JEE Journal of Ecological Engineering

Journal of Ecological Engineering, 2026, 27(8), 319–329
https://doi.org/10.12911/22998993/218787
ISSN 2299–8993, License CC-BY 4.0

Received: 2026.02.22
Accepted: 2026.05.12
Published: 2026.07.01

Water crisis in Jordan: An assessment of the blue water footprint in vegetable production

Nabil Beithou[1], Sameh Alsaqoor[1*], Nader Aljabarin[2], Mohammad Bani Khaled[3], Hashim Alhindi[4], Maryam Akho-Zahieh[5], Ali Alahmer[6]

[1] Department of Mechanical Engineering, Tafila Technical University, P.O. Box 179, 66110, Tafila, Jordan
[2] Department of Natural Resources and Chemical Engineering, Faculty of Engineering, Tafila Technical University, Tafila, Jordan
[3] Department of Mechanical and Industrial Engineering, Liwa College, Abu Dhabi, UAE
[4] Department of Civil Engineering, American International University, Aljahra, Kuwait
[5] Department of Electrical and Computer Engineering, Applied Science Private University, Amman, Jordan
[6] Department of Mechanical Engineering, Tuskegee University, Tuskegee, AL 36088, USA
* Corresponding author's e-mail: sameh@ttu.edu.jo

ABSTRACT

Several countries are classified as water-scarce based on the threshold of 500 m³ per person per year. Jordan is among the most water-scarce nations, with renewable water resources of less than 100 m³ per capita. The agricultural sector accounts for over 50% of Jordan's sustainable water supply, using approximately 500 million m³ (MCM) of freshwater annually to produce about 1.8 million tons of vegetables. Given this significant demand, evaluating and minimizing the blue water footprint (BWF) is essential for sustainable water management. This study assesses the potential for freshwater savings in Jordan's vegetable production by applying the BWF framework as a comparative and evaluative tool. Statistical data from multiple sources were analyzed to calculate the BWF of the major vegetables cultivated in Jordan. Results indicate that the BWF for most crops exceeds international averages. Further analysis revealed that over 70% of the cultivated areas rely on open-field irrigation systems located in regions with high water absorption and evaporation rates, contributing to the elevated BWF values. The findings suggest that adopting advanced irrigation technologies and controlled-environment agriculture could significantly reduce the BWF, improving irrigation efficiency and promoting long-term water sustainability. Moreover, tomato cultivation for export purposes was found to consume a disproportionately large share of freshwater; aligning its BWF with global benchmarks could save approximately 52 MCM of freshwater annually.

Keywords: water scarcity, blue water footprint, water management, vegetables, irrigation efficiency.

INTRODUCTION

Jordan faces an acute water crisis, one of the most severe globally, due to its arid climate, limited freshwater availability, and growing population pressures. The nation's renewable water resources have fallen below 100 m³ per capita per year, only one-tenth of the global water scarcity threshold of 1.000 m³ (Abu Qdais, 2019). According to Daoud et al. (2022), Jordan ranks as the second most water-scarce country in the world. Despite an annual rainfall of nearly 8 billion m³, the country's renewable water supply cannot meet its growing demand, which exceeds 1 billion m³ annually (Hadadin et al., 2010). Approximately 500 million m³ (MCM) are consumed by households, 38 MCM by industry, and nearly 600 MCM, over 50% of the total sustainable supply, are used for irrigation Al-Kharabsheh et al. (2020). With a population now exceeding 11 million, water availability per capita is declining rapidly, signaling an unsustainable trajectory unless water use practices are transformed.

The agricultural sector represents the largest consumer of freshwater in Jordan, particularly for vegetable production in the Jordan Valley and

Desert regions. These areas rely heavily on irrigation using surface and groundwater, contributing substantially to the country's overall blue water consumption. The blue water footprint (BWF), defined as the volume of freshwater (surface and groundwater) consumed and not returned to the same catchment, has emerged as a key metric for assessing the sustainability of agricultural production (Egan, 2011), Klemeš, 2015), Ding and Ghosh, 2017). The BWF concept, first introduced in the early 2000s, offers a structured framework for assessing the freshwater consumed in the production of goods and services. It enables policymakers and researchers to quantify water use, uncover inefficiencies, and identify opportunities for improving resource management and sustainability (Sala et al. 2013, Vanham 2016).

Applying the BWF framework to agriculture enables countries, especially those under water stress, to:

- Reassess national and regional water strategies.
- Evaluate the sustainability of water resource management.
- Compare cropping systems and irrigation practices.
- Identify water-intensive "hot spots" in agricultural production.
- Plan future agricultural policies and crop selection based on water productivity and efficiency.

In Jordan, vegetable production relies predominantly on groundwater extraction, particularly in the arid Desert regions, where groundwater withdrawal is both unsustainable and energy-intensive (Talozi et al., 2015). Irrigation practices often depend on farmers' personal judgment rather than data-driven irrigation scheduling, leading to frequent over-irrigation and inefficient water use (Kafle, Balasubramanya, 2023). Studies show that cultivation techniques greatly influence water use efficiency: for example, net-house or greenhouse systems for crops like bananas in the Jordan Valley exhibit lower BWF values than open-field systems, suggesting the potential benefits of adopting similar controlled-environment methods for vegetable production (Shtull-Trauring et al., 2016).

Recent advancements in irrigation technology and water management present promising pathways for reducing freshwater dependency in agriculture. Technological innovations, such as precision irrigation systems, coupled with data-driven irrigation scheduling and policy-based water demand management, can effectively decouple agricultural productivity from unsustainable freshwater use. Additionally, the integration of geographic information systems (GIS) and high-resolution spatial data into agricultural planning enables the identification of site-specific crop selections and irrigation techniques that minimize the BWF while sustaining high yields (Shtull-Trauring et al., 2016). Despite these opportunities, Jordan continues to face significant institutional and governance challenges, including fragmented water management structures, insufficient coordination across sectors, and a heavy reliance on non-renewable groundwater sources such as the Disi aquifer (Schyns et al., 2015). Addressing these constraints calls for a paradigm shift toward evidence-based water governance, where scientific assessments and innovative technologies are systematically integrated into national water policies and agricultural development strategies.

Although several national and international studies have analyzed Jordan's water scarcity and proposed conservation measures, few have employed the BWF as a quantitative evaluation tool to assess agricultural water use. Unlike other regions such as the Mediterranean Basin or Europe, where BWF benchmarks and optimization strategies have been developed (Beithou et al., 2022), Jordan lacks localized assessments that quantify the BWF of its agricultural products. Existing studies tend to focus on total water consumption or irrigation efficiency without distinguishing between green, blue, and grey water components, limiting their ability to inform targeted water-saving interventions.

In particular, no comprehensive evaluation has been conducted on the BWF of major vegetable crops, despite their significant share in Jordan's agricultural production and freshwater use. The absence of crop-specific BWF benchmarking and comparative analyses represents a critical gap in current research and policy frameworks, hindering the development of sustainable water management strategies tailored to Jordan's agricultural sector.

This study aims to:

- Quantify the BWF for major vegetable crops cultivated in Jordan using national production and water use data.
- Evaluate spatial and production-based variations in BWF between cultivation regions and irrigation methods (e.g., open-field vs. controlled environments).

- Identify key contributors to high blue water consumption and propose strategies to enhance irrigation efficiency and sustainability.

BACKGROUND

Water resources and agricultural use in Jordan

Jordan is classified as a semi-arid country, characterized by limited rainfall and high evaporation rates (Alahmer et al., 2018, Qandil et al., 2023). The average annual rainfall volume is estimated at less than 8000 million cubic meters (MCM), of which more than 90% is lost through evaporation due to the country's climatic conditions and limited water retention capacity (Antonelli and Tamea, 2015). In addition to natural aridity, Jordan's water scarcity has been exacerbated by demographic pressures and regional instability. The influx of refugees from neighboring countries, particularly following the Syrian crisis, has increased Jordan's population by approximately 20%, significantly intensifying the strain on already limited water resources. Combined with rapid population growth and the projected impacts of climate change, the pressure on renewable water supplies continues to escalate, threatening the long-term sustainability of both domestic and agricultural water systems.

Currently, the annual renewable water resources per capita in Jordan are below 100 cubic meters, placing the country well beneath both the global water scarcity threshold (1000 m^3 per capita per year) and the "absolute scarcity" threshold (500 m^3) (Al-Addous et al., 2023). Over the past two decades, Jordan's water-stress indicator—measured as the proportion of total water withdrawals relative to available renewable resources, has increased from 80% to nearly 100%, indicating that almost all available water resources are being exploited (Al-Addous et al., 2023). At present, the nation's renewable water supply meets only about two-thirds of total national water demand, creating a persistent water deficit that must be supplemented through non-conventional sources such as desalination, water reuse, and groundwater overdraft.

Industrial water use in Jordan

The industrial sector in Jordan consumes approximately 4% of the total national water use, relying primarily on freshwater sources that could otherwise serve domestic needs (Saidan 2020). Specifically, industrial activities utilize around 32.2 MCM of groundwater, 4.8 MCM of surface water, and 1.7 MCM of treated wastewater annually. Encouragingly, studies indicate that approximately 37.8% of total process water used in industrial operations could be reclaimed and reused through on-site wastewater treatment systems. Such measures present a valuable opportunity to reduce freshwater withdrawals and contribute to circular water economy practices within the industrial sector.

Agricultural water use in Jordan

Agriculture remains the largest consumer of water resources in Jordan, accounting for nearly 52% of the country's total water use, or approximately 600 MCM of freshwater annually. Despite its substantial water demand, the sector remains vital to national food security and rural livelihoods. Over the past decade, Jordan's average annual vegetable production has been approximately 1.74 million tons, with tomatoes accounting for nearly 41.5% of the total yield (Qtaishat et al., 2022), as illustrated in Figure 1. This makes Jordan one of the top 10 global producers and exporters of tomatoes, reflecting both the sector's economic importance and its water intensity.

Vegetable cultivation in Jordan occurs across diverse climatic zones, from the Jordan Valley to the eastern and southern desert regions, with an irrigated area of approximately 369,695 dunums (1 dunum = 1000 m^2) as of 2017 Ministry of Water and Irrigation (2025). Two primary irrigation methods dominate agricultural production:

- Protected cultivation (plastic houses) utilizing drip or surface irrigation, and
- Open-field cultivation employing drip or surface irrigation systems.

Among these, open-field cultivation with drip irrigation is the most prevalent, accounting for roughly 71% of the total irrigated area. While drip irrigation is generally more efficient than surface irrigation, its effectiveness depends on maintenance practices, scheduling accuracy, and soil characteristics. In Jordan's arid environment, open-field systems remain highly susceptible to water loss through evaporation and deep percolation, particularly in sandy or low-retention soils. This widespread reliance on open-field irrigation,

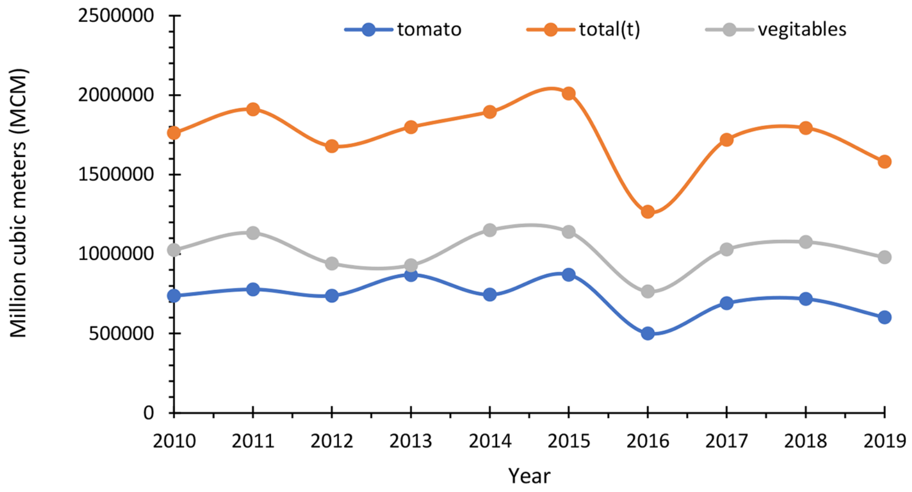

Figure 1. Annual production of total vegetables and tomatoes in Jordan (Ministry of Water and Irrigation, 2025)

combined with high evapotranspiration rates, significantly increases the BWF of vegetable production, underscoring the urgent need for modernized irrigation strategies and improved water management practices.

It is well established that less than 10% of the water used for irrigation contributes directly to plant biomass production, while the remaining 90% is lost through leakage, evaporation, or deep percolation. Consequently, an estimated 540 MCM of water used for irrigation in Jordan is effectively lost each year.

Table 1 summarizes the planted areas of major vegetable crops in Jordan for the year 2022, distinguishing between irrigated and non-irrigated cultivation. The data show that vegetable farming in Jordan is heavily dependent on irrigation, with over 90% of the total planted area (approximately 342.9 thousand dunums) relying on irrigated water sources. Tomatoes, potatoes, and melons occupy the largest cultivated areas, reflecting their economic and export significance. In contrast, non-irrigated farming remains limited, accounting for only about 29.4 thousand dunums, highlighting the critical reliance of Jordan's agricultural sector on managed irrigation systems to sustain production in its arid climate.

Table 2 illustrates the distribution of irrigation methods used for tomato, squash, and cucumber cultivation in Jordan. The data indicates that drip irrigation is the dominant technique, accounting for more than 96% of total irrigation practices across all crop types. Tomatoes and squash are primarily cultivated in open fields, whereas cucumbers are mostly grown in plastic houses under

Table 1. Planted area of non-irrigated and irrigated vegetables by type of crop in Jordan (Qtaishat et al., 2022)

Crop	Irrigated area	Non-irrigated area	Planted area
Tomatoes	75.2	3.5	78.7
Squash	23.2	2.3	25.4
Eggplants	10.7	0.0	10.7
Cucumber	16.2	0.1	16.2
Potatoes	38.8	1.2	40.0
Cabbage	10.6	0.0	10.6
Cauliflower	13.5	0.0	13.5
Hot pepper	7.3	0.0	7.3
Sweet pepper	14.1	0.0	14.1
Broad beans	5.9	3.2	9.0
String beans	6.5	0.0	6.5
Peas	0.4	1.2	1.6
Cow-peas	0.9	0.0	0.9
Jews mallow	9.1	0.0	9.1
Okra	4.5	3.4	7.9
Lettuce	14.7	0.0	14.7
Sweet melon	22.1	0.0	22.1
Water melon	18.4	0.1	18.4
Spinach	3.2	0.0	3.2
Onion green	2.3	0.3	2.6
Onion dry	21.2	7.2	28.4
Snake cucumber	1.3	4.6	5.9
Turnip	0.9	0.0	0.9
Carrot	4.0	0.0	4.0
Parsley	3.4	0.0	3.4
Radish	3.1	0.0	3.1
Other	11.8	2.2	14.0
Total	342.9	29.4	372.2

Table 2. Vegetables plantation and irrigation system in Jordan (Beithou et al., 2022)

Crop	Plastic houses (%)	Plastic tunnels (%)	Open field (%)	Drip irrigation (%)
	drip	Surface	Drip	Surface
Tomato	25.4	0.6	2.14	0.0
Squash	2.23	0.1	7.4	0.0
Cucumber	95.3	1.0	0.0	0.0

controlled conditions. The minimal use of surface and sprinkler irrigation reflects Jordan's ongoing shift toward efficient water-saving technologies, highlighting the country's efforts to optimize limited water resources in agriculture. Research has shown that the adoption of modern farming and irrigation technologies, such as greenhouses, drip irrigation, and hydroponic systems, can significantly increase agricultural productivity while reducing water consumption compared to traditional open-field irrigation methods (Sumarni et al., 2023). Given Jordan's status as one of the most water-scarce countries in the world, it is essential to evaluate the potential impact of shifting from open-field cultivation to alternative irrigation systems on overall water use and irrigation efficiency.

Figure 2 illustrates the proportion of open-field and closed-field (plastic-house) cultivation areas for major vegetable crops in Jordan. The data reveal that open-field farming dominates vegetable production, covering the majority of the cultivated area across most crops. However, a limited number of crops, particularly cucumbers, sweet peppers, and sweet melons, exhibit a substantial share of closed-field (protected) cultivation, indicating a gradual transition toward modern, controlled-environment farming systems. This shift reflects Jordan's increasing adoption of greenhouse and automated irrigation technologies

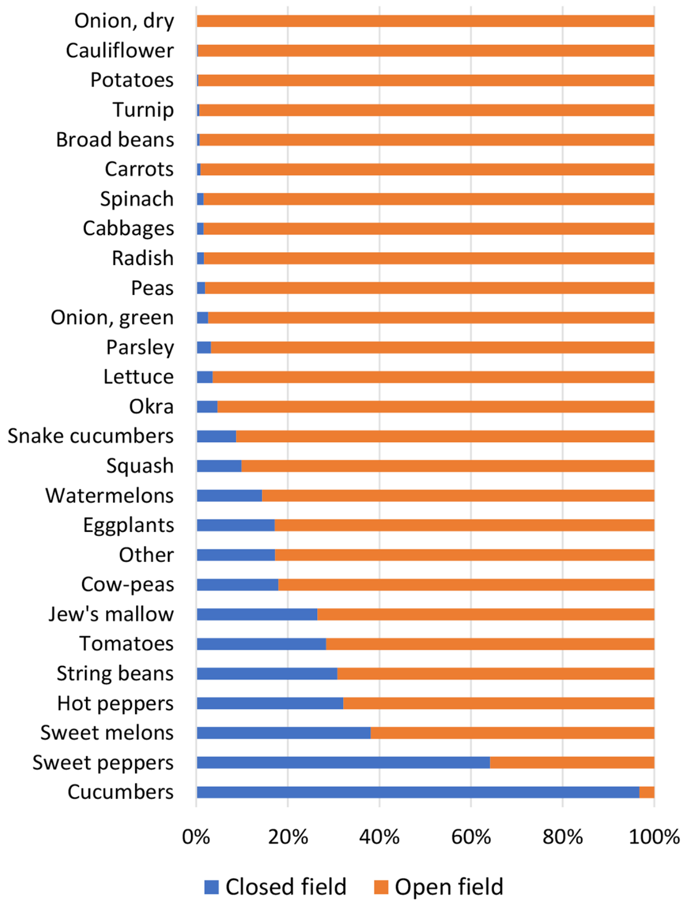

Figure 2. Percentage of open-field and closed-field (plastic houses) cultivation from the total cultivated area for main vegetables in Jordan (Department of Statistics, 2017)

to improve water-use efficiency, minimize evapotranspiration losses, and enhance crop productivity under its semi-arid climate.

The total water cost for vegetable cultivation exceeds 122,798,000 m^3 per growing season, emphasizing the urgent need to expand protected agriculture practices (Shammout et al., 2018). Crops such as cucumbers and sweet peppers have already demonstrated improved irrigation performance under controlled conditions, highlighting their potential as models for efficient water management. To further maximize water savings, a larger share of vegetable production should be directed toward closed-field systems equipped with automatic irrigation controls.

An analysis of data from the Amman Central Market (2010–2018) shows that vegetable planting patterns in Jordan fluctuate annually based on market demand and product prices. Figure 3 demonstrates these variations for selected crops, where some, such as Mulokhya leaves, maintain stable production levels, while others, like beets, exhibit a consistent upward trend. Because agricultural production directly consumes a valuable and limited resource—water—it is essential that crop selection and planting strategies be guided primarily by national water priorities and food security goals, rather than by short-term market fluctuations.

MATERIAL AND METHODS

This study focused on the major vegetable crops cultivated in Jordan, selected based on their economic significance, cultivated area, and irrigation intensity. The crops analyzed include tomatoes, squash, eggplants, cucumbers, potatoes, cabbage, cauliflower, lettuce, green beans, onions, peppers, melons, and carrots. Together, these crops represent over 85% of Jordan's total irrigated vegetable production, with an average total production of 1.7 million tons per year.

The assessment considered vegetables in their fresh form, reflecting direct production from farms rather than processed goods. The data were normalized per unit area (1 dunum = 1000 m²) and per unit yield (ton per dunum) to facilitate comparison across crops and production systems.

The quantitative analysis was based on official national statistics and validated datasets. The main sources were:

- Department of Statistics (DoS, Jordan) (Department of Statistics, 2024), providing ten years of data (2010–2020) on crop yield, cultivated area, and irrigation practices
- Agricultural Credit Corporation (ACC, Jordan) (Agricultural Credit Corporation, 2025), providing technical reference values for irrigation water use per dunum for specific crops,

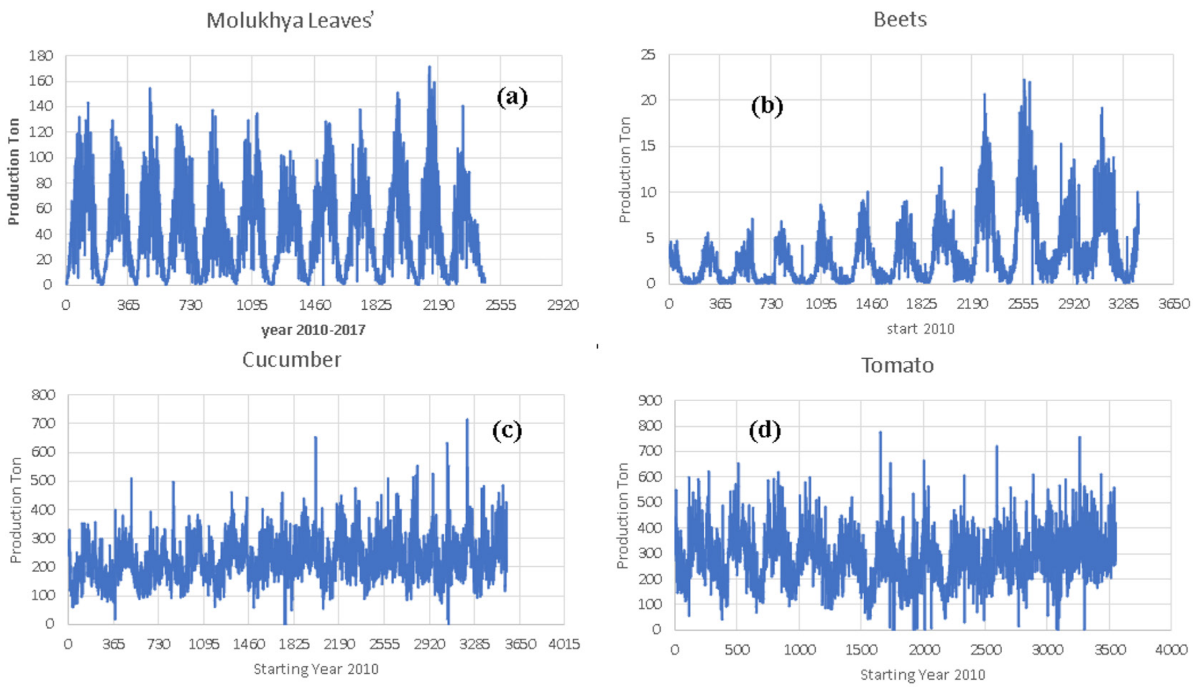

Figure 3. Variation in the production of selected vegetables in Jordan over 2010–2017 (Department of Statistics, 2017)

used here as crop water use (CWU) input values.

- Published literature and FAO datasets, for international benchmark BWF values used for comparison (Mekonnen and Hoekstra, 2010, Van Kooten et al., 2006).

The blue water footprint quantifies the volume of freshwater consumed during crop production, representing evapotranspiration and other non-recoverable uses of irrigation water. The BWF for each vegetable crop was calculated using the following standard equations:

$$BWF = \frac{CWU}{Y} \quad (1)$$

where: BWF – blue water footprint (m³/ton), CWU – crop water use (m³/ha), Y – crop yield (ton/ha).

The crop water use corresponds to the net irrigation requirement, i.e., the volume of water evapotranspiration by the crop and no longer available for reuse, as given by:

$$CWU_{Blue,OF} = A_{OF} \times W_{c,OF} \quad (2)$$

where: $CWU_{Blue,OF}$ – blue crop water uses for open-field cultivation (m³), A_{OF} – cultivated area under open-field drip irrigation (m²), $W_{c,OF}$ – average irrigation water requirement per unit area (m³/ha).

Table 3. Irrigation water requirements for cultivating one dunum (open-field, drip irrigation) of selected vegetables

Crop	Min (m³/dunum)	Max (m³/dunum)	Average (m³/dunum)
Sweet melon	350	450	400
Watermelon	400	500	450
Tomatoes	450	550	500
Squash	350	450	400
Cauliflower	400	450	425
Cabbage	400	500	450
Eggplants	500	600	550
Lettuce	225	300	262.5
Fresh pepper	450	500	475
Potato	750	850	800
Cucumber	350	500	425
Onion (dry)	300	320	310
Green beans	400	500	450
Carrot	320	400	360

The irrigation requirement per crop (Table 3) was derived from ACC and DoS data under open-field, drip irrigation systems. Each BWF value was expressed in liters of freshwater per kilogram of crop (L/kg) to allow direct comparison with international benchmarks.

Comparison with international benchmarks

To evaluate the relative efficiency of water use in Jordan, the calculated BWF values were compared with international reference BWFs from the Water Footprint Network (Mekonnen and Hoekstra, 2010) and controlled-environment case studies (Van Kooten et al., 2006). The potential water-saving ratio was determined by computing the percentage difference between local and benchmark values for each crop.

RESULTS

Crop water requirements

Table 3 presents the irrigation water needs for cultivating one dunum (open-field drip irrigation) of selected vegetables in Jordan. The values range between 225 m³/dunum for lettuce and 850 m³/dunum for potatoes, reflecting variability in crop type and evapotranspiration characteristics.

Figure 4 illustrates the relationship between the monthly production volume (arrival) of dry onions at the Amman Central Market and their market price. These results demonstrates an inverse correlation between supply and price, when production peaks, prices tend to reduce, and when production decreases, prices rise. This seasonal fluctuation is primarily driven by the crop's growing and harvesting cycles, which create temporary market surpluses or shortages.

To maintain stable market prices and ensure continuous product availability throughout the year, it is essential to adopt effective product management strategies. These include regulating supply through planned cultivation schedules and utilizing refrigerated storage facilities to preserve surplus produce during peak harvest months. Such measures can help achieve price stabilization, reduce post-harvest losses, and improve market efficiency for perishable crops like dry onions.

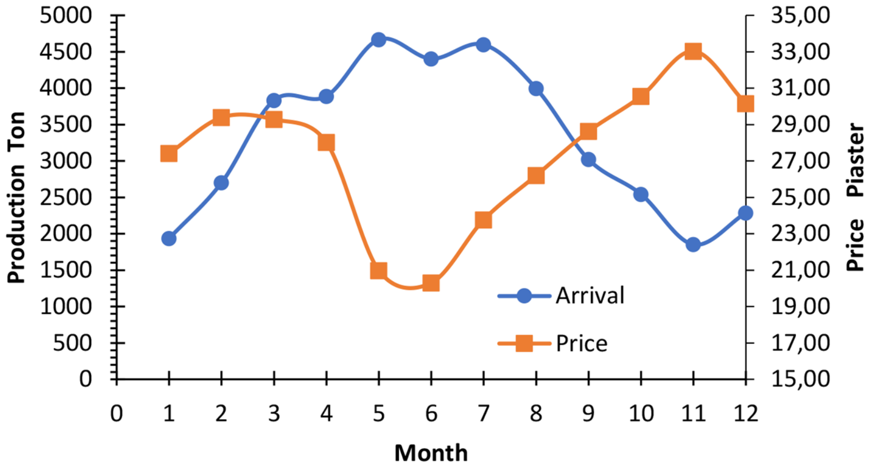

Figure 4. Monthly variation in production volume and market price of dry onions at the Amman Central Market

Blue water footprint

Using Equations 1 and 2, the blue water footprint for each crop was calculated based on production data, cultivated area, irrigation type, and yield obtained from the Department of Statistics in Jordan (2017). The results, presented in Table 4, reveal considerable variation among vegetable types, with BWF values ranging from 43 to 239 L/kg, depending on the crop's irrigation intensity, yield, and cultivation method.

The calculated Blue Water Footprint values indicate that most vegetables cultivated in Jordan consume significantly more freshwater than global averages. As shown in Figure 5, crops such as potatoes, eggplants, green beans, and squash exhibit particularly high BWF values—often exceeding 170–230 L/kg, while cucumbers and lettuce demonstrate relatively efficient water use, with values below 50 L/kg. This disparity reflects the strong dependence on open-field irrigation under arid climatic conditions, which leads to high rates of evapotranspiration and water loss.

Figure 5. Comparison of the blue water footprint for selected vegetables cultivated in Jordan and global average values

Water saving potential

To quantify the potential water-saving opportunity, the Jordanian BWF values for selected crops were compared with global benchmark values, and the difference was used to estimate the possible freshwater savings. As shown in Table 5 and Figure 6, adopting practices that achieve global-level efficiency could

Table 4. Results of blue water footprint for selected vegetable crops in Jordan

Crop	Area (dunum)	Yield (ton/dunum)	Production (ton)	Avg. water used (m³)	BWF (L/kg)
Sweet melon	10,667.2	5.1	53,968.7	4,266,880	79.1
Watermelon	13,277.1	6.4	85,213.2	5,310,840	62.3
Tomatoes	84,923.8	5.7	483,421.3	42,461,900	87.8
Squash	18,984.5	2.5	48,155.9	7,593,800	157.7
Cauliflower	9,294.9	3.3	30,978.4	3,717,960	120.0
Cabbage	5,473.1	6.2	33,803.4	2,736,550	81.0
Eggplants	12,185.8	3.1	38,281.9	7,311,480	191.0
Lettuce	7,763.8	4.5	35,137.0	1,746,855	49.7
Fresh pepper	12,592.7	3.0	37,843.4	6,296,350	166.4
Potato	21,736.0	4.3	93,516.6	16,302,000	174.3
Cucumber	7,850.8	11.6	91,027.7	3,925,400	43.1
Onion (dry)	4,733.0	4.3	20,249.2	1,419,900	70.1
Green beans	3,552.0	2.0	7,425.1	1,776,000	239.2
Carrot	660.2	4.5	2,934.8	211,264	72.0

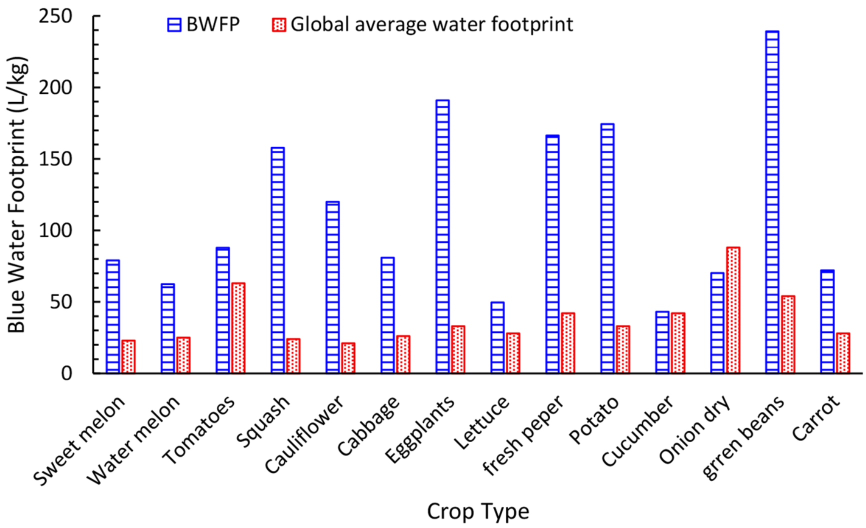

Figure 5. Comparison of the blue water footprint for selected vegetables cultivated in Jordan and global average values

save approximately 52 million cubic meters (MCM) of freshwater annually. This amount nearly equals the national water deficit that Jordan currently covers through imports and water purchases from neighboring countries.

Crops such as potatoes, tomatoes, eggplants, and squash represent the largest potential for improvement, together accounting for more than 70% of the total saving potential. In contrast, crops such as cucumbers already exhibit efficient water use, leaving limited room for further reduction.

Water losses through exporting vegetables

Another dimension of water inefficiency in Jordan arises from the export of high-water-demand crops. Table 6 summarizes the volume of virtual water exported through selected vegetables, particularly tomatoes and sweet peppers. The analysis shows that about 61% of tomato production is exported, corresponding to over 25 MCM of embedded freshwater. Given Jordan's severe water limitations, exporting water-intensive products effectively transfers valuable water resources outside the country.

Table 5. Estimated potential blue water savings for selected vegetable types in Jordan

Crop	Global average BWF (L/kg)	Potential blue water saving (%)	Estimated water saving (L)
Watermelon	25	149	3,180,510
Tomatoes	63	39	12,006,358
Squash	24	557	6,438,058
Cauliflower	21	472	3,067,414
Cabbage	26	211	1,857,662
Eggplants	33	479	6,048,177
Lettuce	28	78	763,019
Fresh pepper	42	296	4,706,927
Potato	33	428	13,215,952
Cucumber	42	3	102,237
Onion (dry)	88	-20	-362,030
Green beans	54	343	1,375,045
Carrot	28	157	129,090
Total	—	—	52,528,419

Table 6. Potential freshwater losses associated with exported vegetables

Crop	Export share (%)	Production (ton)	Virtual water exported (L)
Tomatoes	60.8	185,196.1	25,816,835
Sweet pepper	12.5	38,008.7	787,044

CONCLUSIONS

This study applied the blue water footprint methodology to quantify the freshwater consumption associated with the production of major vegetable crops cultivated in Jordan. The results demonstrate that the BWF values of most Jordanian vegetables are significantly higher than international averages, confirming that current agricultural practices impose a disproportionate demand on limited freshwater resources.

The analysis revealed substantial variation among crops, with cucumbers and lettuce showing relatively low BWF values (below 50 L/kg), while potatoes, eggplants, green beans, and squash exhibited markedly higher values (above 170 L/kg). These differences are largely attributed to the predominance of open-field irrigation systems operating under semi-arid climatic conditions, where high evaporation rates intensify water losses.

By comparing local BWF data with global benchmarks, the study identified a potential water-saving capacity of approximately 52 MCM annually if Jordan's irrigation efficiency were to align with global best practices. Moreover, the assessment of export-related water use indicated that a considerable portion of Jordan's freshwater is virtually transferred abroad through the export of high-water-demand crops, particularly tomatoes and sweet peppers.

Overall, the results confirm that the blue water footprint provides a robust analytical framework for evaluating the sustainability of agricultural water use. The outcomes of this study quantitatively demonstrate the extent of inefficiency in current irrigation systems and highlight the measurable potential for improving freshwater conservation in water-scarce environments such as Jordan.

Acknowledgement

The authors express their sincere gratitude to the Applied Science Private University (Amman, Jordan) and Tafila Technical University (Tafila, Jordan) for their financial support of this research. The authors also acknowledge the valuable support provided by Liwa College (Abu Dhabi, UAE) and the American International University (Al Jahra, Kuwait).

REFERENCES

1. Abu Qdais, H., Abdulla, F., Kurbatova, A. (2019). Wastewater reuse in Jordan and its potential as an adaptation measure to climate change. *Journal of Environmental Engineering and Science*, *14*(4), 203–211. https://doi.org/10.1680/jenes.19.00029. Agricultural Credit Corporation 2025. https://www.acc.gov.jo/en (accessed November 6, 2025).
2. Al-Addous, M., Bdour, M., Alnaief, M., Rabaiah, S., Schweimanns, N. (2023). Water resources in Jordan: A review of current challenges and future opportunities. *Water*, *15*(21), 3729. https://doi.org/https://doi.org/10.3390/w15213729
3. Alahmer, A., Al-Dabbas, M., Alsaqoor, S., Al-Sarayreh, A. (2018). Utilizing of solar energy for extracting freshwater from atmospheric air. *Applied Solar Energy*, *54*(2), 110–118. https://doi.org/10.3103/S0003701X18020044
4. Al-Kharabsheh, A. (2020). Challenges to Sustainable water management in Jordan. *Jordan Journal of Earth & Environmental Sciences*, *11*(1). https://doi.org/10.1080/02508060508691861.
5. Antonelli, N. A. M., Tamea, S. (2017). Food-water security and virtual water trade in the Middle East and North Africa. In *The water-energy-food nexus in the Middle East and North Africa* (pp. 38–54). Routledge. https://doi.org/10.1080/07900627.2015.1030496
6. Beithou, N., Qandil, A., Khalid, M. B., Horvatinec, J., Ondrasek, G. (2022). Review of agricultural-related water security in water-scarce countries: Jordan case study. *Agronomy*, *12*(7), 1643. https://doi.org/10.3390/agronomy12071643
7. Daoud, I. Y. H., Dehnavi, S., Ribbe, L. (2022). Towards good water governance: An analysis of Jordan's National Water Strategy. *Environmental Management*, *69*(5), 847–860. https://doi.org/10.1007/s00267-022-01606-x
8. Department of Statistics. Department of Statistics, Jordan, Statistical Report: Housing Units in Jordan 2015. https://www.dos.gov.jo/EN/statistics/ (accessed September 17, 2024).

9. Ding, G. K. C., Ghosh, S. (2017). Sustainable water management-A strategy for maintaining future water resources. *Encyclopedia of sustainable technologies*. https://doi.org/10.1016/B978-0-12-409548-9.10171-X
10. Egan, M. (2011). The water footprint assessment manual. Setting the global standard. https://doi.org/10.1080/0969160X.2011.593864
11. Hadadin, N., Qaqish, M., Akawwi, E., Bdour, A. (2010). Water shortage in Jordan—Sustainable solutions. *Desalination*, *250*(1), 197–202. https://doi.org/https://doi.org/10.1016/j.desal.2009.01.026.
12. Kafle, K., Balasubramanya, S. (2021). Can perceptions of reduction in physical water availability affect irrigation behaviour? Evidence from Jordan. *Evidence From Jordan (August 25, 2021). IFAD Research Series*, *66*. https://doi.org/10.1080/17565529.2022.2087587.
13. Klemeš, J. J. (Ed.). (2015). *Assessing and measuring environmental impact and sustainability*. Butterworth-Heinemann. https://doi.org/10.1007/s10098-015-0930-0
14. Mekonnen, M. M., Hoekstra, A. Y. (2011). The green, blue and grey water footprint of crops and derived crop products. *Hydrology and earth system sciences*, *15*(5), 1577–1600. https://doi.org/10.5194/hess-15-1577-2011
15. Ministry of Water and Irrigation 2025. https://www.mwi.gov.jo/Default/En (accessed November 6, 2025).
16. Qandil, A., Othman, A., Beithou, N. I. (2023). Experimental analysis of atmospheric water harvester using ammonia vapour absorption system. *Journal of Ecological Engineering*, *24*(2), 221–229. https://doi.org/10.12911/22998993/156612
17. Qtaishat, T., El-Habbab, M. S., Bumblauskas, D. P., Tabieh, M. (2022). Fresh tomatoes are in demand: A marketing and sustainable competitiveness analysis of tomato exports from Jordan. *Journal of Management Information & Decision Sciences*, *25*(5), 1–15.
18. van Kooten, O., Heuvelink, E., Stanghellini, C. (2006, August). New developments in greenhouse technology can mitigate the water shortage problem of the 21st century. In *XXVII International Horticultural Congress-IHC2006: International Symposium on Sustainability through Integrated and Organic 767* (pp. 45–52). https://doi.org/10.17660/actahortic.2008.767.2
19. Vanham, D. (2016). Does the water footprint concept provide relevant information to address the water–food–energy–ecosystem nexus?. *Ecosystem services*, *17*, 298–307. https://doi.org/10.1016/j.ecoser.2015.08.003
20. Sala, S., Bianchi, A., Bligny, J. C., Bouraoui, F., Castellani, V., De, C. C.,..., Wolf, M. A. (2013). Water footprint in the context of sustainability assessment. Report on the application of life cycle based indicators of water consumption in the context of integrated sustainability impact analysis. https://data.europa.eu/doi/10.2788/81274
21. Schyns, J. F., Hamaideh, A., Hoekstra, A. Y., Mekonnen, M. M., Schyns, M. (2015). Mitigating the risk of extreme water scarcity and dependency: The case of Jordan. *Water*, *7*(10), 5705–5730. https://doi.org/10.3390/w7105705
22. Shtull-Trauring, E., Aviani, I., Avisar, D., Bernstein, N. (2016). Integrating high resolution water footprint and GIS for promoting water efficiency in the agricultural sector: a case study of plantation crops in the Jordan Valley. *Frontiers in Plant Science*, *7*, 1877. https://doi.org/10.3389/fpls.2016.01877
23. Saidan, M. N. (2020). Estimation of industrial water demand and reclamation in Jordan: a cross-sectional analysis. *Water resources and industry*, *23*, 100129. https://doi.org/10.1016/j.wri.2020.100129
24. Shammout, M. A. W., Qtaishat, T., Rawabdeh, H., Shatanawi, M. (2018). Improving water use efficiency under deficit irrigation in the Jordan Valley. *Sustainability*, *10*(11), 4317. https://doi.org/10.3390/su10114317
25. Tables Agricultural census 2017 - Department of Statistics 2017. https://dosweb.dos.gov.jo/censuses/agriculture-census/census2017_tables/ (accessed November 11, 2025).
26. Talozi, S., Al Sakaji, Y., Altz-Stamm, A. (2017). Towards a water–energy–food nexus policy: realizing the blue and green virtual water of agriculture in Jordan. In *The Water-Energy-Food Nexus in the Middle East and North Africa* (pp. 173–194). Routledge. http://dx.doi.org/10.1080/07900627.2015.1040544