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Hydro-Economic Assessment of Irrigation Water Pricing Reform under Extreme Water Stress: Econometric Evidence and Policy Simulations from Algeria (1990–2022)

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Abstract :

This study examines irrigation water pricing reform as a demand-management instrument under extreme water stress in Algeria (1990–2022). It develops a hydro-economic framework combining econometric modelling and elasticity-based simulations using FAO AQUASTAT and World Bank data. Results show that population growth, economic activity, and irrigation expansion are key drivers of freshwater withdrawals, while precipitation moderates demand. Simulations based on a price elasticity of −0.25 indicate that tariff increases reduce agricultural water use, with a 10% increase lowering withdrawals by about 2.5% and a 50% increase by nearly 13%. However, water stress remains high, reflecting structural scarcity. Pricing reform requires complementary policies.

Keywords: Hydro-economic modelling, Irrigation water pricing, Water demand management, Water stress, Algeria.
Jel Classification Codes: Q11 ; Q18 ; Q25

Introduction:

Water stress has emerged as one of the most critical environmental and economic constraints facing arid and semi-arid regions. Rapid population growth, rising food demand, climate variability, and the expansion of irrigated agriculture have intensified pressure on limited freshwater resources (Rogers et al., 2002; World Bank, 2018). Traditional supply-oriented water policies—focused on expanding reservoirs, groundwater extraction, and desalination—are increasingly costly and often insufficient to address the structural imbalance between water supply and demand. Improving water-use efficiency and strengthening water demand management have therefore become central pillars of integrated water resources management (IWRM) strategies (Molle & Berkoff, 2007; Berbel et al., 2019).

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Algeria represents a particularly acute case of structural water stress. Total freshwater withdrawals reached approximately 10.3 billion m³ in 2022, while renewable internal freshwater resources per capita declined to about 247 m³ per year—far below the 1,000 m³ water-scarcity threshold (FAO, 2025; World Bank, 2024). Population grew from approximately 25 million in 1990 to more than 45 million in 2022, intensifying pressure on national water resources. Irrigation accounts for around 65–70% of total freshwater withdrawals, reflecting the dominant role of agriculture in Algeria's water balance (World Bank, 2018).

Historically, Algerian water policy has relied heavily on supply-side interventions—dam construction, groundwater development, and large-scale desalination—without eliminating the structural imbalance between growing demand and relatively fixed renewable resources. Among economic demand-management instruments, water pricing has received considerable attention in the literature. Economic theory recognizes that when tariffs reflect at least part of the opportunity cost of water, they can encourage efficiency improvements, discourage wasteful consumption, and support cost recovery (Rogers et al., 2002; Berbel et al., 2019; Molle & Berkoff, 2007).

In Algeria, irrigation tariffs remain relatively low and heavily subsidized, providing limited incentives for conservation and failing to cover operational costs (Azzi, 2019; Benmihoub & Bedrani, 2011). Despite growing policy relevance, empirical research linking irrigation water pricing, aggregate water demand, and national water stress in Algeria remains limited. This study addresses that gap by asking: To what extent can irrigation water pricing reforms reduce freshwater withdrawals and mitigate water stress in Algeria? To answer this question, it develops an integrated hydro-economic framework combining econometric analysis, water accounting, and elasticity-based policy simulations over 1990–2022.

1. Literature Review :

Water pricing has long been central to resource economics because prices transmit scarcity signals and guide efficient allocation. Rogers, de Silva, and Bhatia (2002) argue that water must be recognized as both a social and an economic good—a dual nature that requires policies balancing efficiency, equity, and environmental sustainability. In irrigation systems, the economic rationale for pricing is particularly strong: tariffs can influence farmers' decisions regarding irrigation intensity, crop choice, and investment in water-saving technologies, thereby discouraging excessive withdrawals (Savenije & Van der Zaag, 2002). Three main policy objectives are commonly associated with irrigation pricing: improving allocative efficiency, promoting conservation under scarcity, and supporting financial sustainability of irrigation infrastructure through cost recovery (Molle & Berkoff, 2007).

In practice, however, irrigation water is delivered through complex public infrastructure involving large capital investments and multiple externalities, making fully cost-reflective pricing difficult to achieve. Many governments deliberately maintain subsidized tariffs to protect food security and rural livelihoods, weakening the incentive structure for efficient water use.

The key empirical question concerns the responsiveness of agricultural water demand to price changes. Hanemann (2005) emphasizes that irrigation water demand elasticity tends to be low because water costs typically represent only a

small fraction of total agricultural production costs. Nevertheless, Berbel et al. (2019) find that water pricing can influence farmers' water use when volumetric pricing and reliable metering systems are in place. Martínez-Dalmau et al. (2023), using a hydro-economic model for a Mediterranean river basin, show that pricing can generate significant reductions in irrigation demand when policies reflect local hydrological and economic conditions. Zamani et al. (2021), studying Iran, find that price-based policies improve water productivity most effectively when combined with non-price instruments such as water quotas and improved monitoring. The literature consistently stresses, however, that price increases alone are unlikely to produce dramatic reductions in water use without structural changes in irrigation technology, crop choices, or institutional regulation.

2. Study Context and Data:

2.1 Hydrological context and institutional framework :

Algeria is among the most water-stressed countries in the Mediterranean and MENA region, characterized by predominantly semi-arid and arid climatic conditions, highly variable precipitation, and limited renewable freshwater resources of approximately 11.25 km³ per year (FAO, 2025). Population expanded from approximately 25.4 million inhabitants in 1990 to more than 45 million in 2022—a near-80% increase—substantially intensifying pressure on water resources. Irrigation accounts for approximately 65–70% of total freshwater withdrawals, and the SDG 6.4.2 water stress indicator reached approximately 91.6% in 2022, placing Algeria in the category of extreme water stress in which withdrawals approach or exceed renewable availability (UN-Water, 2021).

Water governance is organized within a predominantly centralized institutional framework. Irrigation water pricing in public irrigation schemes is regulated through Executive Decree No. 05-14, which combines a fixed subscription fee with a volumetric charge. In practice, tariffs remain substantially below the economic cost of water delivery, and public subsidies finance much of the infrastructure and operational costs. This weakens the price signals that could otherwise encourage more efficient water use (Azzi, 2019; Benmihoub & Bedrani, 2011).

2.2 Data sources and variables:

The empirical analysis relies on an annual time-series dataset covering 1990–2022 (33 observations), the longest period for which consistent internationally harmonized data are available. Two international databases were used: FAO AQUASTAT for water resources, withdrawals, and irrigation statistics; and World Bank World Development Indicators (WDI) for demographic and macroeconomic data. Table 1 summarizes the variables used

Table 1. Dataset and variables used in the econometric analysis (1990–2022)

Variable	Definition	Unit
freshwater withdrawals	Total annual water withdrawals from all sectors	billion m³
Population	Total population	persons
Real GDP	GDP at constant prices	constant USD
Irrigated area	Area equipped for irrigation	hectares
Water stress	Withdrawals as share of renewable resources	%
Precipitation	Average annual rainfall	mm/year

Source: FAO (2025); World Bank World Development Indicators (2024).

Table 1 summarizes the variables used in the econometric analysis and clarifies their role within the hydro-economic framework developed in this study. The selected variables reflect the main structural drivers of water demand identified in the literature on water economics and water resource management.

Population and GDP represent macroeconomic drivers of water demand, while irrigated area captures agricultural expansion. Precipitation provides a climatic control variable that influences irrigation needs. Together, these variables allow the econometric model to capture both economic and hydrological determinants of freshwater withdrawals.

2.3 Descriptive overview of the dataset:

Freshwater withdrawals increased substantially over the study period, rising from approximately 4.4 billion m³ in 1990 to more than 10 billion m³ in recent years (Table 2). Population grew from approximately 25 million to more than 45 million inhabitants, and irrigated agricultural area expanded significantly, reflecting public investments in irrigation infrastructure and agricultural intensification. These trends illustrate the structural drivers of increasing water demand.

Table 2. Descriptive statistics of key variables (1990–2022)

Variable	Mean	Min	Max
Freshwater withdrawals (billion m³)	7.8	4.4	10.6
Population (millions)	36.4	25.4	45.5
Real GDP (PPP, trillion USD)	0.54	0.30	0.67
Irrigated area (million ha)	0.82	0.42	1.36

Source: Author's calculations based on FAO (2025) and World Bank data (2024).

Table 3 presents benchmark observations illustrating the widening gap between water demand and renewable water availability. While renewable internal freshwater resources remained relatively stable at around 11 km³ per year, freshwater withdrawals increased substantially and per capita renewable water resources fell from approximately 443 m³ per year in 1990 to about 247 m³ in 2022, placing Algeria well below internationally recognized water scarcity thresholds.

Table 3. Benchmark observations for freshwater withdrawals and renewable internal freshwater resources in Algeria (1990–2022)

Year	Total freshwater withdrawals (b m³)	Renewable water (m³/person/year)	Population (million)	Renewable water resources (b m³)
1990	4.4	443.2	25.4	11.25
2000	5.6	363.9	30.9	11.24
2016	9.2	269.8	40.9	11.03
2017	9.8	264.6	41.7	11.03
2018	10.1	259.8	42.5	11.04
2019	10.4	255.4	43.3	11.06
2020	10.6	255.4	44.0	11.25
2021	10.0	251.3	44.8	11.25
2022	10.3	247.3	45.5	11.25

Source: Prepared by the author based on FAO (2025) and World Bank data (2024).

Table 3 illustrates the widening gap between water demand and renewable water availability in Algeria. While renewable internal freshwater resources remained relatively stable at around 11 km³ per year, freshwater withdrawals increased substantially during the study period.

At the same time, renewable water availability per capita declined sharply due to population growth. Per capita renewable water resources fell from approximately 443 m³ per year in 1990 to about 247 m³ in 2022, placing Algeria well below internationally recognized water scarcity thresholds.

3. Methodology:

3.1 Hydro-economic analytical framework:

The study employs a log-linear econometric model commonly used in empirical water demand analysis (Gujarati & Porter, 2009; Berbel et al., 2019):

$$\ln(TW_t) = \alpha + \beta_1 \ln(POP_t) + \beta_2 \ln(RGDP_t) + \beta_3 \ln(IRR_t) + \beta_4 RAIN_t + \varepsilon_t$$

Where TW = total freshwater withdrawals, POP = population, RGDP = real GDP, IRR = irrigated agricultural area, RAIN = annual precipitation, and ε = error term. The logarithmic specification allows coefficients to be interpreted directly as elasticities. Population, GDP, and irrigated area are expected to carry positive signs, while precipitation is expected to carry a negative sign, reflecting its substitution role for irrigation water.

Because the analysis relies on time-series data, it is necessary to verify the stationarity of the variables before estimation. Augmented Dickey–Fuller (ADF) unit root tests were conducted for each variable in both levels and first differences. The null hypothesis of a unit root is tested against the alternative of stationarity. Table 4 reports the ADF test statistics and their significance levels.

Table 4. Augmented Dickey–Fuller (ADF) unit root test results

Variable	ADF stat (level)	p-value	ADF stat (1st diff.)	p-value	Order of integration
ln(Freshwater withdrawals)	−1.24	0.654	−5.87***	<0.001	I(1)
ln(Population)	−0.88	0.789	−6.12***	<0.001	I(1)
ln(Real GDP)	−1.15	0.697	−4.93***	<0.001	I(1)
ln(Irrigated area)	−1.33	0.621	−5.44***	<0.001	I(1)
Precipitation	−2.87*	0.052	−7.31***	<0.001	I(0)/I(1)

Note: ADF tests include a constant and one lag (AIC-selected). */**/*** denote rejection of the unit root null at 10%/5%/1%. Precipitation is borderline I(0)/I(1); in first differences it is clearly stationary. **Source:** Author's calculations using Stata 17.

The results confirm that all variables are non-stationary in levels (fail to reject the unit root null) but become stationary after first differencing, indicating integration of order one, I(1). This integration structure satisfies the precondition for cointegration analysis. Accordingly, an Engle–Granger two-step cointegration test was applied to assess whether a long-run equilibrium relationship exists between freshwater withdrawals and its explanatory variables. Table 5 reports the results.

Table 5. Engle–Granger cointegration test results

Test step / Statistic	Value	p-value
Step 1: OLS residuals from level regression	—	—
Step 2: ADF test on residuals (no constant)	−4.63	0.012**
Critical value (5%, n=33, k=4)	−4.10	—
Conclusion	Reject null of no cointegration	—

Note: Dependent variable is ln(Freshwater withdrawals). Critical values follow MacKinnon (1991) for k=4 regressors. ** denotes significance at the 5% level. **Source:** Author's calculations using Stata 17.

The Engle–Granger test rejects the null hypothesis of no cointegration at the 5% significance level, confirming the existence of a long-run equilibrium relationship between freshwater withdrawals, population, GDP, irrigated area, and precipitation. This result justifies the use of a level-based OLS specification to estimate the long-run elasticities directly. The model was estimated using OLS with robust standard errors in Stata 17. Additional diagnostic tests—the Breusch–Pagan test for heteroskedasticity, the Breusch–Godfrey test for serial correlation, and Variance Inflation Factors (VIF) for multicollinearity—are reported alongside the regression results in Section 4.4. Statistical significance is evaluated at the 1%, 5%, and 10% levels.

3.2 Water stress accounting and simulation scenarios

The water stress indicator (SDG 6.4.2) is calculated as $WS_t=\frac{TWt}{TRWRt}\times100$, where TRWR = total renewable water resources. Values above 75% indicate very high stress; Algeria's 2022 level of 91.6% places it in the extreme water stress category (UN-Water, 2021).

The impact of irrigation pricing reform is evaluated using price elasticity simulations. The relationship between price changes and water demand is: $\Delta Q/Q = \varepsilon \times \Delta P/P$. Empirical studies estimate irrigation water demand elasticities between −0.15 and −0.35 (Berbel et al., 2019; Zamani et al., 2021). This study adopts the central value $\varepsilon = -0.25$, appropriate for the Algerian context given subsidized irrigation systems and limited price responsiveness in comparable MENA countries. Agriculture accounts for approximately 65% of total freshwater withdrawals (FAO, 2025). Three scenarios are simulated: a 10%, 20%, and 50% increase in irrigation water tariffs.

4. Results:

4.1 Structural trends in freshwater withdrawals:

Before presenting the econometric estimates, it is useful to examine the long-term evolution of freshwater withdrawals and their structural drivers in Algeria. The descriptive evidence highlights several key trends that provide important context for interpreting the econometric results.

Over the period 1990–2022, Algeria experienced substantial demographic and economic expansion. The country’s population increased from approximately 25.4 million inhabitants in 1990 to more than 45 million in 2022, representing an increase of nearly 80 percent (World Bank, 2024).

Economic activity also expanded considerably during this period. Growth in national income and structural economic transformation contributed to increasing water demand across multiple sectors, including agriculture, industry, and urban water supply systems.

These structural changes were accompanied by a substantial increase in freshwater withdrawals. National water withdrawals rose from approximately 4.4 billion m³ in 1990 to about 10.3 billion m³ in 2022, reflecting both population growth and irrigation expansion.

At the same time, renewable freshwater resources remained relatively stable in aggregate terms. As a result, the increase in water withdrawals has translated directly into rising water stress. The combination of demographic pressure, economic development, and irrigation expansion has therefore produced a structural imbalance between water demand and renewable water availability.

4.2 Dynamics of water stress in Algeria:

To illustrate the evolution of hydrological pressure on national water resources, Table 6 reports the dynamics of the water stress indicator (SDG 6.4.2) over selected benchmark years between 1990 and 2022.

Table 6. Evolution of freshwater withdrawals and water stress (1990–2022)

Year	Freshwater withdrawals (b m³)	Renewable water resources (b m³)	Water stress (%)
1990	4.4	11.25	39.1
2000	5.6	11.24	49.8
2005	6.5	11.20	58.0
2010	7.8	11.10	70.3
2015	9.0	11.05	81.4
2016	9.2	11.03	83.4
2017	9.8	11.03	88.9
2018	10.1	11.04	91.5
2019	10.4	11.06	94.0
2020	10.6	11.25	94.2
2021	10.0	11.25	88.9
2022	10.3	11.25	91.6

Source: Prepared by the author based on FAO (2025) and World Bank data (2024).

Table 6 reveals a dramatic increase in Algeria's water stress over the past three decades. In 1990, freshwater withdrawals represented approximately 39 percent of renewable water resources, indicating moderate hydrological pressure. By the early 2000s, water stress had increased to nearly 50 percent, reflecting growing demand associated with population growth and irrigation expansion.

The most significant increase occurred after 2010. By 2018, water withdrawals had reached more than 90 percent of renewable freshwater resources, placing Algeria within the category of extreme water stress according to SDG indicator classifications (UN-Water, 2021).

A water stress level above 90 percent indicates that national water withdrawals are approaching the limits of renewable resource availability. Under such conditions, water systems often rely increasingly on non-renewable groundwater extraction, desalination, or other costly supply augmentation measures.

The data therefore confirm that Algeria's water scarcity is not merely episodic but represents a long-term structural condition driven primarily by increasing water demand.

4.3 Econometric determinants of freshwater withdrawals:

To identify the structural drivers of water demand, the econometric model described in Section 4 was estimated using the dataset covering the period 1990–2022.

Table 7. Determinants of freshwater withdrawals in Algeria (1990–2022)

Variable	Coefficient	Standard error	t-statistic	p-value
Constant	−21.473	5.984	−3.59	0.001
ln(POP)	0.742	0.214	3.47	0.002
ln(RGDP)	0.418	0.163	2.56	0.016
ln(IRR)	0.293	0.121	2.42	0.022
RAIN	−0.0021	0.0009	−2.21	0.034

Source: Author's estimation based on FAO (2025) and World Bank Data (2024).

The regression results indicate that population growth, economic expansion, and irrigation development are all statistically significant drivers of freshwater withdrawals in Algeria.

The estimated population elasticity of water withdrawals (0.742) indicates that a 1% increase in population is associated with an increase of approximately 0.74% in freshwater withdrawals, holding other variables constant. This coefficient indicates a strong demographic effect on aggregate water demand.

Economic growth also contributes positively to water demand. The estimated GDP elasticity of 0.418 suggests that increasing economic activity leads to higher water consumption across multiple sectors, including agriculture, industry, and urban water supply.

The coefficient associated with irrigated area (0.293) is also positive and statistically significant, indicating that the expansion of irrigated agriculture directly increases national water withdrawals. This result reflects the strong contribution of irrigation expansion to aggregate water demand in a context where agriculture accounts for the largest share of water withdrawals.

Finally, precipitation exhibits a negative coefficient, indicating that higher rainfall reduces irrigation demand and therefore lowers water withdrawals. This result reflects the substitution between rainfall and irrigation water in agricultural production.

Overall, the econometric results confirm that Algeria's water demand is strongly driven by structural demographic and economic forces, reinforcing the argument that effective demand-management policies are necessary to moderate long-term growth in water withdrawals**.**

4.4 Model diagnostic tests:

As Shown in table 8, the econometric diagnostics indicate that the model performs well statistically. The coefficient of determination ($R^2 = 0.94$) suggests that the explanatory variables account for a very large share of the variation in freshwater withdrawals.

Table 8. Econometric diagnostic indicators

Indicator	Value
Observations	33
R^2	0.94
Adjusted R^2	0.93
F-statistic	118.6
Durbin–Watson	1.88
Breusch-Pagan test	p = 0.41
Breusch-Godfrey test	p = 0.36
Variance Inflation Factor (max)	3.1
AIC	−42.7
BIC	−36.5

Source: Author's estimation based on FAO (2025) and World Bank data (1990–2022).

The F-statistic confirms that the explanatory variables are jointly statistically significant. The Durbin–Watson statistic is close to the value of 2, indicating that residual autocorrelation is unlikely to be a major concern. .

In addition, the Variance Inflation Factor (VIF) values remain well below commonly accepted thresholds, suggesting that multicollinearity among explanatory variables does not distort the coefficient estimates. Taken together,

these diagnostic indicators support the statistical reliability of the econometric model.

4.5 Robustness analysis:

To test the robustness of the econometric results, an alternative specification was estimated including only population as an explanatory variable. This simplified model helps address potential multicollinearity between population and GDP.

Table 9. Robustness test

Variable	Coefficient	t-statistic	p-value
Constant	-25.501	-18.884	0.000
ln(POP)	1.582	20.478	0.000

Model diagnostics

Indicator	Value
Observations	33
R^2	0.984
Adjusted R^2	0.981
Durbin–Watson	1.20

Source: Author's estimation based on FAO AQUASTAT data and World Bank World Development Indicators.

The simplified model confirms that population growth alone explains a substantial share of variation in freshwater withdrawals. The elasticity estimate suggests that a 1 percent increase in population is associated with a roughly 1.58 percent increase in water withdrawals.

This result highlights the strong influence of demographic pressure on national water demand. However, the simplified model omits economic activity and therefore should be interpreted primarily as a robustness check rather than a preferred specification.

4.6 Policy simulation results: irrigation pricing reform:

The final stage of the analysis evaluates how irrigation water pricing reforms could influence agricultural water demand and national water stress.

The simulations assume a price elasticity of irrigation water demand equal to −0.25, consistent with empirical estimates reported in the literature (Berbel et al., 2019; Zamani et al., 2021). Agriculture is assumed to account for approximately 65 percent of total freshwater withdrawals.

Three policy scenarios are simulated: a 10 percent, 20 percent, and 50 percent increase in irrigation water tariffs.

The simulation results indicate that irrigation water pricing reforms could generate measurable reductions in agricultural water demand. A 10 percent increase in irrigation water tariffs would reduce agricultural withdrawals by approximately 2.5 percent, equivalent to water savings of about 0.17 billion m^3.

These results indicate that irrigation pricing reform can reduce water demand, but its aggregate effect remains insufficient to eliminate Algeria's structural water stress.

Table 10. Impact of irrigation water pricing scenarios on water stress in Algeria

Scenario	Irrigation price increase	Estimated reduction in agricultural withdrawals (b m^3)	Total freshwater withdrawals (b m^3)	Water stress (%)
Baseline	No reform	—	10.3	91.6

Scenario 1	10% increase	0.17	10.13	90.0
Scenario 2	20% increase	0.35	9.95	88.4
Scenario 3	50% increase	0.87	9.43	83.8

Source: Author's simulations based on FAO (2025) water withdrawal statistics and elasticity estimates from Berbel et al. (2019) and Zamani et al. (2021).

Table 10 illustrates the potential impact of irrigation water pricing reforms on Algeria's national water stress indicator. Under the baseline scenario, water stress reaches approximately 91.6 percent, indicating that freshwater withdrawals are approaching the country's renewable water resource limits.

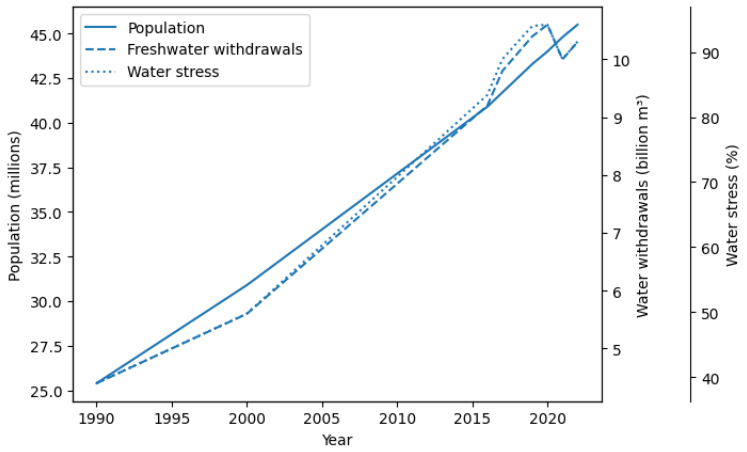
The simulation results suggest that moderate irrigation tariff increases could generate measurable reductions in national water stress. A 10 percent price increase would reduce water stress by roughly 1.6 percentage points, while a 20 percent increase would lower the indicator to approximately 88.4 percent.

More substantial pricing reforms would generate proportionally larger water savings, although the aggregate effect would remain moderate relative to the scale of Algeria's structural water stress. Under the scenario involving a 50 percent increase in irrigation tariffs, total freshwater withdrawals decline significantly, reducing water stress to approximately 83.8 percent.

Despite these reductions, the simulations also confirm that irrigation water pricing reforms alone cannot fully eliminate Algeria's structural water scarcity. Even under the most ambitious pricing scenario, water stress remains above 80 percent, reflecting the strong influence of demographic growth and irrigation demand on the national water balance.

To synthesize the structural drivers of water demand and the evolution of hydrological pressure in Algeria, Figure 2 presents the joint evolution of population, freshwater withdrawals, and water stress over the study period. The figure provides a visual representation of the interaction between demographic growth and increasing pressure on renewable water resources.

Figure 2. Population growth, freshwater withdrawals, and water stress in Algeria (1990–2022)



Source: Prepared by the author based on FAO (2025) and World Bank data (2024).

Figure 2 highlights the structural interaction between demographic growth, increasing water demand, and rising water stress in Algeria. Over the period 1990–2022, the country's population increased from approximately 25 million to more

than 45 million inhabitants. During the same period, total freshwater withdrawals rose from roughly 4.4 billion cubic meters to more than 10 billion cubic meters.

At the same time, renewable freshwater resources remained relatively stable in aggregate terms, resulting in a rapid increase in the water stress indicator. By the late 2010s, water withdrawals had reached more than 90 percent of renewable internal freshwater resources.

The figure therefore illustrates the structural nature of Algeria's water scarcity. Rather than being driven by temporary climatic fluctuations, the increase in water stress appears to result primarily from long-term demographic and economic pressures on a relatively fixed hydrological base.

This structural imbalance reinforces the central argument of the study: demand-management policies, including irrigation water pricing reforms, are likely to play an increasingly important role in ensuring the long-term sustainability of water resources in Algeria.

5. Discussion

The empirical findings of this study provide several important insights into the dynamics of water demand and the potential role of irrigation water pricing reforms in Algeria. By combining econometric analysis with hydro-economic simulations, the results highlight both the structural drivers of water demand and the potential limitations of pricing reforms when implemented in isolation.

5.1 Structural drivers of water demand

The econometric results indicate that demographic and economic factors play a central role in shaping water demand in Algeria. Population growth emerges as a particularly strong determinant of freshwater withdrawals. The estimated elasticity suggests that increases in population are closely associated with increases in water demand, reflecting both direct household consumption and indirect effects through agricultural and economic activities.

This finding is consistent with previous research on water demand in developing and water-scarce regions. Several studies have shown that demographic pressure is one of the most significant drivers of water demand growth, particularly in countries experiencing rapid population expansion (Rogers et al., 2002; World Bank, 2018). As population increases, demand for food production rises, which in turn intensifies the need for irrigation water.

Economic growth also contributes positively to water demand. The estimated elasticity for real GDP suggests that higher levels of economic activity are associated with increased freshwater withdrawals. This relationship reflects the fact that economic development typically increases water demand across multiple sectors, including agriculture, industry, and urban services.

These results confirm that Algeria's water scarcity problem is largely structural. Even if water-use efficiency improves, continued demographic and economic growth will likely maintain strong pressure on national water resources. This reinforces the importance of implementing demand-management policies capable of moderating long-term growth in water consumption.

5.2 Irrigation and agricultural water demand

Agriculture remains the dominant consumer of water in Algeria, accounting for the majority of freshwater withdrawals. This pattern is typical of many countries in

the Middle East and North Africa region, where irrigated agriculture plays a key role in national food production systems (World Bank, 2018).

The expansion of irrigation infrastructure over recent decades has contributed significantly to increasing water demand. While irrigation development has supported agricultural productivity and food security objectives, it has also intensified pressure on surface water and groundwater resources.

Under these conditions, improving irrigation water management becomes essential for reducing overall water demand. Several studies have emphasized that irrigation efficiency improvements—through modern irrigation technologies such as drip irrigation and improved scheduling—can significantly reduce water consumption without necessarily reducing agricultural output (Berbel et al., 2019; Martínez-Dalmau et al., 2023).

However, technological improvements alone may not be sufficient if water pricing structures fail to provide adequate incentives for efficient water use. When irrigation water remains heavily subsidized, farmers may have little economic motivation to invest in water-saving technologies or adjust irrigation practices.

5.3 Effectiveness of irrigation water pricing reforms

The policy simulations conducted in this study provide insights into the potential impact of irrigation water pricing reforms on agricultural water demand. The results suggest that increases in irrigation water tariffs could generate measurable reductions in water withdrawals. Even modest price increases, such as a 10 percent tariff adjustment, may lead to noticeable water savings at the national level.

These findings are broadly consistent with empirical evidence from other water-scarce regions. Studies in Europe, the Mediterranean basin, and parts of Asia have shown that water pricing reforms can influence farmers' water-use behavior when combined with volumetric pricing systems and reliable water measurement (Berbel et al., 2019; Zhang & Oki, 2023).

Nevertheless, the magnitude of the simulated reductions in water demand remains relatively moderate. Even under more substantial price increases, irrigation water demand declines only partially. This outcome reflects the relatively low price elasticity of irrigation water demand documented in the literature. Because water costs typically represent a small share of total agricultural production costs, farmers may not respond strongly to moderate tariff changes (Hanemann, 2005).

Consequently, irrigation water pricing reforms should not be viewed as a single solution to water scarcity. Rather, they should be considered one element of a broader policy framework aimed at improving water-use efficiency and strengthening water governance.

Conclusion

Water scarcity has become one of the most pressing development challenges facing arid and semi-arid regions. Algeria represents a particularly relevant case of structural water stress, where growing water demand driven by population growth, economic development, and irrigation expansion increasingly exceeds renewable water resources. In this context, improving water demand management has become a central priority for sustainable water governance.

This study examined the potential role of irrigation water pricing reform in reducing water demand and alleviating water stress in Algeria. To address this question, the article developed an integrated analytical framework combining

econometric analysis, water accounting, and hydro-economic policy simulations. Using internationally harmonized datasets from FAO AQUASTAT and the World Bank, the analysis evaluated both the structural determinants of freshwater withdrawals and the potential effects of irrigation pricing reforms on water demand.

The evidence shows that Algeria's water demand is shaped by persistent structural pressures, especially demographic growth, economic expansion, and irrigation development. These findings highlight the persistence of structural pressures on water demand in Algeria.

The policy simulations conducted in this study suggest that irrigation water pricing reforms can contribute to reducing agricultural water demand. Even moderate increases in irrigation water tariffs may generate measurable water savings at the national level. However, the results also indicate that the magnitude of these reductions remains relatively limited due to the relatively low price elasticity of irrigation water demand.

Consequently, irrigation water pricing reforms should not be viewed as a single solution to Algeria's water scarcity challenges. Instead, they should be implemented as part of a broader policy framework that includes improved irrigation efficiency, stronger groundwater regulation, enhanced monitoring systems, and institutional reforms aimed at strengthening water governance.

The findings of this study contribute to the literature on water demand management in water-scarce economies by providing a hydro-economic assessment of irrigation pricing reform in Algeria. By combining econometric evidence with policy simulations, the article offers an integrated analytical approach that can help inform water policy design in similar arid and semi-arid contexts.

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