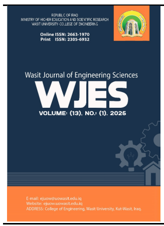

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Original Research

Water Resources Management to Investigate The Extent of The Gap in Wasit Governorate's Water Requirements and Potential Strategies for Mitigation

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ABSTRACT

Wasit Governorate depends on the Tigris River for approximately 78% of its water supply. However, upstream dam construction by neighboring countries has significantly reduced inflows leading to a severe water shortage. Internal mismanagement has further intensified the problem, making the need for a balanced water management strategy urgent. To address this challenge, the study applied the WEAP model and CLIMWAT2 climate data, combined with FAO datasets, to simulate reference, current, and future scenarios As a result of population growth and climate change. Real monitoring data, including weather patterns, consumption rates, and distribution trends informed these. Results showed that the reference scenario covered only 9.61% of demand, while the climate-based irrigation reduced the deficit by up to 53%. The deficit was further reduced through the implementation of integrated and complementary strategies. Overall, the findings suggest that resolving Wasit's water crisis requires both technological solutions and improved administrative practices.

Keywords: Wasit Governorate, water management, scenario, and reduction.

1. Introduction

Water management has become a pressing issue in Iraq, especially in Wasit, where the implementation of Integrated Water Resources Management (IWRM) strategies is essential.[1]. Core challenges are water scarcity, inefficient irrigation, and climate change impacts by declining water quality due to pollution and inadequate infrastructure [2]. Water is a trans boundary resource essential to all societies and not limited by national borders [1]. In Iraq, severe water stress results from upstream dam construction, blocking nearly 65% of natural inflows. Climate change has worsened the situation through rising temperatures, reduced rainfall, and increased evapotranspiration. Internally, weak institutions, outdated infrastructure, and ineffective policies hinder the equitable distribution of resources. Wasit Governorate, in southeastern Iraq, reflects this crisis. The Tigris River, its primary water source for agriculture, domestic, and industrial use, spans 331 kilometers in the region. Due to arid conditions and low rainfall, Wasit is particularly vulnerable to reduced water flows and remains one of the most severely affected areas, where climate and geopolitics combine to threaten water security. Wasit Governorate urgently requires a comprehensive water management framework to balance growing demand with limited resources. Integrated Water Resources Management (IWRM) provides a coordinated approach that enhances socio-economic outcomes while preserving ecosystems. It emphasizes participatory planning, institutional cooperation, and integration of environmental and development goals [3]. In Iraq, particularly in Wasit, interest in IWRM has increased amid worsening water challenges. Chronic shortages, inefficient irrigation, rapid population growth, and climate change have heightened uncertainty. Additionally, water quality is declining due to untreated wastewater, runoff, and poor infrastructure. Untreated wastewater discharge and agricultural runoff contaminate water sources, posing risks to public health and ecosystems [4]. These combined pressures underscore the need for integrated, adaptive strategies to secure long-term water sustainability (see Figure 1).

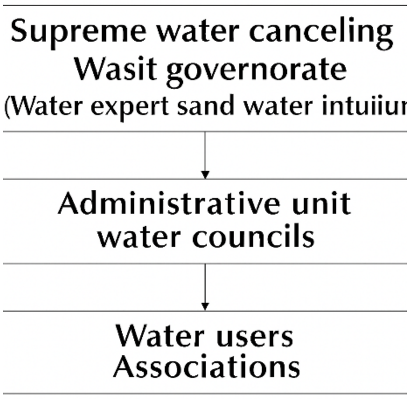

Figure 1. The organizational structure IWRM in Wasit Governorate.

Iraq relies heavily on the Tigris and Euphrates rivers, which are subject to decreased flows due to climate change and upstream water projects in neighboring countries [2]. Studies project significant water shortages by 2035, potentially reaching 44 billion cubic meters [3]. Water scarcity in the Middle East stems from poor management, climate change, and upstream policies. Climate change exacerbates water scarcity through altered precipitation patterns, increased temperatures, and more frequent droughts [4]. Iraq is particularly affected due to weak internal governance and reliance on the Tigris River, which supplies all of Wasit Governorate's Water. Upstream states control nearly 98% of Iraq's Water (Abd-El-Mooty et al., 2016), and the lack of binding trans boundary agreements worsens the threat to Wasit's water security. In Wasit, per capita water availability is declining due to climate pressures, population growth, and uncoordinated inflow management. Past studies focused on sub-basins but overlooked the broader scale. This study uses the WEAP model, grounded in IWRM principles, to simulate and optimize water allocation by sector under real-time conditions. Scenarios that the Water Resources department must adopt to reduce the gap in water import (Waist governorate). A key step in the methodology is building a hydrological and climate database for the study, which integrates time-series data on the Tigris River in Wasit Governorate—specifically, discharge, rainfall, temperature, and evapotranspiration—to capture seasonal and long-term variability. Descriptive and advanced statistical tools are used for scenario development, model validation, and sensitivity analysis. This section outlines a water management framework for Wasit Governorate built on two pathways. The first uses real-time field data, progressing through water gap analysis, climate-based redistribution, wastewater reuse, network maintenance, irrigation modernization, water footprint, prioritization, and supplemental irrigation. The second relies on academic sources, following similar steps. Both approaches identify a 71% gap between supply and demand and propose targeted, data-driven solutions to reduce it. For clarity and coherence, the introduction is structured thematically, beginning with climate-related challenges, followed by geopolitical influences and wastewater concerns, before presenting the rationale for applying the WEAP model.

2. Data Collection

Data was collected from relevant governmental and sectoral bodies and covered multiple domains. This included meteorological data, water consumption figures across all sectors, irrigation water distribution records, agricultural land data, drinking water supply information, wastewater statistics, groundwater levels and usage, flood and floodwater inflow data, and datasets provided by the Food and Agriculture Organization (FAO).

2.1 Proposed Models

The proposed models for the study are built using WEAP and CLIMWAT 2.0 software tools. The Water Evaluation and Planning System (WEAP) is a widely used modeling tool developed by the Stockholm Environment Institute for integrated water resources planning. It provides a flexible framework for simulating water demand, supply, and allocation under different management and climate scenarios. By incorporating hydrological, agricultural, and socio-economic components, WEAP enables decision-makers to evaluate current conditions and explore potential strategies for sustainable water management. The Soil Moisture Method is applied to simulate surface runoff and to calibrate and validate the model. Several scenarios are developed to assess water management strategies in Wasit Governorate. The reference scenario represents the current status of water use and supply. The first alternative scenario involves the standard redistribution of the water quota allocated to the governorate. Another scenario accounts for climatic variations between the northern and central/southern regions. A separate scenario examines the reuse of treated wastewater as an alternative water source. One scenario focuses on improving the drinking water network and using the saved Water to help reduce the gap between supply and demand. Another scenario proposes upgrading traditional irrigation systems with modern mechanized alternatives to enhance water use efficiency. The final scenario introduces the concept of water footprint and virtual Water, which requires restructuring the governorate's agricultural plans to reduce water consumption and improve sustainability.

2.2 The Main Outfall

Given the rising salinity levels, selecting appropriate irrigation methods and salt-tolerant crops is essential for maintaining agricultural productivity [5]. Several studies emphasize the need for effective water management strategies to mitigate the impact of salinity on crop yields [6]. The Main Outfall (a primary drainage water collector) borders the governorate from the southwest. Many farmers benefit from its Water, which measures around 3000 ppm in salinity, after it is mixed with available flows from the tails of Distributary Rivers branching from the Tigris and Al-Gharraf. This mixed Water cultivates certain hybrid crop varieties such as ADAN 2 and Turkish wheat. The governorate utilizes the outfall to meet approximately 2% of its total irrigation needs, As well as the percentage (87%) of the Tigris River imports to Wasit Governorate as shown in Figure 2. The more severe shortage in Winter is mainly attributed to the mismatch between water demand and the timing of river flow availability. In the study area, irrigation demand for certain winter crops peaks when river discharge is relatively low, which amplifies the deficit compared to the summer season. Additionally, the current water allocation system prioritizes certain non-agricultural uses during Winter, further contributing to the observed shortage.

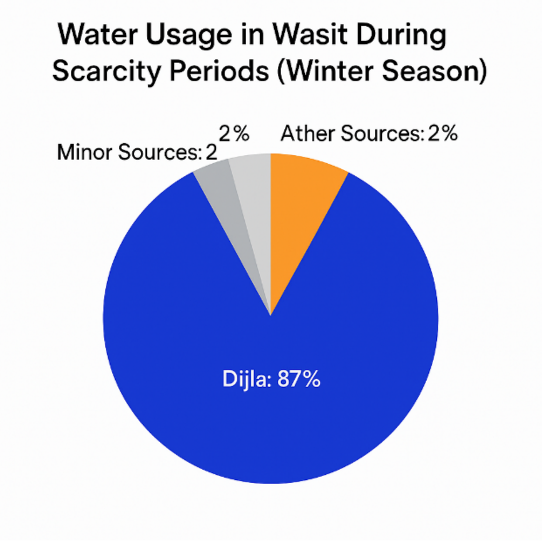

Figure 2. Water used in Wasit during the period of scarcity for Winter

As shown in Figure 3, the distribution percentages of the Water allocated to the governorate from the Tigris River among various uses.

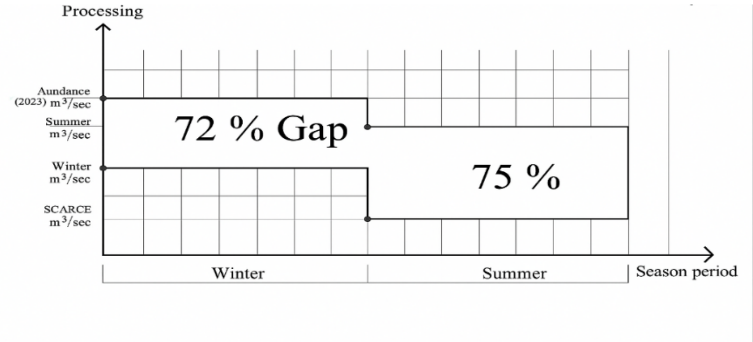

Figure 3. The distribution percentages of the Water

Figure 3. A diagram showing the gap between the available and required amount of Water needed by the Wasit governorate, where the percentage of the gap in the summer is (75%) and in the Winter is (72%) **.** illustrates the gap in the governorate's Water needs due to the decline in water inflows from the Tigris River. Tables 1 and 2 contain data on the water volumes supplied to the governorate from the Tigris River during the winter and summer agricultural seasons, before and after the decline in water inflows.

Table 1 Stage of water abundance for Winter

	Stage of water abundance			
	processing m^3 / sec		Need m^3 / sec	
	Quantity	Source	Agriculture	drink
1	550	Dijla	614	16
2			Calculated based on 75% operation of sub-irrigation sources	
3				
4	550		614	

Table 2. Stage of Water scarcity for summer

Stage of Water Scarcity				**GUP**
processing m^3 / sec		Need m^3 / sec		72%
Quantity	Source	Agriculture	drink	
130	Dijla	614	16	
9	AL-Massab	Calculated based on 75% operation of sub-irrigation sources		
3	R.Drain			
7.4	Sewareg water			
149.4		614	16	

Descriptive Tables 3 and 4 of the discharge volumes included in the structural plan of the irrigation system in Wasit Governorate.

Table 3. Discharge volumes

No.	Q . m^3 / sec	No.	Q . m^3 / sec	No.	Q. m^3 / sec
1	70	11	27.74	21	21
2	0.7	12	1.5	22	0.7
3	60	13	21.79	23	6
4	0.7	14	0.7	24	0.7
5	42	15	90	25	16
6	0.7	16	0.7	26	0.7
7	26	17	23	27	16.35
8	0.7	18	0.7	28	1.5
9	34	19	80	29	39
10	1.5	20	0.7	30	0.7

Table 4. Discharge volumes

No.	Q . m^3 / sec	No.	Q . m^3 / sec
31	0.4	41	0.4
32	0.4	42	3
33	0.4	43	5
34	0.4	44	4
35	0.4	45	120
36	0.4	46	42
37	0.4	47	17
38	0.4	48	22
39	0.4	49	10
40	0.4		

Wasit Governorate now receives only 200 m^3/s from the Tigris River, down from 779 m^3/s, threatening food security and winter crop irrigation over 1.66 million dunams. The study proposes a scenario-based strategy using the agricultural water footprint to balance supply and demand. A reference database covering all Water uses—drinking, industrial, energy, and returns—is essential. Scenarios are based on field-monitored data, with a focus on agriculture, which consumes 78% of total demand. Improving this sector offers the greatest potential for reducing the water deficit.

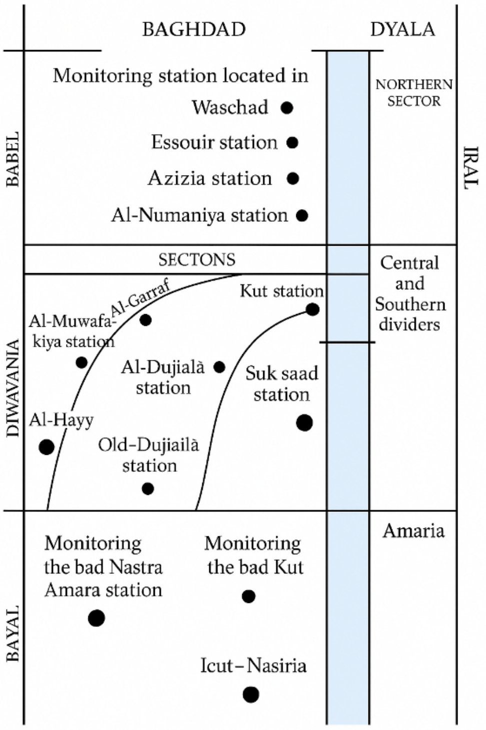

Figure 4. The location of the water monitoring station along the Tigris River

3. Validation Based on Actual Water Consumption Data

3.1. Official Allocation Breakdown

According to data from relevant provincial institutions based on actual monitoring, the total allocated water quota for Wasit Governorate is 200 m³/s. This allocation is divided as follows: 16 m³/s is designated for drinking Water, 2 m³/s for energy projects, 5 m³/s for industrial projects, and the remaining 177 m³/s is allocated to agriculture and livestock.

3.2 . Standard Criteria Applied in Analysis

1. Alignment with WEAP Outputs

All scenarios are validated using WEAP model outputs to ensure accurate water allocation simulations. Performance is assessed through statistical indicators including R^2, NSE, and RMSE. Rather than relying on seasonal averages, time-series data is used to track irrigated areas over time, enabling a more detailed analysis of temporal variability.

1. Climatic Data from CLIMWAT2 (Wasit Governorate)

Monthly variability in temperature, rainfall, and humidity is integrated over the 5-month crop cycle. A nonlinear irrigation-to-area model is used, varying by crop type, zone (north, central, south), and month. Cropping intensity is fixed at 59.7% to reflect seasonal and land-use variations. Traditional irrigation methods contribute to substantial water wastage. Modernizing irrigation techniques is crucial for enhancing water productivity [7].

2. Adjusted Water Footprint Scenario

Crop distribution is region-specific, with 90% wheat and 10% barley in the north, and 75% wheat and 25% barley in the center and south. Crop switching is capped at 25% of the total Area, substituting with low-water crops to reduce demand while maintaining food production targets. used the CERES-Wheat model to simulate winter wheat yield, water productivity (WP), and irrigation water productivity (IWP) under different irrigation scenarios, highlighting the importance of understanding crop response to various water sources for efficient irrigation water management [8]. Investigated the impact of wheat planting methods, irrigation water quality, and water stress on nutrient uptake and water use efficiency, finding that optimizing these factors can improve wheat yields [9]. Found that transitioning from a winter wheat-maize system to a winter wheat-soybean system could enhance productivity while reducing the water footprint and groundwater depletion [10].

3. New Scenario Introduced: Supplemental Irrigation

A CLIMWAT2-based scenario evaluated the use of supplemental irrigation to reduce reliance on river water. Despite allocating 177 m³/s, only 159,560 dunams were irrigated (9.61%), leaving a gap of 1.5 million dunams. Poor performance metrics (R^2 = –141.27, NSE = –141.27, RMSE = 73,922) highlight the limitations of constant-efficiency models, particularly during November and March.

3.3 Recommended Adjustments:

All outputs will be recalculated using monthly CLIMWAT2 data to reflect more accurate climatic variability. Nonlinear models will be applied to estimate irrigated Area by crop type, geographic zone, and season, allowing for more precise water demand analysis. Each scenario will be validated using statistical metrics, including R^2, NSE, and RMSE, to ensure model reliability. Time-series data will replace seasonal averages for both irrigation and climate variables to improve temporal resolution. Updated crop mix assumptions will be used: in the northern zone, 90% wheat and 10% barley; in the central and southern zones, 75% wheat and 25% barley. Conversion to low-water crops will be limited to a maximum of 25% of the total cultivated Area. A new supplemental irrigation scenario will be introduced, enabling the replacement of irrigation events with rainfall when conditions permit. These adjustments will enhance the realism of the scenarios, reduce the risk of overestimation, and align Water planning more closely with actual climatic and agricultural conditions in Wasit.

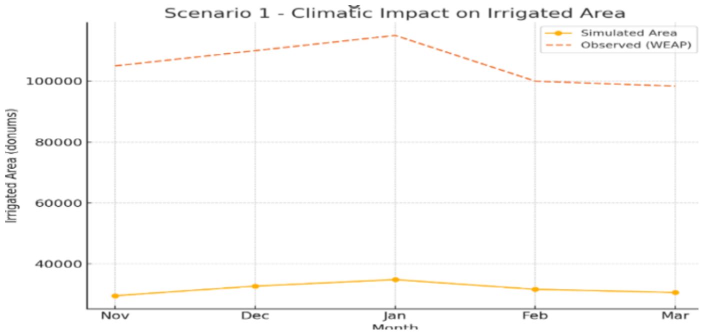

Figure 5. Scenario 1 (Climate & WEAP Adjusted) – Monthly Details

Table 5. Scenario 1 (Climate & WEAP Adjusted) – Monthly Details

Month	Temperature (°C)	Rainfall (mm)	Humidity (%)	Irrigation Efficiency	Irrigated Area (dunums)
Nov	17.5	24.5	58	0.28	29,587
Dec	13.2	30.2	65	0.31	32,757
Jan	11.3	38.6	68	0.33	34,870
Feb	13.9	27.1	61	0.30	31,700
Mar	17.8	22.4	56	0.29	30,644

Table 6. Scenario 1 – Summary & Statistical Evaluation

Scenario	Total Irrigated Area (dunums)	Water Gap (dunums)	Coverage (%)	RMSE	NSE	R^2
1	159,560	1,500,439	9.61	73,922.13	-141.27	-141.27

4. Updated Scenario 1: Baseline Scenario Integrated with WEAP and CLIMWAT2

CLIMWAT2, a database and software developed by the Food and Agriculture Organization (FAO), provides essential climate data for irrigation planning. Utilizing CLIMWAT2 enables the adjustment of monthly water distribution to match seasonal crop water demands, thereby optimizing irrigation efficiency [11]. A five-month climatic analysis for wheat cultivation in Wasit was conducted using CLIMWAT2 data (temperature, rainfall, and humidity) integrated into the WEAP model. Assuming monthly irrigation efficiency varies with climate, higher in Winter, lower in autumn and spring, the fixed 177 m³/s water quota was evenly distributed. However, the actual irrigated Area was estimated non-linearly to reflect crop response to monthly weather variability more accurately. The final results reveal a significant performance gap in meeting irrigation demands. The total irrigated Area under current conditions is 159,560 dunums, leaving a water gap of 1,500,439 dunums. This corresponds to a coverage rate of only 9.61%. Statistical validation of the baseline climate-sensitive scenario in the WEAP model indicates poor model performance, with an R^2 of -141.27, an NSE of -141.27, and an RMSE of 73,922 dunums. These figures underscore the pressing need for enhanced water allocation strategies and more responsive modeling inputs. The results reveal a significant gap between expected and actual outcomes, confirming that climate variability, particularly in November and March, reduces irrigation efficiency. Fixed water-use coefficients are unreliable under such conditions. This highlights the need for adaptive planning using monthly climate data, nonlinear modeling, and real-time adjustments to improve water management accuracy and resilience in Wasit Governorate.

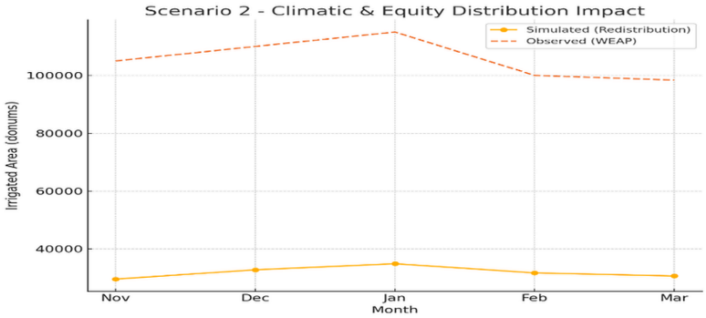

Figure 6. Scenario 2 – Monthly Irrigation Details (Climate & WEAP Adjusted)

Table 7. Scenario 2 – Monthly Irrigation Details (Climate & WEAP Adjusted)

Month	Efficiency	North Irrigated Area (dunums)	Central+South Irrigated Area (dunums)	Total Irrigated Area (dunums)
Nov	0.28	15,567	14,020	29,587
Dec	0.31	17,235	15,522	32,757
Jan	0.33	18,347	16,523	34,870
Feb	0.30	16,679	15,021	31,700
Mar	0.29	16,123	14,520	30,644

Table 8. Scenario 2 – Summary & Statistical Evaluation

Scenario	Total Irrigated Area (dunums)	Water Gap (dunums)	Coverage (%)	RMSE	NSE	R²
1	159,560	1,500,439	9.61	73,922.13	-141.27	-141.27

4.1 Updated Scenario 2: Equity-Based Reallocation with WEAP and

The scenario allocated 93.13 m³/s to northern Wasit and 83.87 m³/s to central and southern zones, ensuring geographic equity. The 177 m³/s total was spread over five months, with irrigation efficiency adjusted monthly using CLIMWAT2 data. A nonlinear approach was used to estimate irrigated areas by month and zone, recognizing that efficiency varies with climate, especially in November and March. Thus, fixed conversion rates could not accurately project cultivated areas. The final results confirm a significant shortfall: The total irrigated Area reached only 159,560 dunums, leaving a water gap of 1,500,439 dunums and resulting in a low coverage rate of 9.61%. WEAP model validation under climate-sensitive conditions confirms poor scenario performance, with an RMSE of 73,922 dunums, an NSE of -141.27, and an R² of -141.27. These metrics indicate a weak correlation between simulated and observed values, underscoring the model's limitations in capturing current water distribution dynamics. The analysis shows that while this scenario achieves regional equity in water allocation, it does not increase the total irrigated Area under actual climate conditions. Limited impact is often attributed to outdated infrastructure, low efficiency, and a lack of upgrades. Therefore, its success depends on parallel efforts in irrigation modernization, demand management, and climate-adaptive planning.

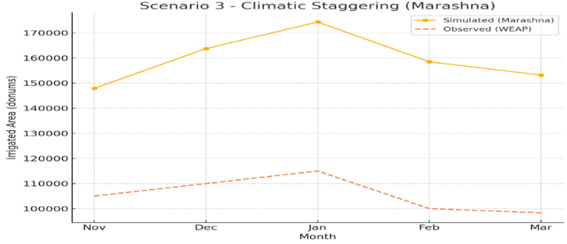

Figure 7. Scenario 3 – Monthly Irrigated Area (Marashna with Climate & WEAP)

Table 9. Scenario 3 – Monthly Irrigated Area (Marashna with Climate & WEAP)

Month	North Irrigated Area (dunums)	Central+South Irrigated Area (dunums)	Total Irrigated Area (dunums)
Nov	147,936	0	147,936
Dec	0	163,786	163,786
Jan	174,353	0	174,353
Feb	0	158,503	158,503
Mar	153,220	0	153,220

Table 10. Scenario 3 – Summary & Statistical Evaluation

Scenario	Total Irrigated Area (dunums)	Water Gap (dunums)	Coverage (%)	RMSE	NSE	R²
1	797,800	862,199	48.06	54,209.59	-75.51	-75.51

4.2 Updated Scenario 3: Climate-Based Rotation (Marashna) with WEAP and CLIMWAT2

The rotational irrigation scenario introduces a staggered schedule between Wasit's northern and central/southern zones, with a 15–20 day delay to optimize water reuse and reduce simultaneous demand. Under this plan, The northern zone irrigates in November, January, and March. The central/southern zones irrigate in December and February. This rotation reduces peak demand overlap and allows repeated use of the same water volumes, improving the efficiency of the fixed 177 m³/s allocation without increasing supply. It is designed to ensure temporal equity and reflects seasonal shifts in irrigation efficiency using monthly CLIMWAT2 climate data. Final results show substantial improvements in irrigation coverage. The total irrigated Area increased to 797,800 dunums, reducing the water gap to 862,199 dunums and raising the coverage rate to 48.06%. WEAP model validation reflects moderate gains in performance, with an RMSE of 54,209 dunums, and both NSE and R² values at -75.51. While model accuracy remains low, the reduced error and improved coverage suggest partial effectiveness of the applied interventions. Despite negative validation metrics—reflecting calibration issues and data variability the scenario shows a clear improvement in irrigated Area compared to the baseline and static models. This is largely due to optimized irrigation timing, which improves water circulation across zones. The results confirm that alternating water distribution by region and month can enhance efficiency within current limitations. However, further improvements in data resolution, infrastructure coordination, and real-time control are necessary to enhance model accuracy and facilitate practical implementation. Aging and inadequate water infrastructure lead to losses and inefficiencies in water distribution [12].

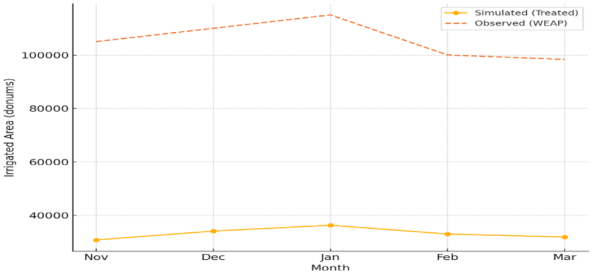

Figure 8. Scenario 4 – Monthly Irrigation Using Treated Water (Climate & WEAP)

Table 11. Scenario 4 – Monthly Irrigation Using Treated Water (Climate & WEAP)

Month	Efficiency	Irrigated Area (dunums)
Nov	0.28	30,824
Dec	0.31	34,126
Jan	0.33	36,328
Feb	0.30	33,026
Mar	0.29	31,925

Table 12. Scenario 4 – Summary & Statistical Evaluation

Scenario	Total Irrigated Area (dunums)	Water Gap (dunums)	Coverage (%)	RMSE	NSE	R²

1	166,231	1,493,768	10.01	72,587.94	-136.18	-136.18

4.3 Updated Scenario 4: Reuse of Treated Wastewater with Climate Data and WEAP Validation

This scenario examines the use of treated wastewater by adding 7.4 m³/s to Wasit Governorate's water quota. The added volume is distributed evenly over the five-month growing season. Monthly climate variability—temperature, rainfall, and humidity—is included using CLIMWAT2 data to capture realistic shifts in irrigation efficiency. Employing advanced wastewater treatment technologies to reuse Water in agriculture and industry can alleviate freshwater demand [13]. Results show a marginal improvement over the baseline: The total irrigated Area reached 166,231 dunums, leaving a water gap of 1,493,768 dunums and a coverage rate of 10.01%. WEAP model validation metrics remain poor, with an RMSE of 72,588 dunums and both NSE and R^2 at -136.18. These results indicate a limited impact from the applied scenario and highlight the continued mismatch between available Water and agricultural demand. Treated wastewater slightly increases irrigated Area but has a limited impact under climate-sensitive conditions. Alone, it cannot close the irrigation gap due to high demand and efficiency losses. However, it enhances system resilience by providing a reliable backup source. For meaningful results, it should be combined with rotational irrigation, crop restructuring, and efficiency improvements.

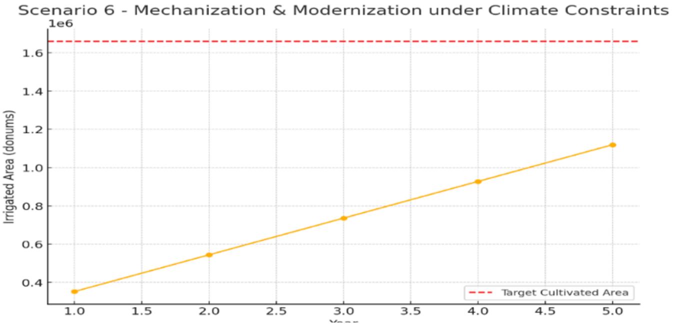

Figure 9. Scenario 6 – Summary & Statistical Evaluation (Urban Water Efficiency with Climate)

Table 13. Scenario 7. – Summary & Statistical Evaluation (Urban Water Efficiency with Climate)

Year	Total Irrigated Area (dunums)	Water Gap (dunums)	Coverage (%)	RMSE	NSE	R^2
Year 1	161,363	1,496,836	9.72	73,561.53	-139.88	-139.88
Year 2	163,166	1,496,833	9.83	73,200.94	-138.50	-138.50
Year 3	165,329	1,494,670	9.96	72,768.23	-136.86	-136.86

4.4 Updated Scenario 5: Drinking Water Network Efficiency Improvement with Climate Impact and WEAP Validation

This scenario focuses on the gradual reduction of water losses from Wasit Governorate's drinking water distribution networks to redirect the saved volumes to support agricultural irrigation. Over a three-year implementation period, the expected savings are Year 1: 2.0 m³/s, Year 2: 4.0 m³/s, and Year 3: 6.4 m³/s.

Recovering and redirecting treated wastewater for irrigation, with monthly water distribution adjusted according to CLIMWAT2 data, addresses critical issues of water scarcity and promotes sustainable water management[14]. While the increase in irrigated Area may be modest, converting a significant portion (e.g., over 40%) of urban water losses into productive agricultural use substantially contributes to long-term sustainability[15]. This approach requires careful consideration of several factors, including water quality, irrigation techniques, crop water requirements, and the integration of climate data for optimized distribution[16, 17]. Recovered Water is redirected to irrigation, with monthly distribution adjusted using CLIMWAT2 data to reflect seasonal efficiency. Though the irrigated area gain is modest, the scenario improves long-term sustainability by converting over 40% of urban water losses into productive use. Its effect is limited during low-efficiency months, such as November and March. The scenario's value increases when integrated with Marashna (climate-based rotation) for optimized timing. Modern irrigation systems to improve delivery efficiency. Crop restructuring to lower the water footprint. Together, these measures can amplify water savings, expand irrigation coverage, and enhance system resilience under ongoing resource constraints. The values of R^2 and NSE were mainly due to limitations in the availability and accuracy of observed hydrological and climatic data in the study area. The scarcity of reliable long-term records, particularly for irrigation return flows and groundwater interactions, reduced the model's ability to capture the real system behavior. To improve performance, future work will focus on: (i) expanding the calibration dataset with additional observed records, (ii) refining parameterization of irrigation water demand, and (iii) incorporating more accurate climate and land-use data. We acknowledge this limitation and will clarify it in the revised manuscript as showing table (14).

Table 14. Updated Scenario 5: Drinking Water Network Efficiency Improvement

Year	Irrigated Area (dunums)	Water Gap (dunums)	Coverage (%)	RMSE (dunums)	NSE	R²
Year 1	161,363	1,498,636	9.72	73,561	–139.88	–139.88
Year 2	163,166	1,496,833	9.83	73,201	–138.50	–138.50
Year 3	165,329	1,494,670	9.96	72,768	–136.86	–136.86

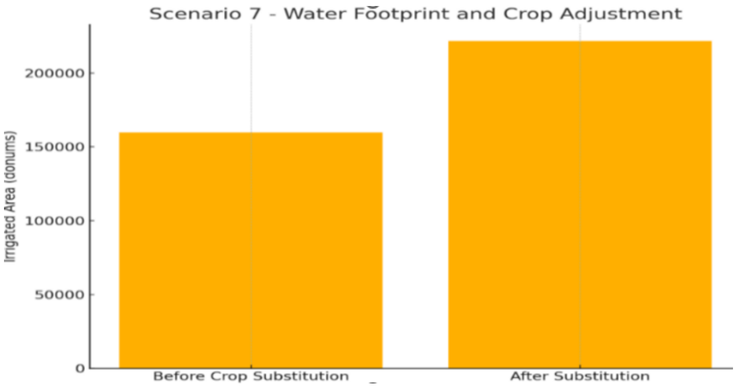

Figure 10. Scenario 6 – Mechanization With Climate Adjustment

Scenario 6 – Mechanization With Climate Adjustment

Table 15. Scenario 6 – Mechanization With Climate Adjustment

Year	Total Irrigated Area (dunums)	Water Gap (dunums)	Coverage (%)
1	351,560	1,308,439	21.18
2	543,560	1,116,439	32.74
3	735,560	924,439	44.31
4	927,560	732,439	55.88
5	1,119,560	540,439	67.44

4.5 Updated Scenario 6: Mechanization and Irrigation Network Improvement Under Climate Influence

Scenario Concept

- A 5-year plan is implemented to modernize irrigation systems.
- An annual increase of 192,000 dunums of irrigated Area is projected.
- The starting point is the climate-adjusted irrigated Area from Scenario 1: 159,560 dunums.

Annual Results Analysis.

Table 16. Annual Results

Year	Irrigated Area (dunums)	Water Gap (dunums)	Coverage Rate (%)
1	351,560	1,308,439	21.18
2	543,560	1,116,439	32.74
3	735,560	924,439	44.31
4	927,560	732,439	55.88
5	1,119,560	540,439	67.44

This scenario proves to be one of the most effective medium-term solutions. Irrigated areas grow steadily year by year, reflecting improvements in infrastructure and delivery efficiency. With continued investment, coverage may exceed 67% within five years.

4.6 Updated Scenario 7: Water Footprint and Crop Pattern Adjustment Under Climatic Conditions

This scenario improves water-use efficiency by converting 25% of cultivated land (415,000 dunums) to low-demand crops like barley and lentils, based on regional crop ratios. The shift raises irrigation efficiency by 15%, adding 62,250 dunums to the irrigated Area. Total coverage reaches 221,810 dunums (13.36%), reducing the gap to 1,438,189 dunums. Though modest in impact, the scenario is scalable, low-cost, and aligned with sustainable agriculture. It reduces the sector's water footprint and boosts crop resilience. However, it does not address infrastructure or scheduling inefficiencies. Its full potential is unlocked when integrated with rotational irrigation, mechanization, and wastewater reuse, forming a foundation for broader climate-adaptive planning (see Figure 11).

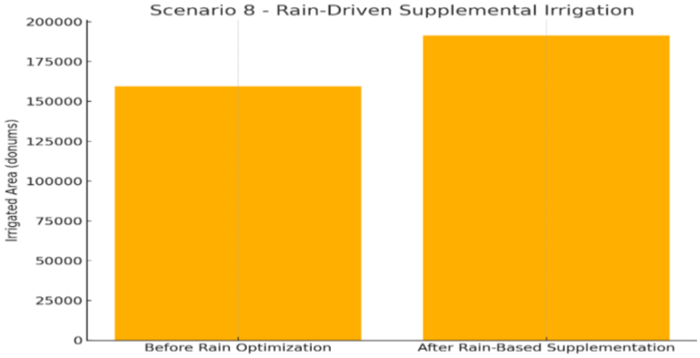

Figure 11. Scenario 8- Rain-Driven Supplemental Irrigation

Table 17. Scenario 7 – Water Footprint Adjustment

Adjusted Area (dunums)	Efficiency Gain Area (dunums)	Total Irrigated Area (dunums)	Water Gap (dunums)	Coverage (%)
415,000	62,250	221,810	1,438,189	13.36

4.7 Updated Scenario 8: Supplemental Irrigation Based on Rainfall Monitoring

As shown in Table 17, this scenario replaces one in five irrigation events with seasonal rainfall, targeting 20% water savings. Implementation depends on accurate weather forecasting, real-time rainfall monitoring, and alignment with crop irrigation calendars. Success requires reliable weather stations, data-driven decisions, and farmer training. The results show that the base irrigated Area without rainfall substitution was 159,560 dunums. By substituting rainfall for irrigation where feasible, savings were redirected to irrigate an additional 31,912 dunums. This brought the total irrigated Area to 191,472 dunums. Despite this improvement, the remaining water gap is 1,468,527 dunums, resulting in a coverage rate of 11.53%. Analysis: Although area gains are limited, this scenario offers a low-cost, practical way to improve water efficiency. Its strength lies in complementing other strategies, particularly climate-based rotation and modern irrigation, where timing and delivery efficiency enhance rainfall use. However, its success depends on accurate forecasting and addressing spatial rainfall variability through better prediction tools and farmer engagement (Tables 18–19).

Scenario 8 – Rain-Supplemented Irrigation

Table 18. Scenario 8 – Rain-Supplemented Irrigation

Base Irrigated Area (dunums)	Area Gained via Rain (dunums)	Total Irrigated Area (dunums)	Water Gap (dunums)	Coverage (%)
159,560	31,912	191,472	1,468,527	11.53

Table 19. Scenario 8 – Rain-Supplemented Irrigation

#	Scenario Description	Irrigated Area (dunums)	Water Gap (dunums)	Coverage (%)	Notes
1	Baseline Scenario	159,560	1,500,439	9.61	Climate-based baseline
2	Equity-Based Redistribution	159,560	1,500,439	9.61	Water fairness; no hydraulic gain
3	Climate-Based Rotation (Marashna)	797,800	862,199	48.06	Among the most effective seasonal redistribution strategies

4	Treated Wastewater Reuse	166,231	1,493,768	10.01	Limited impact under current climate conditions
5	Drinking Water Efficiency (up to 3 years)	Up to 165,329	Up to 1,494,670	Up to 9.96	Gradual improvement; needs integration
6	Mechanization and Network Improvement	1,119,560	540,439	67.44	Best mid-term scenario for irrigation efficiency
7	Water Footprint & Crop Pattern Modification	221,810	1,438,189	13.36	Modest gains; requires legislative and policy integration
8	Supplemental Irrigation via Rainfall Substitution	191,472	1,468,527	11.53	Low-cost and applicable if the forecast accuracy is high

5. Conclusion

This analysis employed the WEAP model integrated with FAO and CLIMWAT2 climate data for Wasit Governorate, using monthly records on temperature, humidity, and rainfall during the five-month agricultural season. Among the simulated options, the climate-based scheduling scenario showed the best short-term impact, covering 48.06% of water demand without increasing quotas. This was achieved by adjusting irrigation timing according to climatic variations between the northern and southern regions. However, statistical validation revealed weaknesses, with RMSE = 54,209 dunams and negative NSE and R^2 values (–75.51), indicating high sensitivity to implementation accuracy. In contrast, the mechanization and irrigation network scenario offered the most substantial long-term potential, achieving 67.44% coverage by year five. Despite its effectiveness, it requires significant investment in infrastructure and technical capacity building. Other partial interventions—treated water reuse, improved drinking water networks, and supplemental irrigation—produced minimal progress, each remaining below 11% coverage and yielding poor statistical results. Based on water footprint methodology, the crop pattern adjustment scenario increased irrigated land by 62,250 dunams, bringing total coverage to 810,000 dunams (13.36%). It reflected actual crop distribution ratios (90/10 in the north and 75/25 in the center/south) and capped crop replacement at 25%. Simulations confirmed that the relationship between water volume and irrigated Area is nonlinear, driven by monthly climatic fluctuations in irrigation efficiency.

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