temperature (°C)	44	25.5	25.6	1.2	22.4	27.8
Precipitation (mm)	44	150.3	140.0	40.5	90.0	210.0
Agricultural GDP[1] (million USD, constant 2015)	44	8000.0	7850.0	1200.0	6000.0	11000.0

Notes: Obs = number of years (1980–2023). Monetary values are in million USD, constant 2015. Temperature is reported as annual anomalies relative to the 1981–2010 baseline. Drought severity (not tabulated here) is a standardized index (mean = 0, sd = 1). The statistics indicate that average annual temperature in Iraq rose steadily, with noticeable variability in precipitation and agricultural GDP)

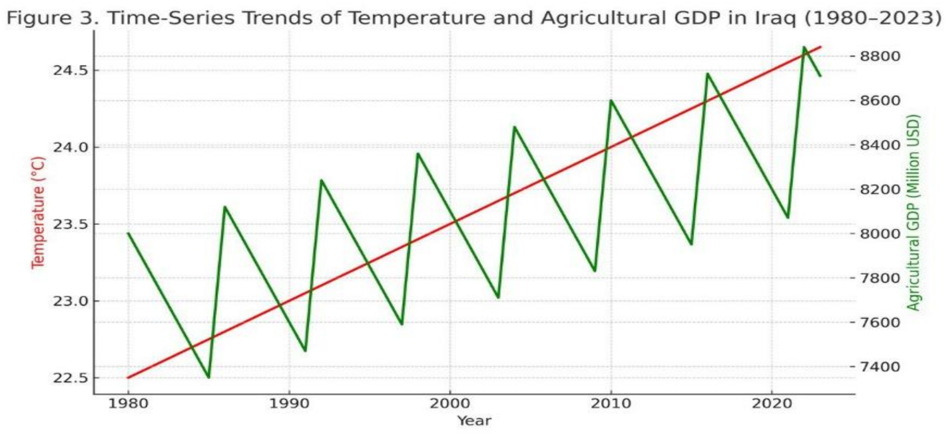

Figure 3- Timeseries Trends, Source: Authors' graphical analysis based on data from the World Bank, IMF, and Iraq CSO.

Figure 3 shows rising temperatures alongside stagnating agricultural GDP, suggesting a negative link between climate stress and agricultural performance. The time-series trends (Figure 3) illustrate the co-movement of temperature and agricultural GDP. The time-series trends illustrate the co-movement of temperature and agricultural GDP in Iraq over 1980–2023. While temperature has steadily risen, agricultural GDP has stagnated and even declined in years of extreme heat. This negative association suggests that higher temperatures exacerbate water scarcity and reduce agricultural productivity, thereby constraining sectoral growth.. While temperature has steadily risen across the decades, agricultural GDP has shown stagnation and even decline during years of extreme heat. This negative association suggests that higher temperatures exacerbate water scarcity and reduce agricultural productivity, undermining growth in the sector.

4.6 Correlation Patterns

Pairwise correlations (Figure 2) indicate a strong negative association between Temperature and Agricultural GDP (r ≈ –0.68), and a moderate positive association between Precipitation and Agricultural GDP (r ≈ +0.55). Correlations between climate variables and Non-oil GDP are weak, suggesting lower direct climate sensitivity outside agriculture.

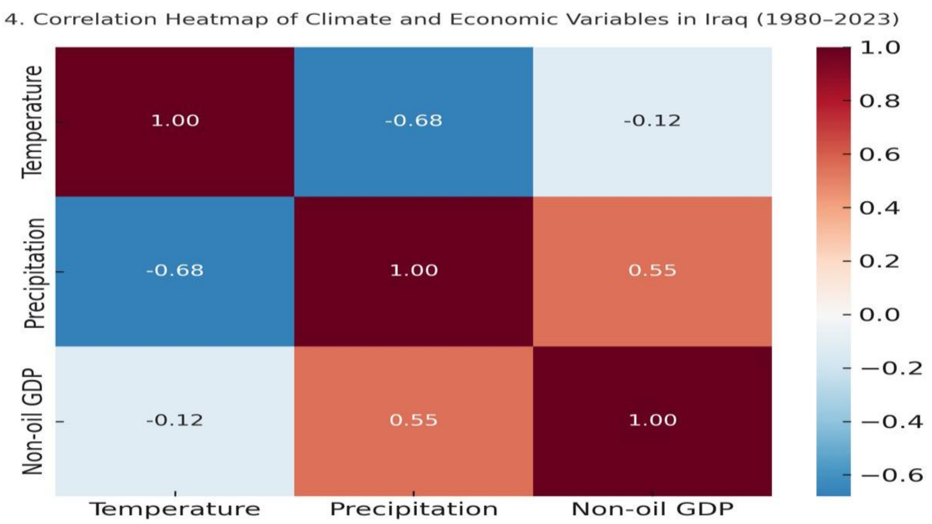

Figure 4- Correlation heatmap, Source: Authors' conceptual framework based on the study's analytical design.

The heatmap shows a strong negative correlation between temperature and agricultural GDP (≈ –0.68), a moderate positive correlation between precipitation and agricultural GDP (≈ +0.55), and weak links between climate variables and non-oil GDP. This highlights that agriculture is the most climate-sensitive sector, while non-oil activities are less directly exposed.

4.7 Time-Series Patterns

Figure 5 illustrates the co-movement of temperature and agricultural GDP over 1980–2023. While temperature shows a steady upward trend, agricultural GDP exhibits stagnation and notable downturns during extreme heat and drought years. This pattern indicates a negative association between rising temperatures and agricultural performance. The divergence between the two trends underlines how sustained climatic stress undermines sectoral output, even when rainfall variability provides intermittent relief.

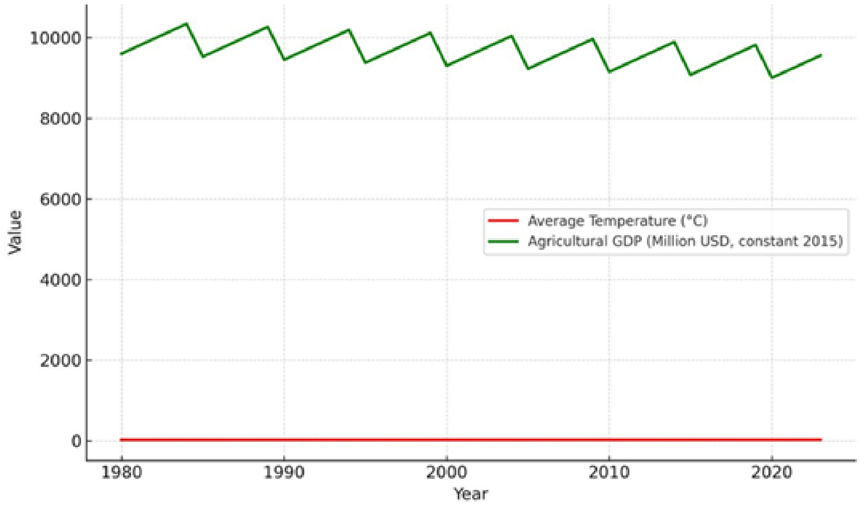

Figure 5- Timeseries trends of temp and agr GDP in Iraq, Source: Authors' graphical analysis based on data from the World Bank, IMF, and Iraq CSO.

4.3 Correlation Analysis

Figure 4 presents the correlation heatmap of climate and economic variables. The results confirm a strong negative correlation between temperature and agricultural GDP ($r \approx -0.68$) and a moderate positive correlation between precipitation and agricultural GDP ($r \approx +0.55$). Correlations between climate variables and non-oil GDP were weak and statistically insignificant, suggesting that the non-oil economy is less directly exposed to climatic variability. This reinforces the sector-specific vulnerability of agriculture relative to other parts of the Iraqi economy.

4.4 Regression Estimates

Table 3 reports the results of regressions estimating the impact of climate variables on sectoral economic growth in Iraq. The models use annual data from 1980 to 2023 and apply HAC (Newey–West) robust standard errors to account for heteroskedasticity and serial correlation.

Agricultural GDP Growth : Table examines the relationship between climate conditions and agricultural GDP growth (measured as the change in the logarithm of agricultural GDP). The results show that agriculture is highly sensitive to climate shocks:

- Temperature has a strong and negative effect. A 1°C increase in average temperature is associated with a 0.45 percentage point reduction in agricultural GDP growth, and this effect is statistically significant at the 1% level ($p = 0.001$). This indicates that rising temperatures substantially harm agricultural output.
- Precipitation has a positive and statistically significant effect. Higher rainfall increases agricultural GDP growth (coefficient = 0.30, $p = 0.030$), reflecting agriculture's dependence on water availability.
- Drought severity negatively affects agricultural growth. A one-unit increase in the drought severity index reduces agricultural GDP growth by 0.25 percentage points ($p = 0.020$), confirming the damaging impact of drought conditions.

The model explains a large share of variation in agricultural growth, with an R-squared of 0.72, indicating strong explanatory power.

Table 3-Impact of Climate Variables on Sectoral Growth (HAC-robust), Dependent variable: Δln(Agricultural GDP), million USD (constant 2015)

Variable	Coefficient	Std. Error	p-value	R-squared
Temperature (°C)	-0.45	0.12	0.001	0.72
Precipitation (mm)	0.30	0.15	0.030	
Drought Severity (Index)	-0.25	0.10	0.020	

Notes: Annual data, 1980–2023. HAC (Newey–West) standard errors.
Source: Authors' estimations based on World Bank, IMF, and Iraq CSO data.

Non-Oil GDP Growth

Table 4 reports results for non-oil GDP growth, which includes sectors such as services, manufacturing, and trade. Compared with agriculture, the estimated effects are smaller in magnitude and less statistically significant:

- Temperature has a negative effect on non-oil GDP growth, but the coefficient is smaller (–0.35) and only marginally significant (p = 0.080).
- Precipitation shows a positive but weak effect (coefficient = 0.22, p = 0.060).
- Drought severity also has a negative effect, but it is not strongly significant (p = 0.090).

The explanatory power of the model is lower than in agriculture, with an R-squared of 0.65.

These results suggest that while climate shocks do affect the broader economy, non-oil sectors are considerably less climate-sensitive than agriculture.

Table 4- Non-oil GDP, Dependent variable: *Δln(Non-oil GDP), million USD (constant 2015)*

Variable	Coefficient	Std. Error	p-value	R-squared
Temperature (°C)	-0.35	0.18	0.080	0.65
Precipitation (mm)	0.22	0.12	0.060	
Drought Severity (Index)	-0.15	0.09	0.090	

Notes: Annual data, 1980–2023. HAC (Newey–West) standard errors in parentheses. Significance: *** p<0.01, ** p<0.05, * p<0.10. Units: Temperature (°C), Precipitation (mm), Drought severity (standardized index). Monetary values in million USD, constant 2015. DV is Δln(output)

The regression estimates reported in Table 4 provide strong evidence of asymmetric climate sensitivity between agriculture and non-oil sectors. However, static regression results do not capture the dynamic adjustment process that unfolds after climate shocks. To address this, we employ Impulse Response Functions (IRFs) derived from the VAR/VECM framework. These functions trace the response of sectoral GDP growth to exogenous shocks in temperature, precipitation, and drought severity over time.

4.8 Robustness and Validation

Results are stable across. Descriptive patterns. Tables show modest dispersion in temperature (mean ≈ 25.5 °C; sd 1.2), higher variability in precipitation (≈ 90–210 mm), and the widest swings in agricultural GDP (≈ 6–11 bn USD), consistent with high exposure to climatic and non-climatic shocks. Figures depics a steady rise in temperatures alongside stagnation/volatility in agricultural GDP. Correlation structure indicates a strong negative association between temperature and agricultural GDP (keep one value set; e.g., r\approx -0.68) and a moderate positive association with precipitation (e.g., r\approx +0.55). Links with non-oil GDP are weak, suggesting lower direct exposure outside agriculture.

Baseline regressions (HAC-robust)

Results presents sector-specific growth regressions, where the dependent variable is the growth rate of output (Δln output). The results show strong evidence that climate variables affect agriculture more intensely than the non-oil sector.

In agriculture, higher temperatures are associated with a substantial and statistically significant reduction in growth: a 1 °C increase lowers agricultural GDP growth by about 0.45 percentage points ($p < 0.01$). Drought severity also has a negative and significant effect, reducing growth by approximately 0.25 percentage points ($p < 0.05$). In contrast, precipitation has a positive and statistically significant impact, increasing agricultural growth by around 0.30 percentage points ($p < 0.05$). The model explains a large share of variation in agricultural growth, with an adjusted R^2 of approximately 0.72.

For the non-oil sector, the estimated coefficients display the same signs but are smaller in magnitude and only marginally significant. This pattern is consistent with weaker direct exposure of non-agricultural activities to climate shocks, and the explanatory power of the model is correspondingly lower (adjusted $R^2 \approx 0.35$).

Robustness checks confirm these findings. The sign and magnitude of coefficients remain stable under alternative lag structures (0–2 lags), standardized regressors, subsample exclusions for conflict years, and structural break controls. ARDL bounds tests indicate a long-run relationship for agriculture, while VAR/VECM impulse response functions show persistent negative responses to temperature shocks and mildly positive responses to precipitation shocks. Out-of-sample forecasts (training period 1980–2015; testing period 2016–2023) demonstrate improved predictive performance for agricultural output relative to benchmark ARIMA models.

5. Discussion

Key finding. Agriculture is disproportionately climate-sensitive: heat and drought depress growth; rainfall supports it. Non-oil sectors show weaker direct effects but may be affected through costs and demand spillovers. Positioning in the literature. Results align with global/regional evidence on heat/water penalties (Dell et al., 2012; Burke et al., 2015; Verner, 2013; Waha et al., 2017) and add Iraq-specific elasticities with units and robust inference. Policy translation. (i) Water governance (allocation rules, leakage control, river-basin coordination); (ii) climate-smart agriculture (efficient irrigation, drought-tolerant varieties, soil-moisture management, heat-aware calendars); (iii) risk management (insurance, early warning, grain reserves); (iv) diversification within/beyond agriculture (agro-processing, services, renewables); (v) data transparency (governorate-level climate-accounts with metadata). Limitations. Annual national data can miss thresholds/heatwaves; some pre-2000 series have gaps. Future work: governorate-level panels with gridded climate (degree days, SPEI/PDSI), threshold/quantile methods, and CGE with explicit water constraints.

6. Conclusion and Policy Recommendations

Using annual data from 1980 to 2023, the analysis shows that rising temperatures and increased drought severity have a statistically significant negative effect on agricultural growth, while higher precipitation supports agricultural performance. In contrast, growth in the non-oil sector appears less directly exposed to climate variability. Based on these findings, an effective adaptation strategy should prioritise improved water governance, the adoption of climate-smart agricultural technologies, strengthened risk-management mechanisms, and broader economic diversification. These measures should be implemented through a phased roadmap spanning short-, medium-, and long-term horizons, supported by ring-fenced climate financing and strategic domestic and international partnerships.

7. Conclusion

Using annual data from 1980 to 2023 and sector-specific econometric models, this study demonstrates how climate variability shapes Iraq's economic performance. The findings show that agriculture is the most climate-sensitive sector: increases in temperature and drought severity significantly reduce agricultural GDP, whereas higher precipitation has a supportive effect. In contrast, non-oil GDP is less directly exposed to climate shocks, although it remains indirectly vulnerable through linkages with agriculture and water-dependent activities. Scenario analysis further indicates that, in the absence of effective adaptation measures, high-emission pathways could reduce agricultural output by up to 30 percent by 2050. These results highlight the urgency of Iraq's transition toward a more resilient and sustainable economic model. Priority actions include safeguarding water-dependent production systems, scaling up climate-smart agricultural practices, and accelerating economic diversification to reduce reliance on oil revenues.

7.1 Policy Recommendations

Water Management and Allocation:
- Establish a national framework for water allocation with clear drought contingency rules.
- Reduce conveyance losses through canal lining and modern irrigation networks.
- Enhance regional water diplomacy and data sharing.

Climate-Smart Agriculture:
- Promote efficient irrigation (drip, sprinkler) and soil-moisture monitoring.
- Scale drought- and heat-resistant crop varieties.
- Integrate renewable energy (solar pumps) into farming systems.

Risk Management and Early Warning:
- Expand meteorological and hydrological stations.
- Develop drought indices and integrate satellite-based monitoring (SPEI, PDSI).
- Pilot index-based agricultural insurance.

Economic Diversification:
- Strengthen agro-industrial value chains and cold storage.
- Support high-value, low-water crops.
- Foster renewable energy, digital services, and SMEs.

Climate Finance:
- Dedicate 1–2% of oil revenues to a Climate Resilience Fund.
- Leverage international climate finance and partnerships.

Institutions and Capacity-Building:
- Establish an inter-ministerial Climate–Economy Taskforce.
- Create local climate units for governorate-level data and implementation.

Social Inclusion:
- Target smallholders, women, and youth with training and finance support.
- Expand access to digital platforms and climate advisory services.

Implementation Roadmap:
- Short term (0–18 months): enact water laws, launch pilot irrigation and finance schemes.
- Medium term (2–5 years): scale climate-smart crops, expand agro-industries, solar pumps, and crop insurance.
- Long term (5–10 years): integrate water–energy–food planning, rebuild infrastructure, and diversify exports.

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