Caspian Journal of Environmental Sciences
Online ISSN: 1735-3866
Print ISSN: 1735-3033

Water scarcity and agricultural productivity in Uzbekistan: Open-data evidence from regional wheat production and irrigated area, 2010-2024

Omon Sultonov[1]*, Fakhriddin Isaev[2], Kholboy I. Ibraimov[3], Saodat Toshalieva[4], Anvar Z. Avlokulov[5], Begoyim Tuychiyeva[6], Najmiddin Jumakulov[7]

1. University of Business and Science (UBS), Tashkent city, Chilanzor district, Yakkabog' MFY Gavhar Street, House 1, Uzbekistan
2. Department of Finance and Tourism, Termez University of Economics and Service, Termez, Uzbekistan & Research Center CEDR Under the Tashkent State University of Economics, Tashkent, Uzbekistan & International Islamic Academy of Uzbekistan, Tashkent, Uzbekistan
3. National Institute of Pedagogy and Character Education named after Kori Niyozi, Tashkent, Uzbekistan, Tashkent City
4. Termez State University, Termez, Uzbekistan
5. Tashkent state University of Economics, Tashkent, Uzbekistan
6. Fergana State University,150100, Ferghana City, Uzbekistan
7. Bukhara State Pedagogical Institute, Bukhara, Uzbekistan

* *Corresponding author's E-mail: info@ubsu.uz*

ABSTRACT

Irrigated agriculture remains central to food security in Uzbekistan, but regional evidence on the productivity implications of water scarcity is often limited by public-data constraints. The analysis builds a reproducible open-data panel for thirteen agricultural regions of Uzbekistan over 2010-2024 and examines how wheat productivity relates to irrigation-resource pressure. Wheat yield is calculated from official SIAT statistics on wheat production and wheat sown area. Irrigation-resource pressure is represented by irrigated sown area and by the ratio of wheat area to total irrigated sown area. National irrigation-water withdrawal data provide the system-level context for 2013-2024. The empirical strategy uses two-way fixed-effects panel models with region and year effects; inference is checked with region-clustered, HC3 and panel-HAC standard errors. Irrigation withdrawals for agriculture declined from 48.9 km^3 in 2013 to 39.9 km^3 in 2024, while national wheat yield rose from 4.72 to 5.32 tons ha^{-1}. Regional productivity differences remained wide: average wheat yield ranged from 2.65 t tons ha^{-1} in Karakalpakstan to 6.60 tons ha^{-1} in Andijan. The fixed-effects estimates do not provide stable evidence that broad irrigated-area indicators alone explain regional wheat yield after accounting for region-specific characteristics and national year shocks. The pressure proxy is negative, but inference is sensitive to the covariance estimator. The results do not diminish the importance of water scarcity; rather, they show that aggregate region-year open statistics cannot identify field-level irrigation adequacy, canal reliability, salinity exposure or farm-management responses. The article provides a transparent baseline and specifies the higher-resolution data needed for credible economic valuation of water scarcity.

Keywords: Agricultural productivity, Irrigated area, Open data, Panel data, Water scarcity, Wheat yield.
Article type: Research Article.

INTRODUCTION

Water scarcity has become one of the main limits on agricultural adjustment in dryland economies. In irrigated farming systems the constraint is not only the volume of water available at national scale. Yield outcomes also depend on the timing of delivery, the condition of canals and drainage, soil salinity, crop choice, and the capacity

Caspian Journal of Environmental Sciences, Vol. 24 No. 4 pp.1199-1208 Received: Feb. 22, 2026 Revised: May 15, 2026 Accepted: July 02, 2026
DOI: 10.22124/cjes.2026.10052
© The Author(s)
Publisher: University of Guilan

of farms to convert each cubic metre of water into harvestable output. Recent water-productivity research therefore treats irrigation water as part of a wider production system rather than as a single input that can be judged only by withdrawals or irrigated area. Uzbekistan is a useful case for examining this problem because wheat production is strategically important and remains closely tied to the irrigation and drainage network. A 2024 World Bank policy note describes irrigation and drainage as the backbone of the country's agricultural and food systems and reports that more than 95% of crop production depends on this network. The same assessment argues that future reform should move from expenditure-centred infrastructure planning toward service-oriented and performance-based irrigation management. That policy diagnosis creates a clear empirical question: how much can be learned from the official open statistics that are already available, and where do those data become too coarse for causal inference?

Recent peer-reviewed studies sharpen the relevance of that question. Babadjanova *et al.* (2024) analyse whether domestic wheat farming can meet climate-induced food-security challenges in Uzbekistan and show that climate and salinity risks cannot be separated from wheat supply prospects. Hamidov *et al.* (2024) examine the governance of water- and energy-saving technologies in Uzbekistan and underline that technological adoption depends on institutional coordination, not on engineering feasibility alone. Khasanov *et al.* (2025) study small-reservoir options in Kashkadarya Province and show how local storage can be framed as an adaptation response to agricultural water scarcity. These studies provide strong sectoral evidence, but they do not substitute for a transparent national or regional open-data baseline. New spatial and modelling evidence also points to a measurement problem. Worqlul *et al.* (2025) estimate green and blue water footprints for irrigated crops in the Chirakchi Watershed and report increasing reliance on irrigation under declining rainfall conditions. Veysi *et al.* (2024) propose a framework for interpreting WaPOR water-productivity indicators and show that gross and net productivity measures can lead to different conclusions. Khamidov *et al.* (2022) document salinity dynamics in Khorezm under climate change, while Rakhmatova *et al.* (2024) project drought risks for Uzbekistan under RCP and SSP scenarios. Together, these studies indicate that water scarcity affects wheat productivity through field-level and seasonal mechanisms that are not fully visible in regional annual statistics. The empirical design of the present article is deliberately conservative. It uses only open internet sources: SIAT regional indicators for wheat production, wheat sown area, irrigated sown area and irrigation-water withdrawal. Wheat yield, irrigation-water intensity and an irrigation-pressure proxy are recalculated from these raw indicators, and the resulting panel covers thirteen agricultural regions over 2010-2024. No administrative water-delivery files, field surveys, or unpublished irrigation-system records are inserted. This restriction makes the analysis reproducible, but it also narrows the interpretation of the econometric results. Three questions guide the analysis. First, what do open official data show about national irrigation-water withdrawals and wheat productivity during 2010-2024? Second, are broad regional proxies for irrigation scale and irrigation pressure statistically related to wheat yield after region and year fixed effects are included? Third, can the available open-data panel support monetary estimates of water-scarcity losses, or should such estimates wait for crop-specific and irrigation-system-level water-delivery data? The answer matters for environmental economics because over-precise loss estimates based on coarse indicators can mislead policy as much as the absence of estimates. The manuscript therefore offers a transparent empirical baseline for Uzbekistan. It separates verified open-data evidence from unobserved field-level mechanisms and identifies the additional information needed for stronger causal assessment. In this sense, the analysis complements remote-sensing and hydrological studies: it does not replace field or basin-scale water accounting, but shows how far official open statistics can be used without creating unsupported claims.

Literature review

Research on agricultural water scarcity has moved away from using withdrawals alone as a measure of pressure. Molden *et al.* (2010) and Zwart *et al.* (2010) established that water productivity should be interpreted through both crop output and consumptive water use. Bastiaanssen & Steduto (2017) later developed a remote-sensing-based water productivity score for wheat, rice and maize, making clear that satellite-derived evapotranspiration can improve the comparability of water productivity across regions. These approaches are especially relevant in data-scarce irrigated systems because water delivered to fields is often not publicly observable. A related debate concerns the difference between field-level efficiency and basin-level water saving. Grafton *et al.* (2018) warn that irrigation-efficiency investments may fail to reduce total depletion if saved water is reused, reallocated or encourages expansion. Ozcelik *et al.* (2021) similarly caution that water-productivity indicators can point policy in the wrong direction when they ignore hydrological context. For Uzbekistan, this means that rising wheat yield

under falling aggregate irrigation withdrawals cannot automatically be read as proof of successful water saving at crop level. It may reflect agronomic change, crop-area adjustment, weather, data aggregation, or unobserved reallocation of water among users. The economic water-scarcity literature adds another layer. Rosa *et al.* (2020) distinguish physical scarcity from economic scarcity, where production is constrained by access, infrastructure, finance or governance even when water exists somewhere in the system. Vallino *et al.* (2020) show that economic water scarcity in agriculture can be measured empirically but requires careful country-level interpretation. Hermans *et al.* (2025), focusing on rural Central Asia, argue that water scarcity interacts with climate change, livelihoods and mobility, making purely technical interpretations incomplete. These arguments fit the Uzbek context, where irrigation reliability, drainage quality and institutional performance affect production decisions. Recent Uzbekistan-specific research has become more detailed. Babadjanova *et al*. (2024) combine climate-change and salinity considerations in an assessment of national wheat security and show that wheat supply is vulnerable to environmental stress. Hamidov *et al.* (2024) examine water- and energy-saving technology governance and conclude that institutional complementarity is important for the adoption of innovations. Khasanov *et al.* (2025) analyse small reservoir construction in Kashkadarya Province as a strategy for agricultural water scarcity, linking local storage to adaptation. These studies justify the focus on wheat and irrigation, but they also show why a national open-data panel should not be interpreted as a complete water-accounting model. Remote-sensing and water-footprint studies give the clearest evidence on mechanisms. Worqlul *et al.* (2025) evaluate the water footprints of cotton, wheat, carrot and potato in the Chirakchi Watershed and find declining rainfall contributions and stronger dependence on blue water for dominant crops. Veysi *et al.* (2024) show that WaPOR-based indicators require careful interpretation because gross and net water productivity may tell different stories. Khamidov *et al.* (2022) show that salinity in Khorezm is linked to climate change and water-management conditions; their findings are important because salinity can reduce yields even where irrigated area appears stable. Rakhmatova *et al.* (2024) add evidence on drought risks under climate scenarios, reinforcing the need to connect crop statistics with meteorological and soil information. Taken together, the literature defines a specific empirical gap. Official open statistics can describe national irrigation-water withdrawals, regional wheat yields and irrigated-area structure over time. They cannot show how much water reached wheat fields, when it arrived, how much was consumed as evapotranspiration, or how salinity and drainage changed within the growing season. The analysis below addresses that gap by testing what is observable in open regional statistics and by avoiding the conversion of weak proxies into unsupported monetary loss estimates.

MATERIALS AND METHODS

Study area, data and constructed variables

The empirical sample contains thirteen agricultural regions of Uzbekistan: the Republic of Karakalpakstan and the regions of Andijan, Bukhara, Jizzakh, Kashkadarya, Navoi, Namangan, Samarkand, Surkhandarya, Syrdarya, Tashkent, Fergana and Khorezm. Tashkent City is excluded, since it is not comparable as an agricultural production region. The period 2010-2024 gives a balanced panel of 195 region-year observations. The database is built from open official statistics. Wheat production in all categories of farms, wheat sown area and irrigated sown area are taken from the SIAT portal of the Statistics Agency under the President of the Republic of Uzbekistan. National irrigation-water withdrawal is taken from the SIAT indicator prepared by the Ministry of Water Resources. All variables used in the econometric models are either directly reported in those sources or are calculated from them. Wheat yield is calculated as wheat production divided by wheat sown area. Because wheat production is reported in thousand tons and area in hectares, the constructed yield variable is expressed as tons per hectare. Irrigation pressure is proxied by the ratio of wheat sown area to total irrigated sown area. This ratio should not be read as water delivery to wheat; it measures how much of the region's irrigated cropping base is occupied by wheat. Total irrigated sown area is used as a broader indicator of the scale of irrigated agriculture.

Table 1. Data sources and constructed variables.

Variable	Source	Unit	Coverage
Wheat production	SIAT indicator 1.03.03.0010	thousand tons	region-year, 2010-2024
Wheat sown area	SIAT indicator 1.03.03.0065 / wheat sown area	ha	region-year, 2010-2024
Irrigated sown area	SIAT indicator 1.03.03.0074	ha	region-year, 2010-2024
Irrigation-water withdrawal	SIAT indicator 3.01.02.0002	million m^3	national, 2013-2024
Wheat yield	Author calculation	tons ha^{-1}	region-year, 2010-2024
Irrigation-pressure proxy	Author calculation	ratio	region-year, 2010-2024

Note: The analysis uses only open data; no administrative or non-public dataset is inserted in the manuscript.

Econometric specification

The baseline model is a two-way fixed-effects specification. The dependent variable is the logarithm of regional wheat yield. Region fixed effects control for time-invariant differences in soils, irrigation infrastructure, historical cropping patterns and geography. Year fixed effects control for national shocks that affect all regions, including policy changes, national weather conditions and common market factors. Three specifications are estimated. Model 1 relates log wheat yield to log irrigated sown area. Model 2 adds log wheat sown area to separate the scale of wheat cultivation from the broader irrigated base. Model 3 replaces irrigated area with the log of the wheat-area-to-irrigated-area ratio. Standard errors are clustered by region in the main table. Because the number of regions is modest, the replication package also reports HC3 and panel-HAC checks. The estimates are interpreted as regional associations after fixed effects, not as field-level crop-water production functions. The formulas and the final CSV files were recalculated before submission. The maximum absolute discrepancy between stored and recalculated wheat yield, log yield, irrigation pressure, national water intensity and national wheat yield is zero within numerical rounding. The replication package includes the rechecked panel, national water-intensity series, model table and calculation-audit file.

RESULTS

The results are presented in three steps. The first describes the national water-withdrawal context. The second summarises regional productivity differences. The third reports fixed-effects estimates and robustness checks. This sequence prevents a common interpretation error: national withdrawals, regional yield gaps and within-region panel coefficients measure different things.

National irrigation-water context

Irrigation water withdrawn for agriculture fell from 48.9 km^3 in 2013 to 39.9 km^3 in 2024, a change of -18.4% percent. Water withdrawal per irrigated hectare fell by 9.3% over the same period, from 14638 to 13272 m^3 per hectare. National wheat yield moved in the opposite direction, rising from 4.72 to 5.32 tons ha^{-1}. The national pattern suggests that aggregate productivity gains occurred despite lower water-withdrawal intensity, but it does not prove that water stress became less important at the farm level.

Table 2. National irrigation-water context, selected years.

Year	Irrigation withdrawal (million m^3)	Irrigated area (ha)	m3 per irrigated ha	National wheat yield (ton ha^{-1})
2,013.0	48,912.3	3,341,497.0	14,637.8	4.720
2,017.0	53,745.0	3,143,387.0	17,097.8	4.308
2,021.0	38,452.1	3,017,473.0	12,743.1	4.566
2,024.0	39,934.5	3,008,836.0	13,272.4	5.325

Note: Water intensity is calculated as irrigation withdrawal divided by national irrigated sown area.

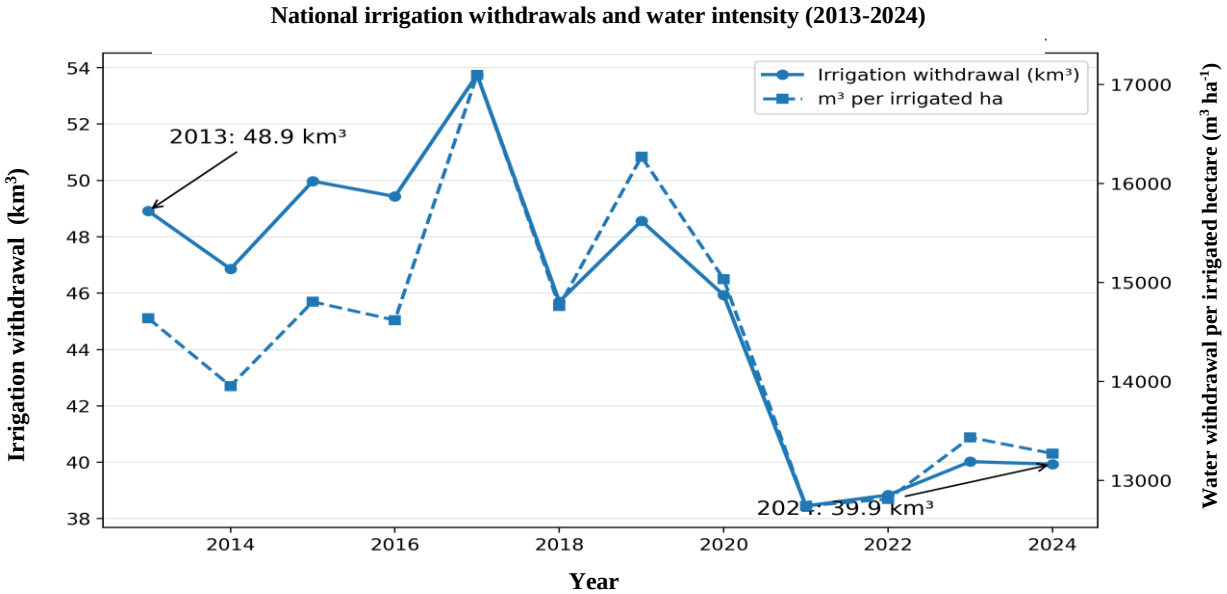


Fig. 1. Irrigation-water withdrawals and water withdrawn per irrigated hectare in Uzbekistan, 2013-2024. Reading note: The left axis shows total irrigation water taken for agriculture; the right axis normalizes the same withdrawal by irrigated sown area. The decline after 2020 is visible in both measures.

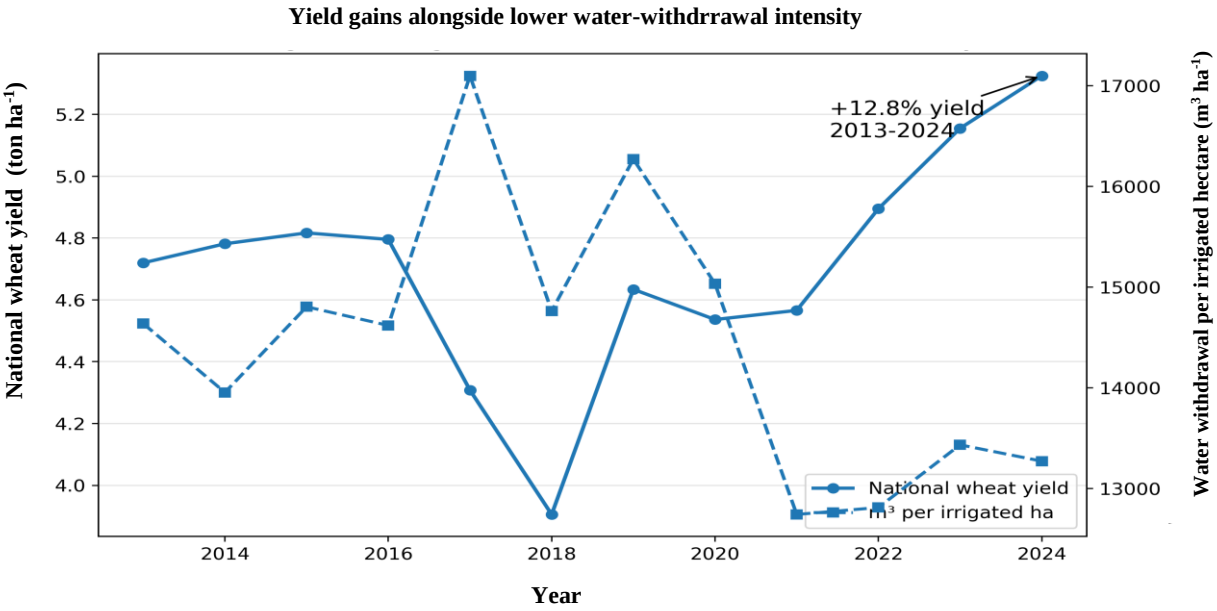


Fig. 2. National wheat yield and irrigation-water intensity, 2013-2024. Reading note: The figure is descriptive. It shows that national yield rose while water-withdrawal intensity fell, but it does not identify whether the yield increase came from varieties, management, regional composition or irrigation reliability.

Regional wheat productivity

Regional wheat productivity differs strongly across Uzbekistan. Over 2010-2024, Karakalpakstan had the lowest mean wheat yield at 2.65 tons ha^{-1}, while Andijan had the highest mean yield at 6.60 tons ha^{-1}. These differences are not water effects by themselves. They combine soils, temperature, salinity, irrigation infrastructure, seed varieties, farm practices and crop-allocation history.

Table 3. Regional wheat productivity and irrigated-area indicators, 2010-2024

Region	Mean yield	Minimum yield	Maximum yield	Mean irrigated area	Mean pressure proxy
Karakalpakstan	2.646	2.131	3.012	256,364.0	0.256
Jizzakh	3.398	2.561	4.444	250,636.8	0.568
Kashkadarya	3.950	3.261	4.490	380,666.5	0.581
Tashkent	4.191	3.412	4.732	304,870.8	0.412
Samarkand	4.457	3.238	5.195	285,481.8	0.568
Syrdarya	4.687	4.172	5.283	215,755.7	0.416
Khorezm	5.025	4.131	7.163	218,762.7	0.240
Navoi	5.071	4.204	5.822	94,069.9	0.477
Namangan	5.372	4.495	6.459	205,054.7	0.416
Surkhandarya	5.383	4.297	6.815	245,065.0	0.458
Fergana	5.899	4.145	7.697	270,289.8	0.429
Bukhara	6.158	5.724	6.549	240,330.1	0.346
Andijan	6.600	5.944	7.578	219,620.4	0.369

Note: Regions are ordered by mean wheat yield. The pressure proxy is wheat sown area divided by irrigated sown area.

The baseline coefficient of log irrigated sown area is small and statistically insignificant under region-clustered inference. After adding wheat sown area as a control, the irrigated-area coefficient remains statistically weak. The wheat-area coefficient is negative, which is consistent with the idea that expanding wheat over less favourable land may reduce average yield, but the result is not stable across robust inference methods. The pressure proxy has the expected negative sign: when wheat occupies a larger share of the irrigated cropping base, regional yield tends to be lower after fixed effects. However, the statistical inference is sensitive to the covariance estimator. Region-clustered and panel-HAC p-values do not support a strong claim, while the HC3 check is more suggestive. The manuscript therefore avoids converting the coefficient into monetary damage. The correct reading is that open regional data point to a plausible pressure channel but do not provide a stable causal estimate.

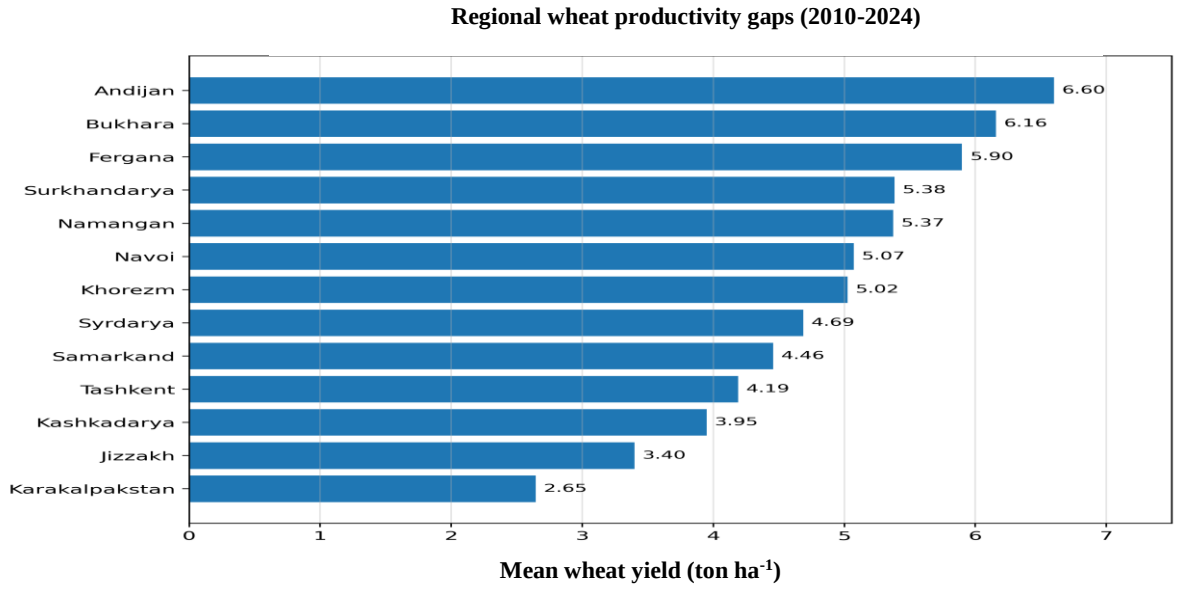


Fig. 3. Mean regional wheat yield, 2010-2024; Reading note: This between-region comparison is a diagnostic description, not a causal ranking. Low mean yield in Karakalpakstan should be investigated together with salinity, climate and local irrigation reliability.

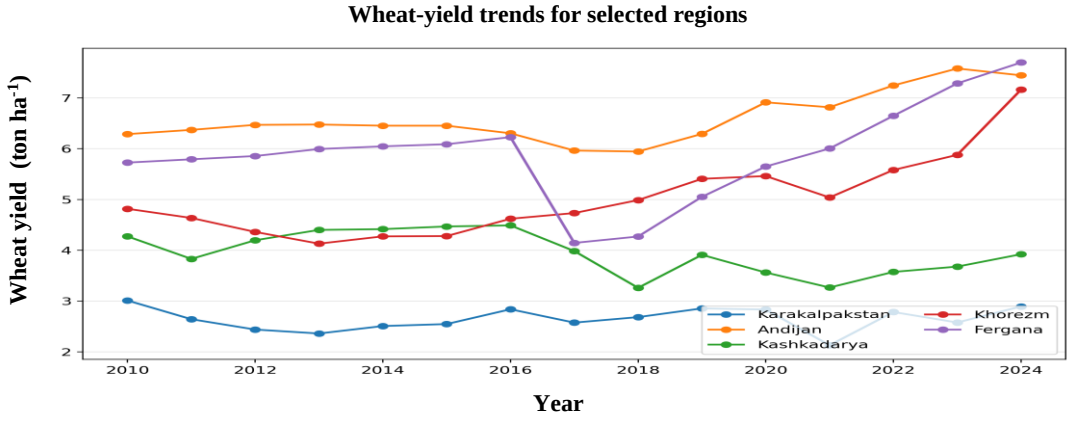


Fig. 4. Wheat-yield trends for selected regions; Reading note: The figure selects regions with contrasting average yields and water-stress conditions to avoid overcrowding. Full regional data are included in the replication files.

Panel estimates

Table 4. Two-way fixed-effects estimates of wheat productivity.

Model	Variable	Coefficient	Cluster SE	Cluster *p*-value	HC3 *p*-value	HAC-panel *p*-value	N	R^2
M1: FE baseline	ln(irrigated sown area)	-0.049	0.175	0.782	0.768	0.777	195	0.890
M2: FE with wheat area	ln(irrigated sown area)	0.071	0.202	0.732	0.647	0.672	195	0.897
M2: FE with wheat area	ln(wheat sown area)	-0.411	0.315	0.216	0.018	0.068	195	0.897
M3: FE pressure proxy	ln(wheat area / irrigated area)	-0.274	0.224	0.245	0.034	0.094	195	0.894

Note: Dependent variable is log wheat yield. All models include region and year fixed effects. Cluster p-values use region-clustered standard errors; HC3 and panel-HAC p-values are shown as sensitivity checks.

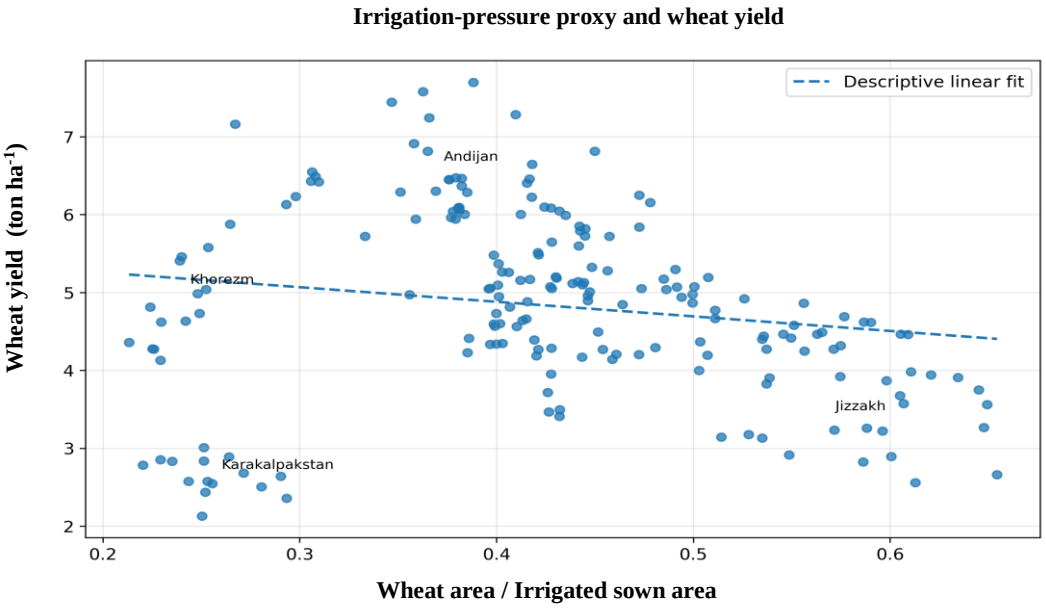


Fig. 5. Irrigation-pressure proxy and wheat yield, region-year observations. Reading note: The fitted line is descriptive and uses pooled observations. It helps visualize the negative association, but the fixed-effects estimates in Table 4 are the basis for inference.

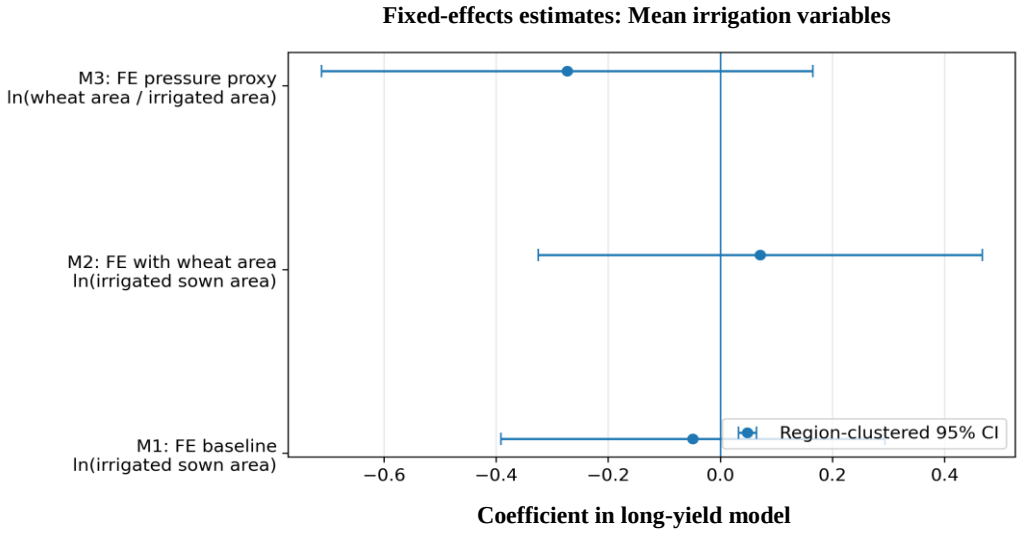


Fig. 6. Fixed-effects coefficient estimates with region-clustered 95% confidence intervals; Reading note: Intervals crossing zero show why the paper does not report a precise economic-loss estimate from the available open regional panel.

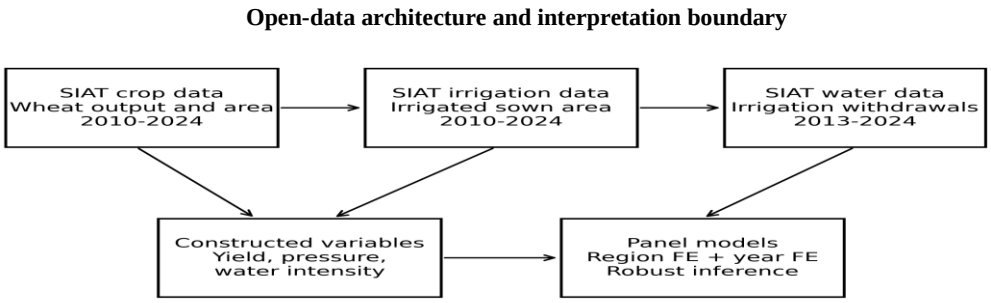


Fig. 7. Open-data architecture used in the empirical assessment; *Reading note.* The figure separates measured open-data variables from unobserved water-delivery mechanisms. This boundary is central to the interpretation of the results.

DISCUSSION

The empirical findings should be read together with the literature on water productivity and irrigation management. National irrigation withdrawals declined, but national wheat yield increased. This pattern can occur when agronomy improves, wheat area contracts, low-yield plots leave production, or farm management becomes more effective. It can also occur when national data hide local shortages. Aggregate water withdrawal is a system-level indicator; it is not the same as crop-specific irrigation adequacy. The weak and unstable fixed-effects relationship between regional yield and broad irrigated-area indicators does not mean that water scarcity is harmless. The indicators used here are intentionally coarse because the article relies only on open data. Actual field outcomes depend on water timing, depth, salinity, canal reliability, groundwater pumping, drainage condition and management response. None of these mechanisms is measured directly in the public regional panel. Recent Uzbekistan-specific studies help explain why higher-resolution evidence is needed. The Chirakchi watershed water-footprint analysis separates green and blue water and reports rising dependence on irrigation for dominant crops. The wheat food-security projections show that temperature and salinity can reduce future wheat supply. Small-reservoir analysis in Kashkadarya shows how GIS and remote sensing can identify locally relevant water-storage interventions. These papers work at spatial and process scales closer to the mechanisms that aggregate regional statistics cannot observe. For environmental-economics assessment, the central lesson is methodological discipline. A regional open-data panel is valuable for establishing trends and testing broad associations. It should not be used to assign exact monetary losses to water scarcity unless the necessary exposure variables are observed. A stronger valuation study would combine crop-specific water delivery, evapotranspiration from WaPOR, rainfall from CHIRPS, heat-stress indicators from ERA5-Land, vegetation indicators from MODIS, and salinity or drainage data with official crop statistics.

Policy implications

First, official crop and water statistics should be linkable at crop, district and irrigation-system levels. The public regional data are useful, but they separate wheat production from the actual water delivered to wheat fields. This separation prevents reliable economic valuation of water scarcity. Second, water-saving policies should be evaluated at the irrigation-system and basin level, not only at the field level. Efficiency improvements can raise farm productivity without reducing total depletion if saved water is reused or if irrigated area expands. Third, remote sensing should be treated as a complement to official statistics. WaPOR, MODIS, CHIRPS and ERA5-Land can provide evapotranspiration, vegetation, rainfall and temperature indicators at spatial scales closer to crop processes. The most useful monitoring system would combine these layers with official production and irrigation-service records. Fourth, northern and environmentally stressed regions need separate diagnostics. Karakalpakstan's low average wheat yield does not by itself identify the cause, but it is a strong signal that salinity, water reliability, drainage and agronomic management should be analysed together.

Limitations

The analysis is restricted to open internet data. This improves reproducibility and allows independent checking, but it also limits causal claims. The database does not contain actual water delivery to wheat fields, intra-seasonal irrigation timing, salinity of irrigation water, groundwater substitution, farm technology, soil quality or canal reliability. For this reason, the coefficients are not converted into monetary damage values. The panel is regional rather than district- or field-level. Some water scarcity effects may be visible only at finer spatial scales or during specific growth stages of wheat. Cotton and horticultural crops are also relevant for water scarcity, but comparable open data should be audited crop by crop before they are included in the same model.

CONCLUSION

Open data show that irrigation-water withdrawals for agriculture declined between 2013 and 2024, while national wheat yield increased. Regional wheat-yield gaps remained large during 2010-2024, with the lowest mean yield in Karakalpakstan and the highest mean yield in Andijan. These descriptive patterns are important for policy, but they do not automatically measure the economic cost of water scarcity. Two-way fixed-effects estimates do not provide stable evidence that broad irrigated-area indicators alone explain regional wheat productivity after region and year effects are controlled. The pressure proxy has a negative sign, but inference is not strong enough to support a monetary damage estimate. The most defensible conclusion is therefore practical: open regional statistics are a strong starting point for transparency, but field-level water delivery, evapotranspiration, rainfall,

heat stress, salinity and farm-management data are necessary for credible causal valuation. The article leaves a reproducible baseline for further work. Its main value is not an overstated coefficient, but a clear separation between verified open-data evidence and the higher-resolution water-accounting information required for sound irrigation and food-security policy.

REFERENCES

Abrorov, S, Isaev, F, Khamidova, SY, Mustafoyev, G, Mamadiyarov, Z & Xashimova, S 2025, Circular economy approaches for the management of textile waste in Tashkent: Viability and policy recommendations. *Caspian Journal of Environmental Sciences*, 23(5): 1167–1174. https://doi.org/10.22124/cjes.2025.9358.

Babadjanova, M, Bobojonov, I, Bekchanov, M, Kuhn, L & Glauben, T 2024, Can domestic wheat farming meet the climate change-induced challenges of national food security in Uzbekistan? *International Journal of Water Resources Development*, 40(3): 448–462. https://doi.org/10.1080/07900627.2023.2290523.

Bastiaanssen, WGM & Steduto, P 2017, The water productivity score (WPS) at global and regional level: Methodology and first results from remote sensing measurements of wheat, rice and maize. *Science of the Total Environment*, 575: 595–611. https://doi.org/10.1016/j.scitotenv.2016.09.032.

Climate Hazards Center 2026, *CHIRPS rainfall data*, University of California, Santa Barbara, accessed June 2026.

ECMWF 2026, *ERA5-Land hourly data from 1950 to present*, Copernicus Climate Data Store, accessed June 2026.

Eshkaraev, S, Bakhodirovna, KD, Fakhriddin, I, Nodira Batirdjanovna, A, Askarov, I, Umarov, S & Mirzaev, O 2025, Dynamic stability analysis and control of AC/DC microgrids with energy storage systems for transient state mitigation. *Journal of Operation and Automation in Power Engineering*, 13(Special Issue): 17–28. https://doi.org/10.22098/joape.2025.18911.2464.

FAO 2026, WaPOR: Water Productivity through Open access of Remotely sensed derived data, Food and Agriculture Organization of the United Nations, accessed June 2026.

Fakhriddin, I, Tursunov, O, Suluv Yangiboevna, K, Ernazarov, M, Mirzaev, O, Khurramovich Karimov, F & Anvar Nazirjonovich, K 2025, Load–frequency control of a restructured multi-area power system with DFIG-based wind integration using coordinated AVR–PSS–FACTS and optimized PID controllers. *Journal of Operation and Automation in Power Engineering*, 13(Special Issue): 44–53. https://doi.org/10.22098/joape. 2025.18913.2466.

Grafton, RQ, Williams, J, Perry, CJ, Molle, F, Ringler, C, Steduto, P, Udall, B, Wheeler, SA, Wang, Y, Garrick, D & Allen, RG 2018, The paradox of irrigation efficiency. *Science*, 361(6404): 748–750. https://doi.org/10.1126/ science.aat9314.

Hamidov, A, Kasymov, U, Allahverdiyeva, N & Schleyer, C 2024, Governance of technological innovations in water and energy use in Uzbekistan. *International Journal of Water Resources Development*, 40(1): 123–139. https://doi.org/10.1080/07900627.2022.2062706.

Hermans, K, Djanibekov, N, Abdullaev, I & Umirbekov, A 2025, Future research directions for understanding the interconnections between climate change, water scarcity, and mobility in rural Central Asia. *Climate and Development*. https://doi.org/10.1080/17565529.2024.2436090.

Karakulov, F, Menglikulov, B, Mamasadikov, A, Kholbutaeva, S, Mukhtorov, A, Abdulkhaeva, G, ... & Durmanov, A 2025, The impact of climate-smart technology adoption on agricultural productivity and environmental sustainability. *Emerging Science Journal*, 9(6): 3087–3115.

Khamidov, M, Ishchanov, J, Hamidov, A, Donmez, C & Djumaboev, K 2022, Assessment of soil salinity changes under the climate change in the Khorezm Region, Uzbekistan. *International Journal of Environmental Research and Public Health*, 19(14): Article 8794. https://doi.org/10.3390/ijerph19148794.

Khakimov, Z, Urinov, U, Saidova, M, Narmanov, O, Ernazarov, D, Khodjaeva, Z, Sabirova, R, Berdikulov, K, Isayev, F, Sherimbetov, I, Abdullaeva, KZ, Rakhimova, AA & Ochilov, Y 2025, Insect biodiversity in Uzbekistan: From vast steppes to Caspian shores, a keystone for Eurasian ecosystems. *Caspian Journal of Environmental Sciences*, 23(4): 1101–1105. https://doi.org/10.22124/cjes.2025.9221.

Khasanov, K, Bakiev, M, Rasulov, O, Babajanova, N & Abdurahmanov, I 2025, Addressing water scarcity in agriculture through small reservoir construction in Kashkadarya Province. *Research in Agricultural Engineering*, 71(3): 143–154. https://doi.org/10.17221/20/2025-RAE.

Khurramov, A, Avlokulov, A, Qushmatov, O, Xayitboyev, M, Bobokulov, SB, Abdieva, NS, Abdiganiyeva, S, Toshalieva, ST, Khalikova, U, Karimov, FK, Yakubova, DT, Bunet, A & Mirzayeva, LS 2026, Green transition, institutions and environmental efficiency in OECD economies. *Caspian Journal of Environmental Sciences*, 24(3): 837–864. https://doi.org/10.22124/cjes.2026.9797.

Mamadiyarov, Z, Isaev, F, Abrorov, S, Isadjanov, A, Gavhar, A & Mukhammadkhuja, S 2026, Economic impacts of climate change on agricultural production and adaptive strategies for farmers in the Fergana Valley, Uzbekistan. *Caspian Journal of Environmental Sciences*, 23(5): 1193–1200. https://doi.org/10.22124/cjes.2026.9361.

Meylikulov, S, Fakhriddin, I, Madina, K, Muhammadi, T, Musabekov, Z, Farxodjon, O & Anarboyevich Nurmanov, U 2025, Dynamic modeling and state feedback control for enhancing small signal stability in islanded microgrids with diesel generator frequency damping. *Journal of Operation and Automation in Power Engineering*, 13(Special Issue): 29–43. https://doi.org/10.22098/joape.2025.18912.2465.

Molden, D, Oweis, T, Steduto, P, Bindraban, P, Hanjra, MA & Kijne, J 2010, Improving agricultural water productivity: Between optimism and caution. *Agricultural Water Management*, 97(4): 528–535. https://doi.org/ 10.1016/j.agwat.2009.03.023.

NASA 2026, MOD13Q1 Terra Vegetation Indices 16-Day Global 250m, NASA LP DAAC, accessed June 2026.

Ozcelik, N, Rodriguez, M, Lutter, S & Sartal, A 2021, Indicating the wrong track? A critical appraisal of water productivity as an indicator to inform water efficiency policies. *Resources, Conservation and Recycling*, 168: Article 105452. https://doi.org/10.1016/j.resconrec.2021.105452.

Rakhmatova, N, Nishonov, BE, Kholmatjanov, BM, Rakhmatova, V, Toderich, KN & Khasankhanova, GM 2024, Assessing the potential impacts of climate change on drought in Uzbekistan: Findings from RCP and SSP scenarios. *Atmosphere*, 15(7): Article 866. https://doi.org/10.3390/atmos15070866.

Rosa, L, Chiarelli, DD, Rulli, MC, Dell'Angelo, J & D'Odorico, P 2020, Global agricultural economic water scarcity. *Science Advances*, 6(18): eaaz6031. https://doi.org/10.1126/sciadv.aaz6031.

Sindarov, F, Ochilov, F, Khalmirzaev, M, Das, U, Mullabayev, B, Soxadaliyev, A, Kazakov, O, Khurramov, A, Khurramova, M, Sharafutdinova, X, Umarova, G, Xudoyqulova, S & Shodieva, D 2026, Energy price shocks, fossil fuel dependence, and carbon emissions (CO_2): A multi-stage transmission framework analysis. *Caspian Journal of Environmental Sciences*, 24(2): 495–515. https://doi.org/10.22124/cjes.2026.9635.

Statistics Agency under the President of the Republic of Uzbekistan 2026, SIAT open data indicators on wheat production, wheat sown area, irrigated sown area and irrigation-water withdrawal, accessed June 2026.

Vallino, E, Ridolfi, L & Laio, F 2020, Measuring economic water scarcity in agriculture: A cross-country empirical investigation. *Environmental Science & Policy*, 114: 73–85. https://doi.org/10.1016/j.envsci.2020.07. 017.

Veysi, S, Galehban, E, Nouri, M, Mallah, S & Nouri, H 2024, Comprehensive framework for interpretation of WaPOR water productivity. *Heliyon*, 10(16): e36350. https://doi.org/10.1016/j.heliyon.2024.e36350.

World Bank 2024, Uzbekistan: Policy perspectives for irrigation and drainage sector reform, World Bank, Washington, DC.

World Bank 2025, Uzbekistan to modernize its irrigation infrastructure with World Bank support, World Bank, Washington, DC.

Worqlul, AW, Akramkhanov, A & Gafurov, Z 2025, Water footprints of irrigated crops in the Chirakchi Watershed, Uzbekistan. *Frontiers in Agronomy*, 7: Article 1595665. https://doi.org/10.3389/fagro.2025.1595665.

Zwart, SJ, Bastiaanssen, WGM, de Fraiture, C & Molden, DJ 2010, A global benchmark map of water productivity for rainfed and irrigated wheat. *Agricultural Water Management*, 97(10): 1617–1627. https://doi.org/10.1016/ j.agwat.2010.05.018.

Bibliographic information of this paper for citing:

Sultonov, O, Isaev, F, Ibraimov, KI, Toshalieva, S, Avlokulov, AZ, Tuychiyeva, B, Jumakulov, N 2026, Water scarcity and agricultural productivity in Uzbekistan: Open-data evidence from regional wheat production and irrigated area, 2010-2024, Caspian Journal of Environmental Sciences, 24: 1199-1208.

Copyright © 2026