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Enhancing Water Management in Jordan: A Fresh Tomato Water Footprint Analysis

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Abstract—This study aims to determine the average water footprint for tomatoes in Jordan spanning from 1994 to 2023, covering both summer and winter seasons. Utilizing the CROPWAT 8.0 model, input data from the Department of Statistics, NASA POWER, and local farmers near Baqoura, Deir Alla, and Ghour Alsafi stations were analyzed, to find the green water footprint (rainfall), blue water footprint (irrigation) and grey water footprint (water needed to dilute pollutants) in these stations . Results revealed the average total water footprint for the Baqoura station to be approximately 7000 m3/ton during winter and around 3,000 m3/ton for summer, with similar readings for the other stations. Significant findings include ET green, ET blue, Crop Water Use (CWU) green and blue, and production yield for 2023. The aim of finding such data is to aid the decision-making for agricultural practices for tomatoes in the area. Despite inconsistencies in data recording, particularly regarding fertilizer application and sunshine, the water footprint serves as a valuable tool for estimating seasonal variations in water needs as well as provide comparative data to determine which method is best for determining the best water usage for tomatoes. Comparative studies globally suggest variability in water footprints, with factors such as climate, irrigation methods, and soil conditions influencing results

Keywords: Green water footprint, blue water footprint, grey water footprint, crop water use, application ratio, evapotranspiration, crop coefficient, CROPWAT 8.0 model

Introduction.

Knowing the water footprint is crucial in Jordan, due to the dependence on agriculture and extreme water scarcity. The country's expanding population, arid environment, and limited supply of water all have an impact on the sustainability of agriculture (MoE, 2022). Analyzing the water footprint becomes essential to understanding the dynamics of water usage, especially when growing crops like tomatoes.

Jordan faces severe water stress, with an annual renewable water resource of 75 cubic meters per person, well below the 'absolute water scarcity' threshold (MWI, 2016). This places Jordan among the lowest in the region. A 3% decrease in water use in Jordan could increase infant mortality rates from 13.4 to 15.9 deaths per 1,000 live births, emphasizing the urgency of addressing water challenges (UNICEF, 2022). Jordan grapples with consequences, particularly in agriculture and industry, due to insufficient rainfall. Modernizing the municipal water supply system could save half of the nation's water consumption while transforming agricultural production might reduce water use fivefold (Beithou, et al., 2022). With 196,000 hectares of cropland, 43% irrigated, and 57% rainfed, preserving strategic crops and arable land is crucial for addressing water shortages. Water scarcity challenges water-intensive crops like wheat and barley, impacting food security and necessitating solutions for sustainable water management (FAO, 2022; DoS, 2022).

Jordan's rainfall exhibits significant geographic and temporal variation, with 90% of the country falling within the dry to semi-arid category (Salahat & Al-Qinna, 2015). Monthly data from 22 meteorological stations spanning 1961 to 2012 reveal the impact of climate change, resulting in shorter rainy seasons, reduced precipitation levels, and an average annual rainfall decline of 1.1 mm (DoS, 2022). Some areas still experience extreme rainfall events. Aridity categorization maps indicate a shift towards lower rainfall means, with the west-middle region becoming moderately arid and the southern and northern-eastern regions becoming super arable. Regional variations range from 75-110 mm in the Badia region to 100-200 mm in the steppes region, while certain parts of the Jordanian Desert receive less than 30 mm annually. Past studies such as those done by Salahat and Al-Qinna showcase fewer rainy days and decreased overall rainfall in Jordan, but comprehensive trends remain unclear (Salahat & Al-Qinna, 2015). The annual rainfall data from 2010 to 2022 highlights significant variations. Notably, 2015/2016, 2018/2019, and 2019/2020 recorded high rainfall at 9,483, 9,568, and 10,836 MCM, while 2011/2012 and 2020/2021 had lower rainfall at 5,943 and 5,414.6 MCM (DoS, 2022). These fluctuations impact water availability for agriculture and reservoir storage. Understanding such trends is crucial for planning sustainable water use and adapting to climatic variations in the region, emphasizing effective water resource management.

Globally, tomatoes are one of the most widely cultivated and consumed vegetables. They are rich in essential nutrients like vitamins C and K, potassium, and antioxidants. Tomatoes are grown in diverse climates around the world, ranging from temperate regions to tropical areas. Major tomato-producing countries include China, India, the United States, Turkey, and Egypt. In recent years, there has been increasing attention on sustainable tomato production practices, including organic farming methods, water conservation techniques, and reducing post-harvest losses. Additionally, advancements in technology and breeding have led to the development of high-yielding tomato varieties with improved resistance to pests and diseases. Overall, tomatoes remain a cornerstone of global agriculture, providing essential nutrition and contributing significantly to the economies of producing regions

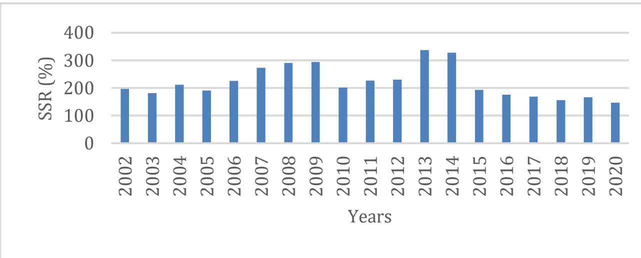

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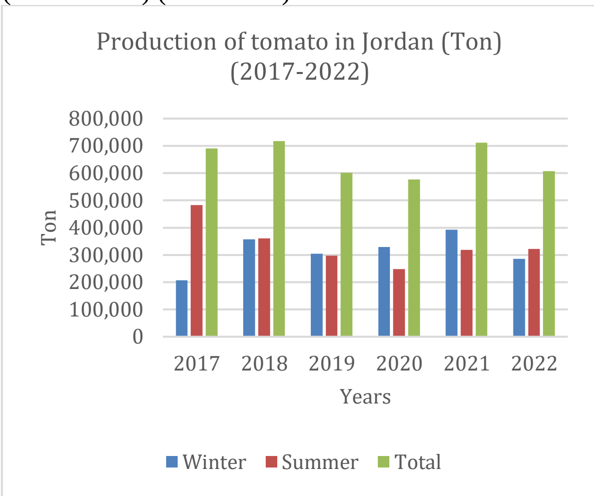
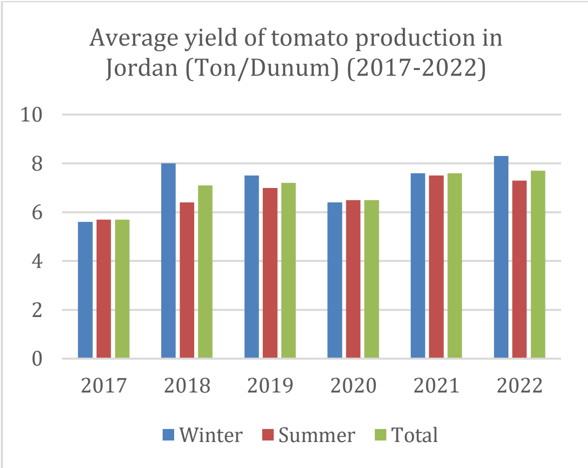
Figure 1: Graph depicting the trends of Production, Export, Import, and Self-Sufficiency in Tomatoes in Jordan (2002-2020)
Source: DoS, 2022

Figure 1 illustrates Jordan's tomato self-sufficiency from 2002 to 2020, based on data from the Jordanian Department of Statistics. The period saw fluctuations, with a notable increase in self-sufficiency from 2008 to 2014. However, subsequent years witnessed a decline in production and exports, leading to decreased self-sufficiency and increased tomato imports. Jordan's decreased tomato production between 2014 and 2020 can be attributed to a variety of things. To begin with, Jordan's tomato value chain faces several challenges even though tomatoes are an essential commodity for the nation's food security. This includes a great deal of players working in the informal sector, along with a high degree of fragmentation and informality. Furthermore, insufficient infrastructure, restricted financial accessibility, and insufficient coordination impede the effectiveness of tomato cultivation inside the nation (Alhammad & Awaideh, 2023). Consequently, during the designated period, all these challenges contributed to a role in the decline in tomato production. The data also highlights the significance of tomatoes in Jordan's vegetable exports, constituting 65% in 2015. The tomato sector experienced dynamic trends, with factors like the pandemic contributing to fluctuations in average yield in 2019–2020 (DoS, 2022; Leeters & Riccen, 2016

Figure 2: Average Yield of Tomato Production (Ton/Dunum) (2017-2022)





The data from 2017 to 2022 focuses on Jordan's tomatoes. It includes average yield per year, total yield, and cultivated areas. In 2022, tomatoes comprise 21% of vegetable land, leading over potatoes and dry onions (DoS, 2022). Figure 2 show the mean annual yield of tomato cultivation ranges approximately from 6 to 9 tons per dunum per year, exhibiting slight fluctuations across consecutive years. The dataset depicts consistent trends with minor variances observed between the summer and winter seasons. However, tomato production in Jordan exhibits slightly greater variability across both years and seasons. In 2017, there is a notable contrast in tomato output between summer and winter, whereas, in 2018, the disparity between summer and winter production was negligible. This pattern has persisted in recent years, exemplified in 2022, where tomato yields remain at approximately 300,000 tons per dunum during both summer and winter seasons.

The idea of virtual water is crucial to tomato production and foreign trade in Jordan, where water shortage is a serious problem. Water is necessary for production even if it may not be physically present in the final product.

Therefore, virtual water symbolizes the amount of water used in the manufacturing process and the transportation of goods. Importing tomatoes rather than growing them locally can help conserve water resources because tomato growth requires a lot of water. This idea is especially applicable to Jordan, where sustainable agriculture faces difficulties due to water shortage. Policymakers can effectively utilize scarce water resources to meet the nation's food needs by making informed judgments about agricultural trade dynamics and food security laws by having a thorough understanding of virtual water (FAO, 2012).

Water Footprint:

The water footprint is a crucial metric for assessing the impact of production on water resources, categorizing water usage into grey, green, and blue footprints. The blue footprint measures freshwater consumption in goods and services production, excluding crop irrigation methods. However, a favorable blue water footprint doesn't universally signify sustainability due to factors like inadequate irrigation resources (Herath, et al., 2014). The green footprint represents changes in soil moisture during agricultural production, emphasizing the reliance on natural rainfall. Finally, the grey footprint quantifies water pollution, considering pollutant loads and adhering to water quality standards. These three footprints collectively offer a comprehensive view of water management practices and environmental impacts, guiding strategies for sustainable water use (Herath, et al., 2014; Ansorge, et al., 2022; Ene & Teodosiu, 2011).

The water footprint is crucial for assessing water quality, overall availability, and facilitating spatial and temporal identification. Integrating water quality in the assessment framework is crucial to quantifying changes in usability (Ansorge, et al., 2022). The availability footprint, considering both quantitative and qualitative aspects, determines whether water meets specific needs. Proposing a water quality index aids in assessing consumptive water use and quality exploitation (Nouri, et al., 2019).

Elevated temperatures increase evaporation, potentially reducing water availability. Temperature and precipitation shifts influence agricultural productivity, a key water footprint factor. Recognizing the intricate climate change-water resources relationship is vital for comprehending the impacts on footprints and implementing adaptive strategies across sectors (ElFetyany, et al., 2021).

The objective of this study is to determine the average water footprint for tomatoes in Jordan across both summer and winter seasons from 1994 to 2023.

A comprehensive understanding of the water footprint and its correlation with water quality is pivotal for sustainable water management (Jia, et al., 2019). Some water footprint methods face criticism for limiting meaningful comparisons among products from regions with varying water-resource availability. Measurement challenges include assessing soil water content, drainage, and nitrate concentrations (Cucek, et al., 2012). To enhance comparisons and address environmental impacts, alternative methods and increased data collection are needed. Efforts to refine water footprint measurement techniques are ongoing for accuracy and relevance across diverse contexts (Herath, et al., 2014). Certain greywater footprint calculation methods overlook natural self-purification processes, potentially leading to inaccurate sustainability assessments. Moreover, the greywater footprint neglects the impact of additional pollutant sources in the river basin, resulting in an actual water footprint higher than calculated. These limitations highlight the need for improvements in the greywater footprint methodology, incorporating natural purification processes and considering a broader range of environmental factors for a thorough and precise evaluation of water use sustainability (Ansorge, et al., 2022).

Review of Literature:

The purpose of this analysis of the literature is to investigate the strategies that are frequently used to evaluate the water footprint of tomatoes in Jordan and worldwide, in comparison to assessments of other crops that are comparable. Furthermore, this review aims to clarify the difficulties and constraints associated with precisely identifying the different elements of tomatoes' water footprint, with a special emphasis on the grey water footprint. This investigation is important because it offers a comparative framework for analyzing tomatoes' water footprint, which will help farmers make better decisions about their farming methods. We want to determine the current state of tomato water footprints in Jordan and globally by reviewing the literature and assessing how this information might guide decisions related to agriculture, society, and the environment. The main objective of this review is to advance knowledge about the implications of tomato water footprints and how they influence sustainable farming methods. The literature search strategy primarily targets studies investigating the water footprint of various crops, including tomatoes, across different geographic regions. These studies typically delve into the assessment of green, blue, and grey water footprints, elucidating methodologies employed, outcomes obtained, data disparities, and methodological challenges encountered during data acquisition. The consensus among researchers underscores challenges inherent in data collection processes, particularly regarding the accuracy of inputs such as sunshine data, fertilizer usage and self-purification processes (Ansorge, et al., 2022), soil characteristics, and agricultural practices (Deepa, et al., 2021). Research endeavors focus on scrutinizing and interpreting green, blue, and grey water footprints, utilizing meteorological parameters like humidity, temperature, and precipitation. Notably, emphasis is placed on exploring the water footprint of tomatoes and its implications for optimal water resource management. Understanding the hydrological ramifications and associated challenges of water inflow and outflow modeling is pivotal in informing decisions regarding sustainable agricultural practices.

The assessment of water footprints across various countries reveals significant disparities in water usage and availability. In Egypt, for the period 2012-2016, the national water footprint averaged 111.05 billion m3, surpassing the available water resources of 75.66 billion m3, resulting in a substantial water deficit. This underscores the urgent need for comprehensive analyses to inform effective water management policies, particularly amidst potential climate change impacts affecting temperature, precipitation patterns, and agricultural productivity (ElFetyany, et al., 2021). Similarly, in Saudi Arabia, the water footprint of tomato production is significant, with green, blue, and grey water footprints totaling 469 m3/ton, considerably higher than the global averages reported by WaterStat (Multsch, et al., 2013). Meanwhile, in Rhode Island, the average water footprints from 2000-2014 indicate varying patterns, with the blue water footprint notably higher than green and grey footprints, suggesting diverse regional water usage dynamics. These findings underscore the importance of considering geographical and seasonal variations in water footprints worldwide, necessitating tailored approaches to sustainable water resource management and agricultural practices across different regions (Symeonidou & Vagiona, 2019).

Research about quantifying and reducing the water footprint of rain-fed potatoes in New Zealand investigates the water footprint associated with rain-fed potato production, focusing on quantification and mitigation strategies. Through a combination of field measurements and mechanistic modeling, the study evaluates the blue water footprint (groundwater use), green water footprint (soil-water store use), and grey water footprint (water required to dilute NO3-N in drainage) of potato cultivation. Results indicate minimal impacts on water quantity, with the green water footprint deemed negligible and the blue water footprint even showing a negative value, suggesting no detrimental effects on water quantity. However, the grey water footprint, primarily originating from the cropping stage, is identified as a potential concern due to leached NO3-N concentrations. Various fertilizer application scenarios are modeled, illustrating potential reductions in nitrate concentrations and the grey water footprint. The study underscores the necessity of considering both water quantity and quality aspects in assessing the water footprint of agricultural systems. Challenges include the reliance on assumptions and approximations in water footprint calculations, as well as the difficulty in capturing temporal variability in water and nutrient dynamics influenced by weather conditions. Integrating field measurements with modeling approaches is recommended to improve the accuracy of long-term water footprint estimations (Herath, et al., 2014).

El-Marsafawy and Mohamed (2021) conducted a comprehensive investigation into the water footprint (WF) of Egyptian crops, analyzing diverse regions and comparing footprints with the global average. The study included an economic analysis, emphasizing green and blue WF components. Results showed modest green water contribution to Egyptian crop WF compared to blue water. The average total WF was around 680 m3/ton, deviating from the global average. Economic analysis revealed varying net returns for specific crops, with higher returns for crops like pepper and eggplant. Using the CropWat model, the study enhanced understanding of the relationship between water usage and economic returns, emphasizing the need for a comprehensive water footprint evaluation in guiding sustainable water management practices in Egypt's agriculture (El-Marsafawy & Mohamed, 2021).

Methods:

The primary focus of this study revolves around investigating key indicators, specifically the water footprint associated with tomato cultivation in Jordan. The calculation of the water footprint of crop production in this study adheres to the guidelines outlined in the water footprint assessment manual by Hoekstra et al. (2011) and employs the CROPWAT model. The selection of this methodology is grounded in its widespread adoption as a standalone approach, providing comprehensive volumetric water footprints. This approach considers the three components of water volume (blue, green, and grey), offering valuable insights for effective water resources management.

Data Collection:

The climate data required as input for the CROPWAT 8.0 model (FAO, 2024) covering the period from 1994 to 2023 was sourced from NASA POWER. This dataset encompasses measurements obtained from three meteorological stations in Jordan, namely Baquora, Deir Alla, and Ghour AlSafi. The collected data serves as crucial input for the model to accurately calculate crop water requirements and irrigation needs. Simultaneously, the study incorporates production data for tomatoes illustrating the yield in tons per hectare. This combination of climate and production data forms the foundation for a comprehensive analysis of the water footprint associated with tomato cultivation in the specified region over the specified timeframe, scince tomato is the
Crop yield is the output from a specific land area or crop, a key metric for productivity. Typically expressed per unit area, it provides insights into annual production, accounting for variations in growth stages (Duarte, et al., 2014). In assessing a crop's water footprint, yield is crucial, especially in calculating the grey component. This component considers variables like chemical application rate, leaching-runoff, maximum concentration, and pollutant levels (Jia, et al., 2019).
Initially, raw climate data (maximum and minimum temperature, relative humidity, wind speed, and sunshine) were converted into monthly averages and further transformed in Microsoft Excel 365. Long-term average climate data for each station were input into the CROPWAT 8.0 model under the "$Climate/ET_0$" icon. Reference evapotranspiration (ET_0) was calculated using

the FAO 56 Penman-Monteith method within the software, as presented in Equation (1) (Allen, et al., 1998)

$$ET_o=\frac{0.408\Delta(R_n\text{-}G)+\gamma\frac{900}{T+273}u_2(e_s\text{-}e_a)}{\Delta+\gamma(1+0.34u_2)}$$

Equation (1)

Where:
ET_o = reference evapotranspiration, (mm/day).
R_n = net radiation at the crop surface, $(MJ/m^2/day)$.
G = soil heat flux density, $(MJ/m^2/day)$.
γ = psychometric constant, (kPa/°C).
T = mean daily air temperature at 2 m height, (°C).
u_2 = wind speed at 2 m height, (m/s).
e_s = saturation vapor pressure, (kPa), and e_a = actual vapor pressure, (kPa).
$(e_s – e_a)$ = saturation vapor pressure deficit, (kPa).
Δ = slope vapor pressure curve, (kPa/°C).

The estimation of actual crop evapotranspiration (ET_c) is achieved by multiplying the crop coefficient (K_c) with the reference evapotranspiration (ET_c). Equation (2) succinctly presents the mathematical representation of the actual crop evapotranspiration.

$$ET_c= K_c* ET_o$$

Equation (2)

where:
ET_c = actual crop evapotranspiration, (mm/day).
K_c= crop coefficient.
The K_c values are obtained from FAO database for both crops.

The rainfall data for each station was incorporated into the software under the "Rain" icon within the module bar. This data serves the purpose of calculating effective rainfall (mm), representing the portion of rainfall stored in the soil profile that aids in crop growth. The calculation employs the USDA Soil Conservation Service method, a default option recommended by FAO. The CROPWAT model facilitates the computation of effective rainfall using the USDA Soil Conservation Service. Collected samples for the three stations of the Average Monthly Climate Data during the period (1990-2023), which will be presented in a table showcasing detailed information.

Crops and Crops Parameters:

The current investigation is focused on major field crops, with a specific emphasis on wheat and barley. The "Crop" module, accessible through the corresponding icon in the module bar, facilitates the selection of crop-related data. Opening the data window defaults to the non-rice crop data type, such as vegetables and such. Crop coefficient (K_c) values for wheat and barley were sourced from the FAO database embedded within the CROPWAT 8.0 model. These K_c values encompass information related to various development stages (initial, development, mid-season, and late season), rooting depth (m), correct depletion (fraction), yield response factor, and crop height (m). The duration of each growth stage, set at 180 days for both crops, was obtained from the FAO crop calendar of Jordan. Planting and harvesting dates aligned with the FAO crop calendar of Jordan were also incorporated into the study.

Soil Parameters:

Choosing the "Soil" module is done by selecting the respective icon in the module bar. The soil parameters are sourced from the FAO database, considering soil type. The CROPWAT 8.0 model incorporates comprehensive soil information, encompassing total available soil moisture (mm/m), maximum rain infiltration rate (mm/day), maximum rooting depth (cm), and initial soil moisture depletion (as % TAM) for determining initially available soil moisture (mm/m). As per the findings of Jacobs (2016), loam soil is identified as optimal for the cultivation of wheat and barley crops.
To compute the rates of green and blue evapotranspiration (ET), the software provides two options: the crop water requirement option and the crop irrigation schedule option.

Crop Water Requirement Option (CWR):

The Crop Water Requirement (CWR) module can be accessed by selecting the "CWR" the icon in the module bar, requiring "$Climate/ET_0$", rain, crop, and soil data. Crop water requirement (CWR, mm) represents the necessary water amount for crop growth, influenced by factors like crop coefficient (K_c) and reference crop evapotranspiration (ET_c, mm), both sensitive to climate variables (temperature, humidity, wind speed, and sunshine). CWR is calculated using equation (2), equivalent to actual crop evapotranspiration (ET_c, mm) under ideal, unrestricted water conditions, as expressed in equation (5) (Allen, et al., 1998).

$$CWR=K_c*ET_o=ET_c$$

Equation (5)

The Green evapotranspiration (ET_{green}) is determined by either the effective rain (P_{eff}) or ET_c,. If P_{eff} surpasses ET_c,, ET_{green}, equals the ET_c, value since crops don't utilize more than ideal growth requires. If P_{eff} is less than ET_c,, ET_{green}, becomes the total effective rain. The computation for ET_{green}, is detailed in equations (6):

$$ET_{green} = \min (ET_c , P_{eff})$$

Equation (6)

The Blue evapotranspiration (ET_{blue}), also termed irrigation requirement (IR), is the disparity between ET_c and P_{eff}. When P_{eff} exceeds ET_c, ET_{blue} is zero, signifying no need for irrigation. In cases where effective rain doesn't fulfil the entire Crop Water Requirement (CWR), ET_{blue} becomes the difference between them. The computation for ET_{blue} is outlined in equations (7):

$$ET_{blue} = \max (0, (ET_c\text{- } P_{eff}))$$

Equation (7)

The Schedule module is accessible through the "Schedule" icon in the module bar, necessitating data on "$Climate/ET_o$", rainfall, crop, and soil. This module conducts calculations, generating a daily soil water balance. Two scenarios are considered:

1. **Rain-fed Condition:** Simulates a scenario without irrigation. Here, green water evapotranspiration (ET_{green}) equals total evapotranspiration (ET_a), with blue water evapotranspiration (ET_{blue}) set to zero.

2. **Irrigated Condition:** Simulating irrigated conditions involves specifying the crop's irrigation method. The total water evapotranspiration (ET_a) throughout the growing period aligns with the term 'actual water use by crop' in the model output.

ET_{blue} equals the minimum of 'total net irrigation' and 'actual irrigation requirement' from the model output. The computation for ET_{blue} is outlined in equations (8):

$$\mathrm{ET_{blue}} = \text{min (total net irrigation, actual irrigation requirement)}$$

Equation (8)

ET_{green} equals the total water evapotranspiration (ET_a) minus the blue water evapotranspiration (ET_{blue}) as simulated in the irrigation scenario. The calculation of ET_{green} is demonstrated in equations (9):

$$\mathrm{ET_{green}} = \text{Actual water uses by crop } (\mathrm{ET_a}) - \mathrm{ET_{blue}}$$

Equation (9)

Crop Water Use (CWU):

Determining the green and blue components of crop water use (CWU) involves obtaining the green and blue evapotranspiration rates specific to the analyzed crop.

The quantity of green crop water use (CWU_{green}, m^3/ha) indicates the volume of rainwater utilized by the crop during evapotranspiration. This is computed by summing the daily green evapotranspiration (ET_{green}, mm/day) across the complete growth duration of the crop and subsequently converting the outcome into water volume in m^3/ha using a factor of 10. The accumulation is conducted by progressing time in 10-day intervals throughout the entire crop growth period, as outlined in equation (10):

$$\mathrm{CWU_{green}} = 10 \times \sum_{d=1}^{Igp} \mathrm{ET_{green}}$$

Equation (10)

The blue component of CWU (CWU_{blue}, m^3/ha) represents the irrigation water needed for crop growth, encompassing both ground and surface water. The computation of this quantity is elucidated in equation (11).

$$\mathrm{CWU_{blue}} = 10 \times \sum_{d=1}^{Igp} \mathrm{ET_{blue}}$$

Equation (11)

Water Footprint Calculations:

The total footprint (WF_{proc}) of the process of growing tomatoes (crops in general) is the sum of the blue, green, and gray water footprint using the Penman-Monteith equation (Allen, et al., 1998).

$$\mathrm{WF} = \mathrm{WF_{green}} + \mathrm{WF_{blue}} + \mathrm{WF_{gray}}$$

Equation (12)

Estimating the green and blue water footprint requires green and blue CWU rates of the studied crop.

1) Green Water Footprint

The WF_{green} is calculated by dividing the green crop water use (CWU, m^3/ha) by the crop yield (Y, ton/ha), as shown in equation (13).

$$\mathrm{WF_{green}} = \frac{\mathrm{CWU_{green}}}{\mathrm{Y}}$$

Equation (13)

Crop yield is obtained from DOS of both crops for the period (1994-2022).

2) Blue Water Footprint

The WF_{blue} is calculated by dividing the CWU_{blue} (m^3/ha) by the crop yield (Y, ton/ha), as shown in equation (14).

$$\mathrm{WF_{blue}} = \frac{\mathrm{CWU_{blue}}}{\mathrm{Y}}$$

Equation (14)

Tomato crop yield is obtained from DOS for the period (1994-2022).

	Winter								
	ET green	ET blue	CWU green	CWU blue	Yield	WF green	WF blue	WF grey	WF Total
	mm/growing period		m^3/ha		ton/ha	m^3/ton			
Baqoura	4.9	719.8	49	7198	1.00415	48.79	7168.21	0.615	7217.62
Deir Alla	3.7	913.7	37	9137	1.09	34.26	8382.57	0.6	8417.43
Ghour Alsafi	3.7	938.4	37	9384	0.67	41.07	11805.36	1.1	11847.53

Table 1 Data found for the stations during Winter 1994-2023

As previously indicated, around 23% of the overall vegetation area is dedicated to tomatoes, with an average of 90% of this area being rainfed from 1994 to 2023.

3) Gray Water Footprint

The amount of water required to mitigate the concentration of the critical pollutant to permissible levels is deemed adequate to dilute other pollutants. As per the water footprint assessment manual by Hoekstra et al. (2011), equation (15) can be applied to calculate the grey water footprint.

$$\mathrm{WF_{grey}} = \frac{(\alpha \times \mathrm{AR})/(\mathrm{c_{max}} - \mathrm{c_{nat}})}{\mathrm{Y}}$$

Equation (15)

Where:
WF_{grey}= grey water footprint, (m^3/ton).

	Summer								
	ET green	ET blue	CWU green	CWU blue	Y	WF green	WF blue	WF grey	WF Total
	mm/growing period		m^3/ha		ton/ha	m^3/ton			
Baqoura	2.5	510.2	25	5102	1.65	15.15	3092.12	0.4	3107.67
Deir Alla	3.4	647.4	34	6474	1.08	31.48	5994.44	0.6	6026.53
Ghour Alsafi	2.3	661.1	23	6611	0.56	55.22	14005.97	0.92	14062.11

Table 2 Data found for the stations during Summer 1994-2023

AR = chemical application rate to the field per hectare, (kg/ha).
α = nitrogen leaching-run-off fraction.
c_{max} = maximum acceptable concentration of the pollutant per unit volume of water, (kg/m^3).
c_{nat} = natural concentration for the pollutant considered per unit volume of water, (kg/m^3).
Y = crop yield, (ton/ha).

RESULTS AND DISCUSSION:

Climate change significantly impacts water footprints in agriculture, affecting irrigation water availability. Altered rainfall and temperatures may raise water use, impacting crop water footprints, such as tomatoes. Understanding these patterns and implementing resilient measures necessitate recognizing the climate change-water footprint link (Maureira, et al., 2022).

This study highlights areas for development in long-term strategies for water management while offering insights into the efficiency of water consumption.

In-depth knowledge of the water footprint and an evaluation of the sustainability of resource use are necessary to address the region's broader issues with water scarcity (Hoekstra, et al., 2011). This section provides an in-depth exploration of the study's findings. For clarity, the data gathered for the Water Footprint (WF) has been organized in tables and depicted graphically across various figures.

The planting schedule involved sowing on the 15th of August for the summer season and the first of February for winter across all stations. The yield results show variations, with Baqoura, Deir Alla, and Ghour Alsafi stations producing 1.00415, 1.09, and 0.67 ton/ha, respectively. The evapotranspiration (ET) values exhibit differences, with Baqoura at 4.9 mm/growing period, and both Deir Alla and Ghour Alsafi at 3.7 mm/growing period for ET green. Similarly, ET blue varies, with Deir Alla and Ghour Alsafi close at 913.7 and 938.4 mm/growing period, while Baqoura is at 719.8 mm/growing period. Crop water use (CWU) for both green and blue is determined by multiplying ET by 10.

During the summer, the green water footprint ranges from 15.15 m^3/ton for Baqoura to 55.22 m^3/ton for Ghour Alsafi, while the blue water footprint is significantly higher at 3,092.12 m^3/ton for Baqoura, 5,994.44 m^3/ton for Deir Alla, and 14,005.97 m^3/ton for Ghour Alsafi. The blue water footprint notably surpasses both the green and grey water footprints, emphasizing the substantial impact of irrigation on the overall water footprint in these agricultural regions. These findings underscore the critical role of irrigation practices in influencing water consumption patterns and the associated environmental footprint.

The grey water footprint calculation for tomatoes in Jordan involves using Urea as the nitrogen source, with a nitrogen content of 123 kg/ha obtained from the FAO crop calendar. Assuming a 10% leaching fraction, consistent with Hoekstra et al. (2011) for Jordan, this method considers the Jordanian irrigation water quality guideline (2014), specifying a 30 mg/L threshold for nitrogen as nitrate ($N\text{-}NO_3$) and an assumed natural concentration of 10 mg/L.

This component, crucial for dilution water, accounts for nitrogen fertilizer use due to its significance as a major pollutant with high application rate (Hoekstra, et al., 2008).

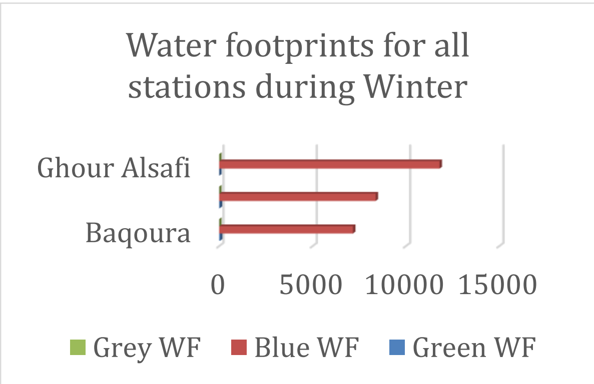


Figure 4 the water footprints are measured in m^3/ton

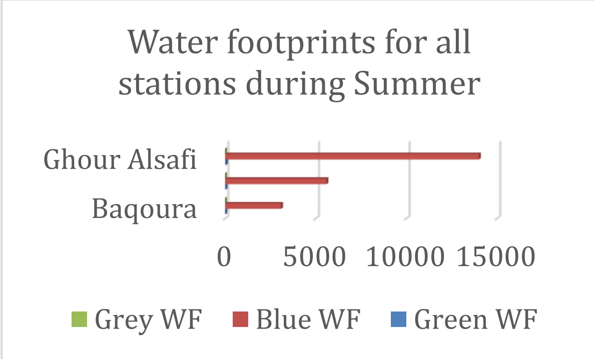


Figure 5 the water footprints are measured in m^3/ton

The contrast between the blue water footprint and the combined green and grey water footprints is evident in these data across all three stations throughout both summer and winter seasons. Additionally, the figures reveal that the blue water footprint at the Ghour Alsafi station is elevated during summer compared to winter, contrary to the expected seasonal pattern where it typically rises during winter

The application ratio (AR) assessments were tailored to the specific farming practices observed in proximity to the study stations. Farmers in the area traditionally applied 4 bags of 50 kg each, totaling 800 kg of urea fertilizer. The nitrogen content in urea fertilizers is 46%, resulting in 368 kg of nitrogen for the total application (Allen, et al., 1998). Considering the cultivated area of 30 dunum

AR	α	c_{max}	c_{nat}	Y	WF_{grey}
kg/ha		mg/L		ton/ha	m^3/ton
123	10%	30	10	1.0041	0.615

Table 3: A sample of grey WF calculations of the Baqoura station for 2023 during the winter

(3 ha), the nitrogen application per dunum was calculated as 368 kg/30 dunum, equating to 123 kg/ha. This nitrogen application rate per hectare is crucial for evaluating potential agricultural risks and optimizing fertilizer management strategies in alignment with local farming practices. The assessment accounts for nitrogen's essential role in crop development and its potential environmental impact, offering insights into sustainable agricultural practices in the study region.

CROPWAT option	WF_{green}	WF_{blue}	WF_{grey}	WF_{total}
	m^3/ton			
Baqoura	15.15	3092.12	0.4	3107.67
Deir Alla	31.48	5994.44	0.6	6026.53
Ghour Alsafi	55.22	14005.97	0.92	14062.11

Table 4: Total WF of Baqoura station in 2023
Source: Researcher's work

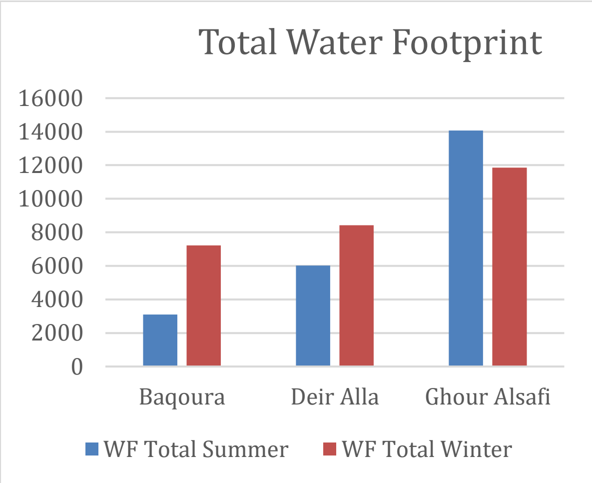


Figure 6 Total WF for all three Stations during both Summer and Winter (1994-2023)

The Department of Statistics only had data on the cultivated area and tomato yields. Consequently, data for the year 2023 pertaining to these parameters were directly obtained from field-level farmers, ensuring the accuracy and reliability of the information incorporated into the study. This approach guarantees a more precise representation of on-the-ground agricultural practices, essential for robust scientific analysis and interpretation.

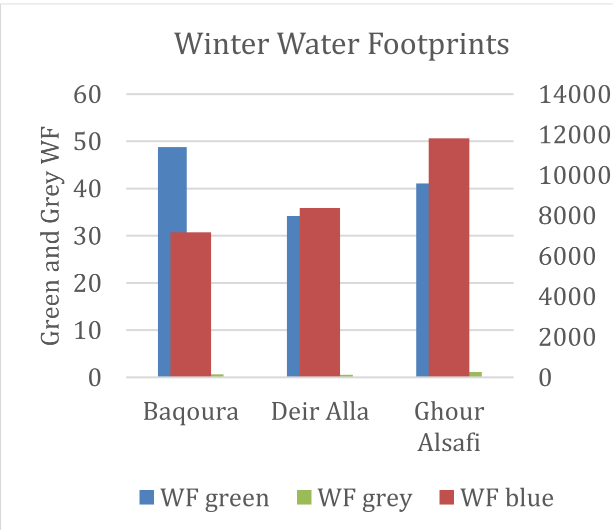


Figure 5: Winter WF (1994-2023)

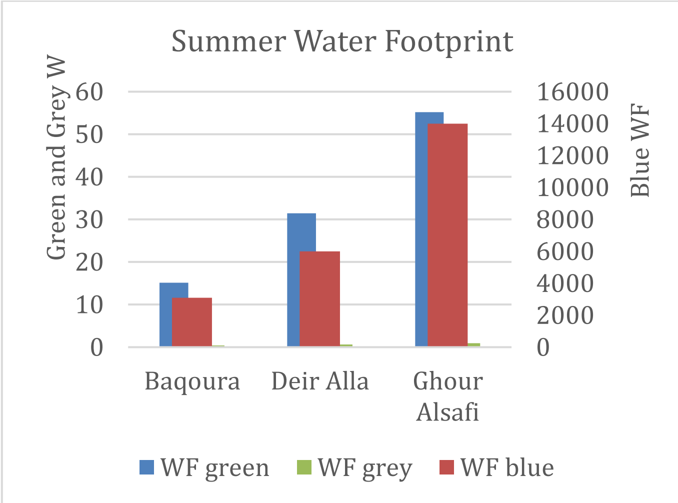
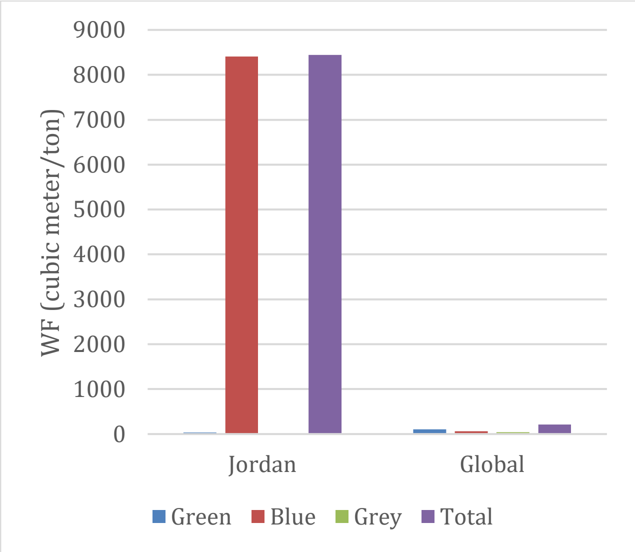


Figure 6: Summer WF (1994-2023)

The comparison between winter and summer seasons reveals intriguing trends in water footprint dynamics across the studied stations. As anticipated, Baqoura and Deir Alla stations exhibited higher green, blue and grey water footprints during the winter than in summer, aligning with expectations due to seasonal variations in precipitation and irrigation demand. Conversely, the Ghour Alsafi station presented an unconventional pattern, with the summer green and blue water footprints surpassing those of winter. Consequently, the total water footprint for Ghour Alsafi was notably higher in summer than in winter, suggesting unique environmental conditions or agricultural practices influencing water usage patterns in this region. These findings underscore the complexity of water resource management and highlight the importance of considering seasonal variations in agricultural water footprints for effective policy formulation and resource allocation strategies.

The discrepancy between water footprints for tomatoes in Jordan and the global average raises questions about underlying factors contributing to these variations. The global water footprint data utilized in this analysis was sourced from a study conducted by Mekonnon and Heikstra, encompassing records solely from the period spanning 1996 to 2005 (Mekonnen & Hoekstra, 2011). The notably lower green water footprint in Jordan compared to the global average could be attributed to differences in agricultural practices, irrigation methods, and climatic conditions. Similarly, the significantly higher blue water footprint in Jordan suggests greater reliance on irrigation and possibly less efficient water management practices. The discrepancy in grey water footprint values may stem from differences in fertilizer usage, soil characteristics, and pollution control measures between Jordan and the global dataset. Exploring recent global water footprint data on tomatoes could provide further insights into temporal trends and variations, aiding in a more comprehensive understanding of water usage patterns and informing strategies for sustainable agricultural water management



CONCLUSION

This study is aimed at elucidating the water demands and associated water footprint essential for optimizing tomato plant productivity. Furthermore, it endeavors to delineate the seasonal fluctuations in water requirements, building upon prior findings. It is noteworthy that Jordan boasts a reputation for producing superior-quality tomatoes, with significant quantities exported internationally. As reported by the Jordanian Department of Statistics, the self-sufficiency ratio for tomatoes surged to 150% of the total tomato yield, with exports totaling 204,482.9 tons, primarily directed towards neighboring countries.

The water footprint production is green water footprint si 493 Mm^3/yr, blue water footprint is 406 Mn3/yr and the grey is 54 Mm^3/yr. on the other hand the virtual water related to import crop production is: the green water is 4409 Mm^3/yr, the blue water is 812 Mm^3/yr and the grey water is 541.8 Mm3/yr and the export is green:364, blue:200 and grey is 62.2 Mm3/yr. this data is from years 1996-2005. (Mekonnen & Hoekstra, 2011). Despite this data dating back to 2005, it is apparent that

The comparison between virtual water and water footprint values reveals distinct applications and implications. Virtual water, at 140 m^3/ton in Aqaba and 111.1 m^3/ton in Mafraq for the specified year, signifies the volume of water embedded in the production of a commodity, providing insight into water usage efficiency during production and trade (Abu-Sharar & Al-Karablieh, 2012). Conversely, the average water footprint of 8446.48 m^3/ton across various regions and seasons in Jordan reflects the total volume of water utilized throughout the entire production process, encompassing both direct and indirect water consumption. While virtual water focuses on trade implications and water efficiency, the water footprint offers a comprehensive assessment of water consumption, aiding in sustainable resource management and policy formulation. The disparity between these values underscores the diverse water management strategies and environmental conditions across different regions and seasons within Jordan.

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