Water and Food Security Project

The Water Crisis in Egypt: Evaluating Food Security, Water Use, and Future Solutions in Zagazig

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Abstract

The issue of water scarcity has become increasingly urgent in Egypt, driven by rapid population growth, economic challenges, and the intensifying effects of climate variability. This research explores Egypt's water crisis, contrasting the nation's water resources with global trends using international data from AQUASTAT and national statistics from the Central Agency for Public Mobilization and Statistics (CAPMAS). Focusing on the agricultural region of Zagazig, the study investigates the current and projected effects of water shortages on food security. It incorporates nearly two decades of weather data and conducts water balance analyses for key crops to assess the consequences of dwindling water supplies on agricultural production. Additionally, the study examines the interplay between demographic and economic trends, evaluating how shifts in population and economic activities influence the demand for water and food.

The research also critically reviews historical and present-day water management practices, identifying inefficiencies such as outdated irrigation techniques and water-heavy agricultural practices that have contributed to the worsening crisis. As part of the search for sustainable solutions, the study evaluates the potential for water reuse by assessing the volume of treated wastewater in Zagazig and its potential to supplement irrigation needs. Through the application of advanced statistical techniques, water balance modelling, and policy analysis, this research provides a comprehensive understanding of the water scarcity dilemma in Egypt, its far-reaching effects on food security, and the pathways for more efficient and sustainable water management strategies.

Keywords: Water scarcity, Egypt, agricultural water use, food security, climate variability, water balance, irrigation practices, treated wastewater, water reuse, economic growth, population dynamics, sustainability, CAPMAS, AQUASTAT.

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1 Introduction

“The world is running out of water,” the United Nations Development Program’s Human Development Reports describe the situation, noting that the world’s freshwater resources, especially in the Middle East and North Africa, are rapidly dwindling (Kevin Watkins, 2006). According to the United Nations Environment Program (UNEP), water resources will not be able to meet the increasing demands on them in the coming decades. As a result, the massive water shortage will be a barrier to development in many parts of the world. Also, as global demand for water increases, groundwater levels are falling in dozens of countries, including China, India, and the United States, which produce nearly half of the world’s grain crops, threatening a global food crisis and threatening global food security (Mishra Arabinda, 2005), which threatens a global food crisis and threatens global food security. Water plays a key role in the economy, as most industries depend on it; water scarcity drives more migration and job losses and destabilizes, leading to fear that it could lead to violent conflicts or so-called water wars. The prevailing issue of water is cooperation, not conflict, as by 2003, 145 treaties had been signed in this century and more than 3,600 treaties historically on various aspects related to water worldwide (Aaron T. Wolf, 2003).

Water security is a pivotal challenge to the development and stability of the Egyptian state. It is a challenge that raises a degree of interest that goes beyond the water sector to other economic sectors; this is considering the insufficiency of available water resources to meet the needs of Egyptian citizens, which are steadily increasing, which may lead to the outbreak of economic and social crises or regional political, economic, and perhaps military conflicts over this limited resource.

Considering the rapid development witnessed by the socio-economic, environmental, and political context in Egypt, which is characterized by high population growth rates of about 1.5% in 2023 (World Bank, no date), Egypt is expected to witness a population increase of sixty million people in 2050. The poorest or conflict-ridden countries often tend to have faster population growth, which comes with increased water consumption, coupled with inefficient water management by policymakers and decision-makers, which may lead to the depletion of water resources, especially groundwater, at an unprecedented rate.

1.1 Water scarcity around the world

Nearly one-fifth of the global population (1.2 billion) reside in physically scarce places, and 500 million more are on the verge of doing so. Nearly 25% of the world's population, or another 1.6 billion people, suffer from economic water shortages, which occur when nations lack the infrastructure needed to extract water from aquifers and rivers. Water scientists often evaluate security by examining the relationship between population and water availability. When annual water supplies drop below 1,700 cubic meters per person, the region is recognized as experiencing water stress. When supplies fall below 1,000 cubic meters per person annually, the population faces water scarcity, and at less than 500 cubic meters per person, the region is classified as experiencing absolute scarcity.

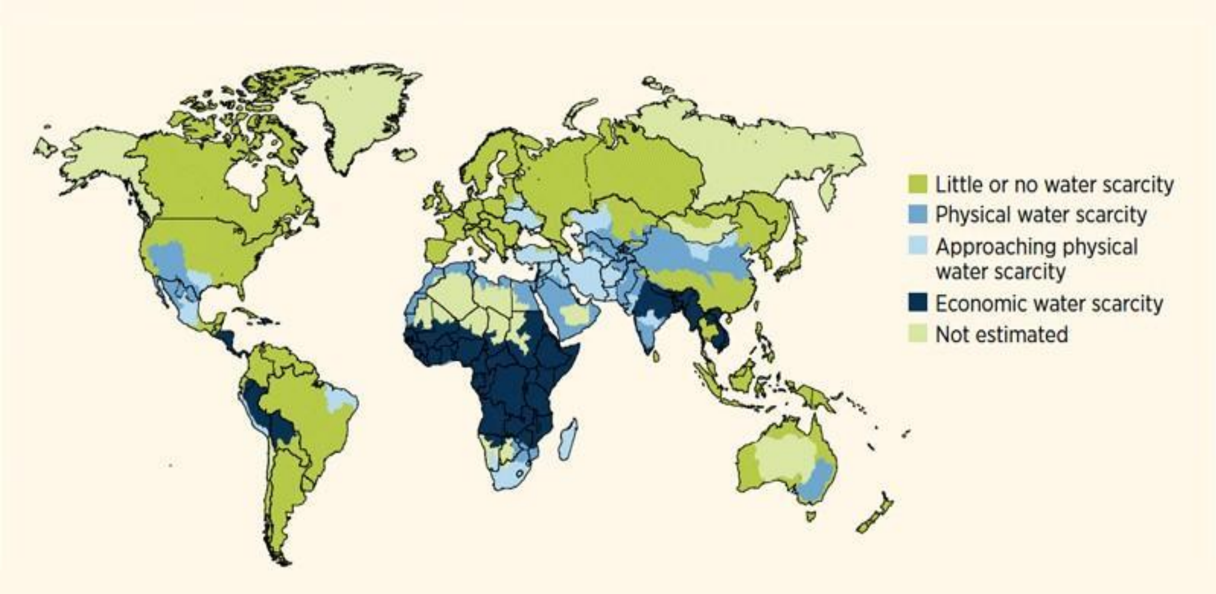

Figure 1 Global physical and economic water scarcity
Source: World Water Development Report 4. World Water Assessment Programme (WWAP), March 2012

1.2 Water situation in Egypt

The Nile River is the longest in the world, at 6,650 km long. The Nile River has two main branches, the White Nile and the Blue Nile. The White Nile originates from Victoria Lake, and the Blue Nile originates from Ethiopia, and it represents 60-70% of Sudan and Egypt's water. In Egypt, the Nile River is a major strategic source of fresh water, accounting for an estimated 55.5 billion cubic meters of its total water resources of 60 billion cubic meters (Al-Masry Al-Youm, 2024). It provides 93% of its water resources; other sources of water in Egypt contribute varying and small proportions compared to the Nile water, including rainwater and groundwater available in the Delta, the Western Desert, and Sinai, which are generally considered non-renewable and threatened by pollution.

Egypt currently faces a net deficit of 28.4 billion cubic meters per year (according to the author's calculations). The annual per capita water supply has deteriorated from 2,000 cubic meters in 1959 to 560 cubic meters in 2021. Over the past 60 years, Egypt's per capita share of water has significantly declined by approximately 1,500 cubic meters due to rapid population growth. In 1959, with a population of 20 million, the water quota of 55.5 billion cubic meters was provided with a per capita share exceeding 2,000 cubic meters annually. Currently, however, this figure has dropped to less than 600 cubic meters per year, well below the United Nations-defined water poverty line of 1,000 cubic meters annually and nearing the threshold for severe water scarcity at 500 cubic meters per person. Egypt faces an annual water deficit of about 20 billion cubic meters, despite utilizing a total of 76 billion cubic meters from various sources. This includes 55.5 billion cubic meters from the Nile, 6 billion cubic meters from rainfall and groundwater and 12 billion cubic meters from reused water (CAPMAS). The average per capita share of water is expected to reach 330 cubic meters annually in 2050 (MWRI).

1.3 The Impact of GERD on Egypt's water situation

In Ethiopia, for 4.8 billion dollars and a height of 5.84 meters, the Ethiopian government began building the Grand Ethiopian Renaissance Dam in April 2022, on the Blue Nile. The start of the storage years in the Renaissance Dam will lead to a decrease in Egypt's share of water by a percentage ranging from 9 to 12 billion cubic meters annually (SISEGY). This will contribute to Egypt losing about 3 million acres of agricultural land and displacing 5 to 6 million farmers.

Figure 1 Map of the Nile River Basin that flows and the location of GERD.

1.4 Objectives of the Study

This study aims to analyse the water balance for two major crops in Zagazig, maize and wheat. It aims to evaluate the crop water requirements for the last two decades, utilizing satellite-based data and historical climate records over two decades. It seeks to quantify the extent to which treated water can contribute to irrigation and highlight the gap between available water resources and agricultural demands. A comparative analysis among different years with different weather data for the same crops would provide a foundation for understanding the existing situation, thereby informing the course of action in the future with regionally and culturally appropriate solutions.

2 Methodology

To calculate the water balance for crops, we utilized historical weather data from NASA POWER's Data Access Viewer. The platform provides high-resolution, satellite-derived data optimized for energy and climate research. We retrieved daily weather data for the study region over 20 years. Although we initially sought field data from Egypt, it was unavailable. In practice, conducting such daily field measurements over two decades would be highly challenging and resource-intensive, underscoring the value of satellite-based datasets for long-term analyses.

2.1 Study Area

Zagazig city is the capital of Al-Sharqia Governorate, located in the eastern Nile Delta. Zagazig is considered one of the largest cities in Lower Egypt and is located on the Mois Canal (Mois Sea) and Ismailia Canal. The total area of Zagazig spans 273.4 square kilometres, with a population of approximately 940,672 (CAPMAS). The region is renowned for its significant agricultural activities, particularly in the surrounding and affiliated areas. This agricultural prominence is deeply tied to the fertile natural environment of the Nile Delta, which provides ideal conditions for cultivation. Of the total area, an impressive 21,637.56 hectares are actively cultivated (Abdallah, 2016). The agricultural sector in Zagazig exclusively relies on Nile water as its primary irrigation source, underscoring its dependence on this vital resource for sustaining crop production.

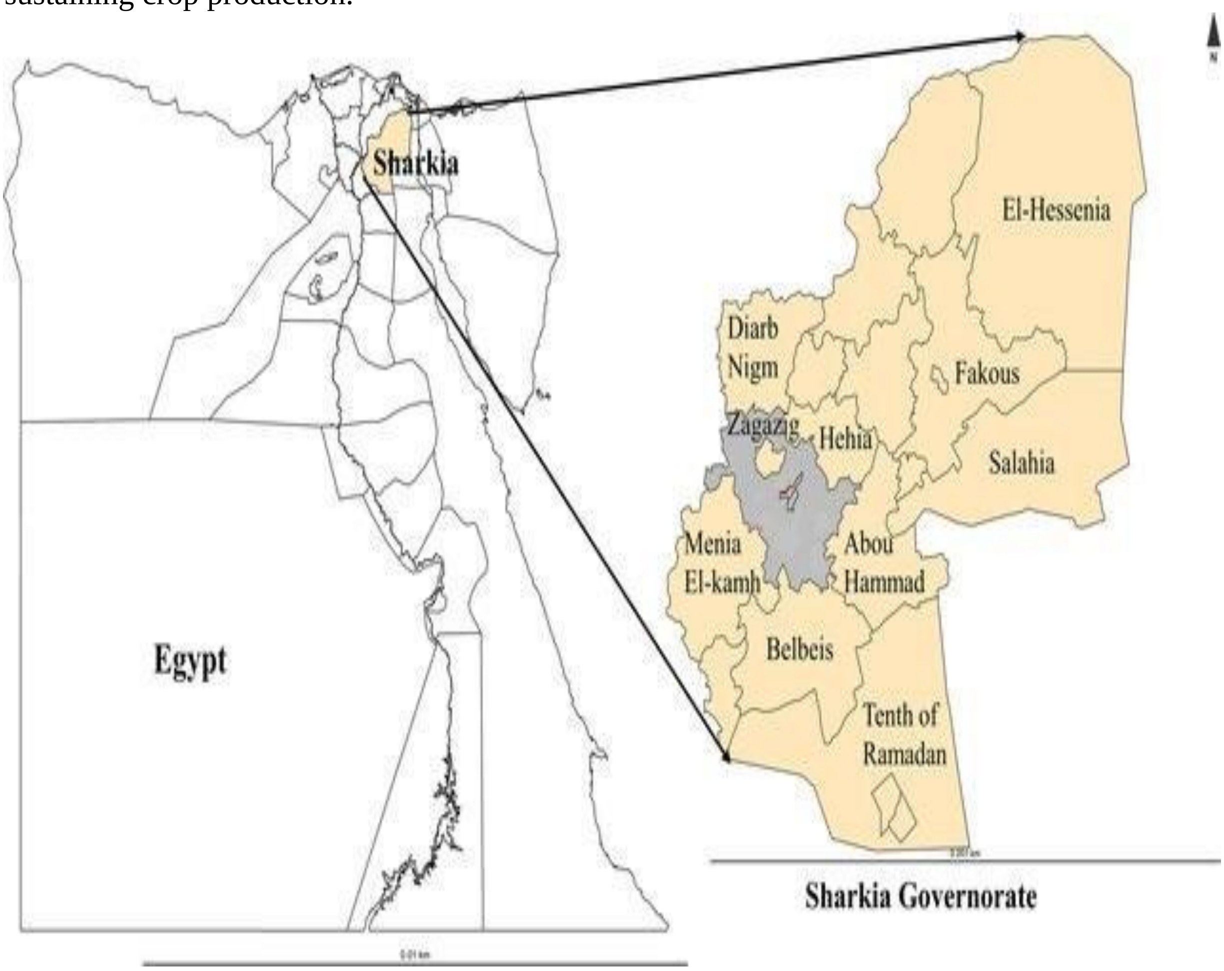

Figure 3 Map of Egypt with the location of Zagazig city (highlighted in grey) in Sharkia Governate

2.2 Climatic Data Collection

Minimum, maximum, and mean temperature; Relative humidity; Wind speed at 2m; Rainfall
The net radiation can be measured from this equation:

$R_n = (S_{down} - S_{up}) + (L_{down} - L_{up})$

S_{down} = *All Sky Surface Shortwave Downward Irradiance*

$S_{up} = \propto . S_{down}$

$L_{down} = All\ Sky\ Surface\ Longwave\ \ Downward\ Irradiance\ \ L_{up} = \varepsilon . \sigma . T_s^4$

$\varepsilon: Surface\ emissivity = 0.95$

$\sigma: Stefan - Boltzmann\ constant = 5.67 * 10^{-8}\ W/m^2 k^4$

$T_s(K) = T_s(c) + 273.15$

Table 1Albedo Values of Different Surface Types

Name	Albedo Value
Bare Soil	0.17
Desert Sand	0.40
Fresh Asphalt	0.04
Green Grass	0.25
New Concrete	0.55
Worn Asphalt	0.12

2.3 Crop Selection

Wheat

It stands as one of the most critical crops in Egypt, playing a pivotal role in ensuring national food security. As the primary grain in the Egyptian diet, wheat is central to daily nutrition and a key component of agricultural and food imports. During the period from 2013 to 2015, wheat and flour imports accounted for approximately 16.78% of the total value of Egyptian agricultural imports, underscoring its strategic importance (Saleh, E. M, 2017). Domestically, wheat cultivation dominated the agricultural landscape, occupying half of the total winter crop area in Egypt during the same period. The average area under wheat cultivation reached about 3.4 million acres, producing an estimated 9.44 million tons annually. Despite this significant production, domestic wheat covered only 54% of national consumption, leaving a substantial wheat supply gap. On average, this gap was approximately 8.11 million tons per year, highlighting Egypt's reliance on imports to meet its growing demand (CAPMAS).

Maize

Maize holds a significant position in the Egyptian crop structure, covering an average area of approximately 2,195 thousand acres, which constitutes about 28.4% of the total grain crop area (7,722 thousand acres). Among this, yellow maize accounts for about 467 thousand acres, representing 21.3% of the total maize area from 2013–2015 (CAPMAS).

2.4 Soil and Crops Data Collection

Input crop coefficients, planting date and growing seasons for each crop (Samiha, 2020).

type of soil: Clayey soil
field capacity = 21%
wilting point = 12%
Initial soil moisture = 20%
depletion factor for maize and wheat = 0.55
$for\ maize\ K_{c\,int} = 0.24, K_{c\,mid} = 1{,}04, K_{c\,fin} = 0.58$
$for\ wheat\ K_{c\,int} = 0.31, K_{c\,mid} = 1{,}06, K_{c\,fin} = 0.25$

2.5 Calculation of Evapotranspiration

The first stage in estimating actual ET is ETo. For the reference evapotranspiration, there are various strategies and techniques. In agricultural water management, reference evapotranspiration is important. FAO56 Penman-Monteith has given important national and international organizations a focal point.

The Penman-Monteith equation was used for the calculation of ETo, as recommended by the FAO (Allen, 1998).

$$ET_0 = \frac{0.408 * \Delta * (R_n - G) + \gamma * \left(\frac{900}{T + 273}\right) * U_2 * (e_s - e_a)}{\Delta + \gamma * (1 + 0.34 * U_2)}$$

ET_0 = the daily reference evapotranspiration (mm/day),
R_n= the net radiation available at the crop surface (MJ/m2/d),
G = the ground heat flux density at the soil surface (MJ/m2/d),
T = the mean air temperature at 2 m height (°C),
U_2 = the mean wind speed at 2 m height (m/s),
e_s = the saturation vapour pressure (kPa),
e_a = the actual vapour pressure (kPa),
$(e_s - e_a)$ = saturation vapour pressure deficit (kPa),
Δ = the slope of the saturation vapour pressure versus the air temperature curve (kPa/°C),
γ = the psychometric constant (kPa/°C).

$$ET_c = k_c * ET_0$$

ET_c : Crop evapotranspiration under standard conditions.

2.6 Soil water balance calculations

The main idea is to evaluate the water requirements for the two types of crops with a long series time, two decades, by making daily soil water balance. We used an Excel sheet to simplify the process. This was done on maize and wheat for 20 years, from 2003 to 2023, with a single sheet for each year separately, evaluating the CWR, GW and BW.

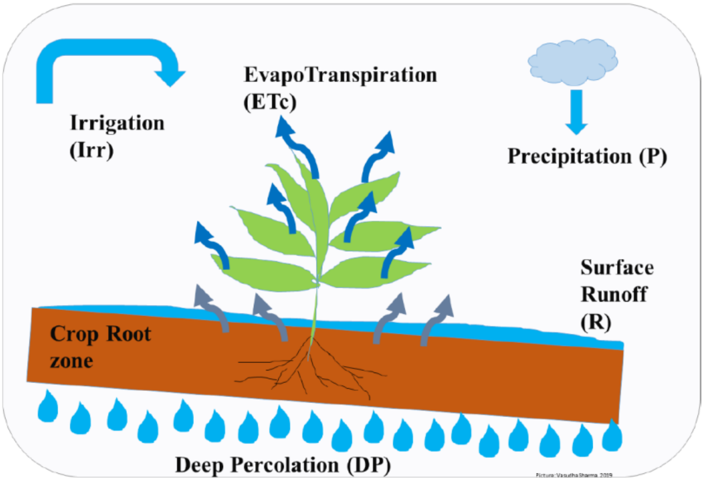

Figure 4 Soil Water Balance

$$\Delta w = P + I - ET_C - DP - R + C$$

$$TAW = (FC - WP) * Z_r \quad , \quad RAW = TAW * DF \;\; \& \;\; MAD = FC - RAW$$

Field Capacity (FC): The maximum water the soil can hold after drainage.
Wilting Point (WP): The point where the soil moisture is so low that plants cannot extract water and begin to wilt.
Root Zone Depth (R_Z): The depth of the soil where plant roots actively grow and extract water.
Total Available Water (TAW): The total amount of water that is available for plant use in the root zone.
Readily Available Water (RAW): The portion of TAW that plants can extract easily without experiencing water stress.
Management Allowed Depletion (MAD): represents the maximum amount of water that can be depleted from the soil before irrigation is required to avoid crop water stress. It is a management tool to decide the optimal timing of irrigation.

$$\Delta w_t = \Delta w_{t-1} + p + I - ET_c - DP - R + C$$

2003 - wheat.xlsx

2003 - maize.xlsx

(in editing mode double-click to access the contents of the Excel file)

3 Results & Discussions

YEAR	MAIZE		WHEAT	
	CWR	GW	CWR	GW
2003	727.987	54.7229	727.987	37.2582
2004	716.222	62.7	712.046	41.4438
2005	712.459	49.6444	712.459	34.8743
2006	722.347	73.962	722.347	57.6316
2007	739.698	66.8862	739.699	49.0147
2008	745.446	61.2695	745.445	42.1484
2009	723.787	46.7668	723.787	32.4947
2010	737.881	41.8524	737.881	27.7625
2011	701.426	70.0018	701.425	53.164
2012	732.804	68.9717	732.803	48.6167
2013	757.282	51.4812	757.282	35.0314
2014	744.683	72.9303	744.682	54.0605
2015	715.348	85.5027	715.348	64.7557
2016	783.788	66.0417	783.788	44.945
2017	738.217	105.556	738.216	90.0183
2018	737.317	91.8389	737.316	74.8426
2019	761.823	62.7529	761.823	44.9335
2020	671.28	193.163	671.281	193.163
2021	741.889	124.743	741.888	110.475
2022	724.117	103.399	724.118	89.0676
2023	737.191	94.8786	737.19	94.8787
tot	15373	1649.06	15368.8	1320.58
avg	732.047	78.5269	731.848	62.8848
max	783.788	193.163	783.788	193.163
min	671.28	41.8524	671.281	27.7625

Table 2 Results

The analysis of crop water requirements (CWR) and green water (GW) usage for maize and wheat over the observed period provided key insights into the water demands for these crops. Over the study period, the average CWR for maize was calculated to be 732.047 mm/year. This value highlights the relatively higher water demand for maize during its growth cycle. The average green water (rainfall) usage for maize was estimated at 78.5269 mm/year, indicating a smaller proportion of green water dependence compared to the total water requirement. The average CWR for wheat was found to be 731.848 mm/year, closely comparable to maize, showcasing its significant water needs. Wheat green water usage averaged 62.8848 mm/year, reflecting a somewhat reduced reliance on it relative to maize.

The temporal variation in CWR and GW usage for both crops displayed consistency across the years, with slight fluctuations influenced by climatic conditions. The nearly equivalent CWR values for maize and wheat underscore similar irrigation demands, which could influence agricultural planning and resource allocation strategies.

The crop water requirements (CWR) for maize and wheat are calculated in terms of cubic meters per square meter per year, based on their respective annual water needs. Maize requires 732.047 mm/year, equivalent to 0.6535201 m^3/m^2/year (BW), while wheat requires 731.848 mm/year or 0.6689632 m^3/m^2/year (BW). The total combined CWR for both crops is calculated as 1.3224833 m^3/m^2/year.

The total volume of treated water available annually is determined by multiplying the daily treated water generation (8000 m^3/day) by 365 days, yielding 2,920,000 m^3/year. To find the maximum area this treated water can irrigate, the total volume is divided by the combined CWR, resulting in an irrigable area of 2,209,767 m^2 or 220.8 hectares.

However, this irrigable area represents only a fraction of the total agricultural area, which spans 21,637.56 hectares. The treated water can thus irrigate just 1.02% of the total agricultural land. This substantial gap between the available treated water and the irrigation demands of the fields highlights the limited capacity of treated wastewater as a sole resource for agricultural irrigation in this context.

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These findings align with existing studies that emphasize the inadequacy of treated wastewater in meeting large-scale agricultural water demands, particularly in water-scarce regions like Egypt. Previous research has consistently shown that while treated wastewater can be a valuable supplementary resource, its use alone cannot offset the high-water requirements of conventional crops such as maize and wheat. The results of this study, therefore, add to the body of evidence highlighting the need for integrated water resource management strategies to address water scarcity in agriculture.

4 Conclusion

The study emphasizes the growing role of treated wastewater as a helpful resource in regions with limited water availability. With freshwater supplies under pressure from population growth, climate change, and industrial activities, treated wastewater offers a sustainable option for uses like irrigation. However, the research shows that relying only on treated wastewater cannot fully meet the high-water needs of crops such as maize and wheat, especially in large farming areas.

This highlights the importance of tailoring water management strategies to specific crops. Choosing crops that use less water or can survive with less water, like drought-tolerant varieties, can make better use of the available water. The findings are in line with other studies from similar dry regions, which suggest combining wastewater reuse with techniques like modern irrigation systems, rainwater collection, and ways to keep the soil moist to support sustainable farming.

The study also supports global goals, such as the United Nations' SDG 6.4, which aims to improve how water is used worldwide. The findings stress the need for policies that focus on better wastewater treatment systems, advanced irrigation methods, and encouraging farmers to save water. Adjusting farming practices to match seasonal water availability and promoting water-efficient tools can significantly ease the strain on limited water resources.

Future studies should focus on improving wastewater treatment to make it more effective and assess the economic and environmental benefits of large-scale reuse. This research reinforces the importance of a complete approach to water management for long-term sustainability.

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