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Improving the Irrigation Systems for the Fallujah Irrigation Projects by Using Water Evaluation and Planning Model (WEAP)

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ABSTRACT

In this study, the water evaluation and planning WEAP model was used to improve the Fallujah irrigation project with 63,000 hectares and an annual budget get 1,476 million $m3$/ yiod (2020-2021). The results showed the total Water used was 1,272 million m^3/year and equaled 86% of Fallujah irrigation budget. The annual production was 524.4 million Kg/year for Fallujah irrigation, and total economic returns were 393.6 million $/year. The study outlined two scenarios for enhancing the irrigation system. The first scenario entailed implementing a sprinkler irrigation system for wheat and barley across all projects. This resulted in a production increase from 524.4 to 625.7 million kilograms per year and a corresponding rise in economic returns from 393.6 to 427.2 million annually. In the second scenario, a sprinkler system was adopted for wheat and barley and a trickle system for other crops. This approach led to production growth from 524.4 to 1164.9 million kilograms per year and a surge in economic returns from 393.6 to 559.4 million annually.

1. Introduction

Water, a ubiquitous substance on Earth, extends across approximately 70% of the planet's total surface, constituting a fundamental component known as the hydrosphere[1]. The water demand can be categorized into agricultural, domestic, and industrial sectors. Of these, agriculture emerges as the most substantial consumer of Water worldwide, accounting for a staggering 85% of the total water consumption [2]. Given the escalating population growth and intensifying competition for available water resources, alongside many other demands, irrigated agriculture is confronted with the imperative of enhancing food production while conserving Water to ensure food security [3].

In the Middle East, Iraq is heavily dependent on the Tigris and Euphrates rivers as its primary water supply sources. It was once abundant in water resources, but the construction of dams in Iraq's main rivers and their tributaries in neighboring nations, coupled with climate change impacts, has significantly reduced river flow [4]. Given the scarcity of water resources, it became imperative to establish water management strategies to guarantee the fulfillment of the population's water

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requirements [5]. This can be achieved by enhancing crop production efficiency and conserving a greater volume of Water [6].

The Fallujah irrigation project relies on a surface irrigation system known for low productivity and efficiency. The primary water source for irrigating summer crops such as sweet peppers, potatoes, cucumbers, and sesame, as well as palm trees, olives, and citrus, along with winter crops such as wheat, barley, and clover, is the Euphrates River. To meet domestic water demands, multiple projects involve water stations drawing from the Euphrates.

Given the increasing population growth, heightened competition for available water resources, and various other demands, irrigated agriculture must enhance food production while conserving Water to ensure food security [7]. A deeper understanding of the water balance within irrigation projects becomes essential to address the complex challenges inherent in irrigation management. This involves reusing treated Water and a comprehensive grasp of climatic data, soil properties, crop types, and irrigation efficiency [8]. Furthermore, the intricacies of irrigation projects necessitate implementing advanced mathematical models for efficient water allocation [9].

The Water Evaluation and Planning Software denoted as WEAP 21, is a contemporary collaborative project involving both the Federal Institute for Geosciences and Natural Resources (BGR) in Germany and the Stockholm International Environment Institute (SEI) based in Boston, USA [10]. It introduces a novel approach to assessing and planning water resources under present and future conditions. It is guided by user-defined assumptions to achieve environmental equilibrium and sustainable development within the studied region [11].

2. Materials and Methods

2.1 Description of Study Area

Fallujah lies in the temperate latitudinal zone of the Northern Hemisphere, positioned between two distinct latitudinal coordinates, namely 33° 21' 09" – 33° 17' 47" North. Furthermore, it is within a specified longitudinal range, specifically 43° 44' 58" – 43° 49' 33" East, as depicted in Figure 1. It is geographically west of Baghdad, approximately 60 kilometers away, and situated to the east of Ramadi, the central city of Anbar Governorate, Fallujah is positioned at an approximate distance of 47 kilometers. [12].

According to Water Resources department of Falluja, Fallujah city encompasses a well-defined administrative boundary that encompasses four distinct units, namely, Al-Saqlawiya district (Project 1), Al-Karmah district (Project 2), the district center (Project 3) and Al-Amriya district (Project 4), spanning a total area of 4,205 square kilometers. The area is characterized by arable land, with numerous orchards and a diverse range of cultivated crops, including wheat, barley, vegetables, and livestock fodder. The total land area encompasses 492,700 hectares, with arable land covering 95,547 hectares.

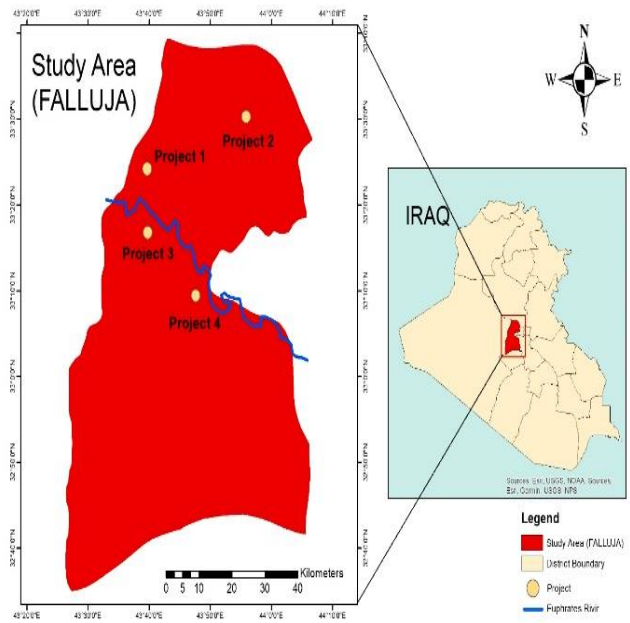


Figure 1. Map of the study area

2.2 *Climates Conditions*

Fallujah is marked by scorching and arid summers and mild winters characterized by limited rainfall [13]. The volume of rainfall in Fallujah is exceedingly scant, rendering it inadequate to satisfy the water requirements of crops. Consequently, local farmers rely heavily on surface irrigation to address their water needs. Air temperature plays a significant role in influencing factors like relative humidity and evaporation, as highlighted by [14].

The study region is in a hot climate zone known for its extended summer season, which spans from March through the end of October and features low humidity levels[15]. In the study region, relative humidity was notably affected by the presence of surface water bodies, including the Euphrates River, Habbaniyah, and Tharthar Lake, all situated at higher elevations above sea level[16]. Wind velocity within the study area exhibits variability, contingent upon seasonal fluctuations and prevailing weather circumstances. Typically, the region encounters moderate wind speeds. Nonetheless, it is crucial to acknowledge that wind velocities can escalate during specific weather phenomena like sandstorms or thunderstorms. In 2022, the daily climate data was acquired from the Upper Euphrates Basin Development Center at the University of Anbar.

2.2 Water Resources of the Study Area

According to the Water Resources Department of Fallujah, the Euphrates River is the region's primary water source for agricultural, domestic, and industrial needs. It enters the study area at Albu Shejel village in the Saqlawia district, runs through the city for 82 kilometers, and exits at Al-Owaisat village. To the north of Saqlawiyah, at the boundary of the Directorate of Resources in Fallujah, the Tharthar canal merges water from Tharthar Lake into the Euphrates River. The Sin al-Dhaban canal on the river's right bank conveys Water from Habbaniyah Lake to the Euphrates. Two additional canals in the northern region contribute to the water supply: the Tharthar-Tigris canal, transferring Water from the Tharthar Canal to the Tigris River over 65 kilometers, and the new irrigation (desalination) canal, extending 60 kilometers from the Tigress River into the Tharthar canal. The Saqlawiya irrigation stream flows through the Saqlawiya and Karma areas at a rate of 26 m3/s, dividing into two branches for irrigation in these regions. Water flow in the Euphrates River varies, influenced by the Haditha Dam's outflow, which depends on water inputs from upstream countries and available water storage, as shown in Figure 2.

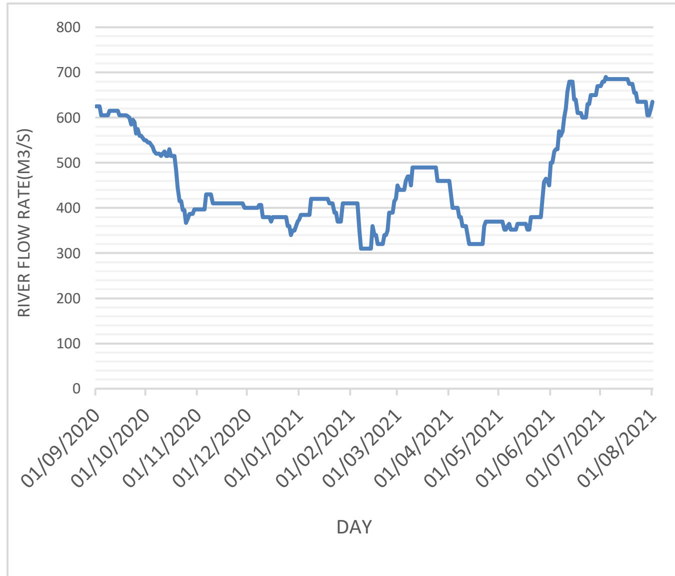


Figure 2. Monthly Euphrates river flow rate at Fallujah city (2020-2021)

2.3 WEAP modelling process

The WEAP program's input data encompass monthly water inflows into the region, including surface water, groundwater, and lateral channels, and the monthly and daily demands of various sites for domestic, agricultural, or industrial purposes[17]. Consequently, key outcomes include determining annual and monthly water deficits or surpluses at each site and evaluating the performance of the examined river or basin[18]. Additionally, by incorporating the MABIA program into the WEAP framework for agricultural demand sites, the actual agricultural water productivity within the region's specific conditions can be estimated [19]. The program generates Numeous outputs, with the most significant ones being the computation of net water requirements, irrigation quantities, and the frequency of irrigations during each phonological phase, crop yields, and consequently, water productivity[20]. Figure 3 illustrates the program's modeling.

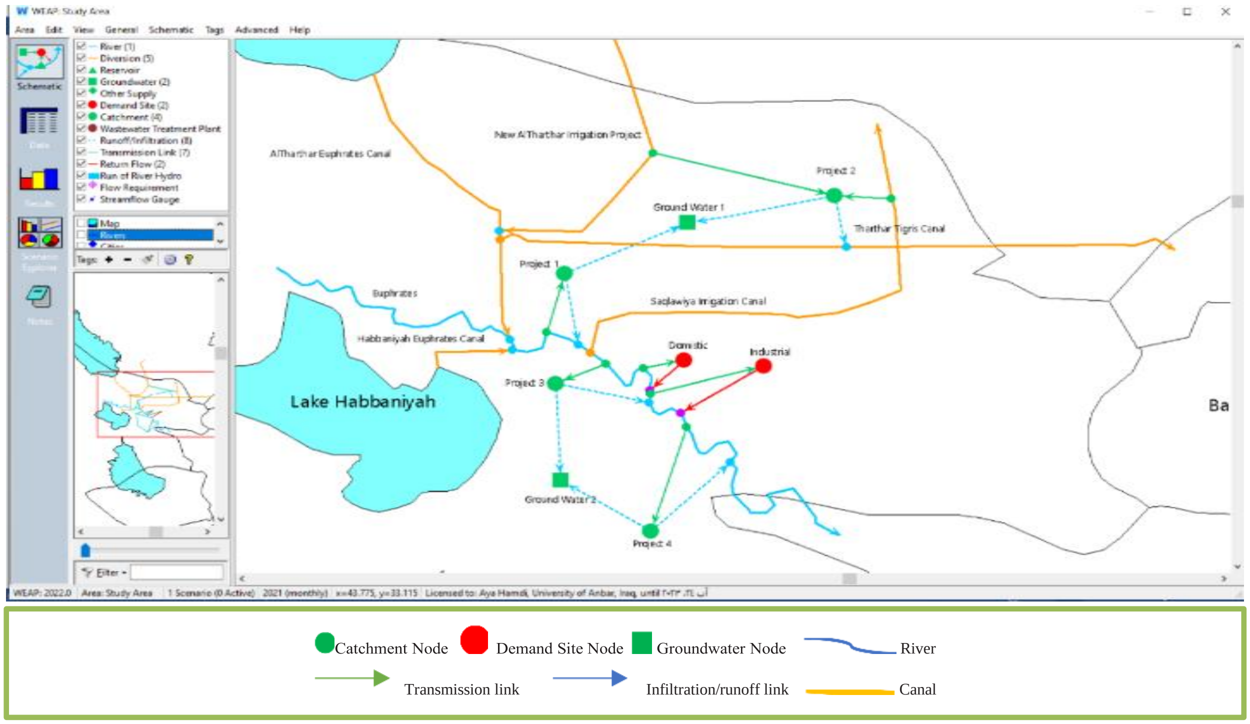


Figure 3 (WEAP-MABIA Schematic of the Fallujah city)

The steps involved in the WEAP-MABIA calculations are as follows:

1- Reference Evapotranspiration (ETref): Reference crop evapotranspiration, known as ETo or ETref, is calculated in the WEAP model using the Penman-Monteith equation[21]:

$$ET0 = \frac{0.408\Delta\,(Rn-G)+\gamma\,\frac{900}{Tmean+273}U2\,(es-ea)}{\Delta+\gamma\,(1+0.34\,U2)} \quad (1)$$

ETo: Reference evapotranspiration (mm day-1).
Rn: Net radiation at the surface of the crop (MJ m-2 day-1).
G: The soil heat flux density (MJ m-2 day-1) is typically considered negligible (G = 0).
Tmean: Average daily air temperature at a height of 2m (°C).
U2: Wind speed at 2m height (m s-1).
es: Vapor pressure of saturation (kPa).
*e*a: Actual vapor pressure (kPa).
es – *e*a: Saturation vapor pressure deficit (kPa).
Δ: Slope of the vapor pressure curve (kPa /°C).
γ: Psychometric constant (kPa /°C).

2- Soil Water Capacity: The MABIA method necessitates data on the Water holding capacity at field and wilt points for each land use within a catchment. When utilizing Soil Profiles, one can directly input field capacity and wilt point values or select a specific texture class from the Soil Library[22].

3- Basal Crop Coefficient (Kcb): The MABIA Method employs a 'dual' Kc method, following the description found in FAO Irrigation and Drainage Paper No. 56. In this method, the Kc value is divided into two components: the 'basal' crop coefficient, Kcb, and a separate component, Ke, representing evaporation from the soil surface. Kcb signifies actual evapotranspiration conditions when the soil surface is dry, but sufficient moisture exists in the root zone to support full transpiration [23].

4- Potential and Actual Crop Evapotranspiration (ETc): Potential crop evapotranspiration is estimated under standard field conditions. However, since precipitation and irrigation often fall short of meeting the full ETc requirement, the soil water content in the root zone decreases to levels where plant roots cannot extract the entire ETc amount. This leads to water stress, resulting in ETa being less than ETc. The reduction in ETa can be estimated using a daily soil water balance [24].

5- Irrigation: The principal objective of irrigation is to apply Water at the appropriate time and in the correct quantity. An irrigation schedule specifies the timing (the specific day) and amount (depth) of irrigation[25]. Various methods are available to determine both the timing and amount of irrigation. The ideal irrigation schedule and quantity would use the percentage of Readily Available Water (RAW) at 100% as the trigger method and the percentage of Depletion at 100% as the irrigation amount method. This approach ensures that irrigation occurs just before crop stress arises and provides enough Water to return the soil to field capacity[26].

6- Yield Response to Water Shortage: Water deficits in crops, resulting in plant water stress, directly impact crop evapotranspiration and crop yield [27]. The WEAP model requires data regarding the maximum crop productivity (Ym) for different irrigation methods and the unit price ($/Kg) for each crop. Crop yields under surface irrigation (Kg/ha) were sourced from the Central Statistical Organization of Iraq in 2022, and the corresponding unit prices for each crop are provided in Table 1.

Table 1 (Crops productivity for various irrigation techniques and Prices ($))
(Source: Central Statistical Organization Iraq, 2022)

Crops	Surface (Kg / ha)	Sprinkler (Kg / ha)	Trickle (Kg / ha)	Market Price ($ / Kg)
Wheat	2779	4158	--------	0.34
Barley	1419	5500	--------	0.32
Maize	5444	--------	7505	0.43
Cucumber	10056	--------	20870	0.43
Eggplants	16264	--------	46500	0.43
Kidney Beans	5020	--------	15000	1.20
Spring Potato	26983	--------	44560	0.48
Sesame	893	--------	1623	1.50
Sunflower	2226	--------	2830	0.73
Sweet Pepper	8710	--------	21620	0.52
Tomato	26866	--------	44400	0.30
Watermelon	19225	--------	37870	0.35
Berseem	12441	--------	9758	0.36
Broad bean	5802	--------	7600	0.52
Cauliflower	8632	--------	23550	0.39
Autumn Potato	26983	--------	44560	0.48
Citrus	4004	--------	4004	1.30
Grape	11800	--------	11800	0.72
Olives	17211	--------	17211	1.26
Palm	9872	--------	9872	1.10

3. Results and discussion

The findings revealed the annual total reference evaporation, determined using the Penman-Monteith Equation, to be 1696 mm. This value exhibited a noticeable rise from 60 mm per month in December to its zenith of 211 mm per month in July, as depicted in Figure 4. This escalation in irrigation water requirements during the summer can be attributed to the higher temperatures. For instance, wheat crops' evapotranspiration (ETc) was 48 mm during the initial stage and increased to 112 mm during the developmental stage. From February to mid-April, the mid-stage recorded 277 mm, with 143 mm in the final stage leading up to harvesting in mid-May, as illustrated in Figure 5.

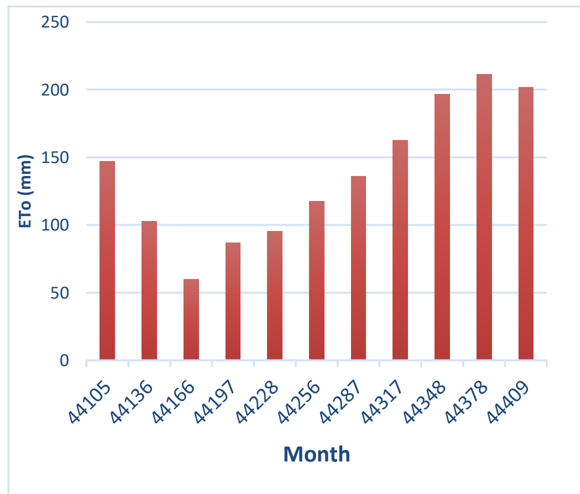


Figure 4 (Monthly reference evapotranspiration (**E 0**) for (2021-2022))

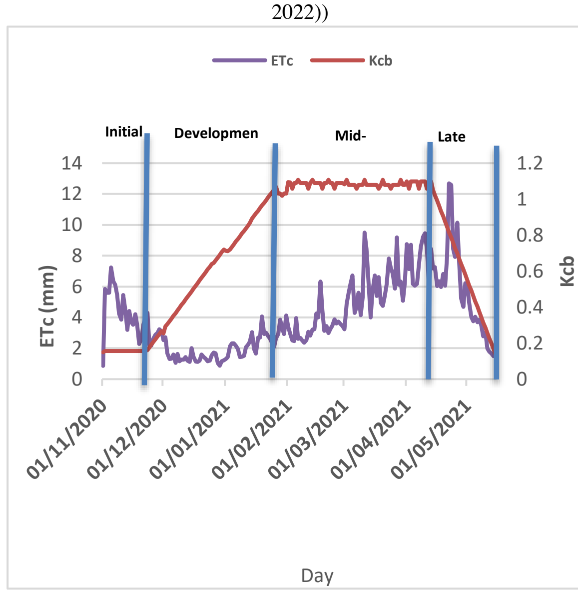
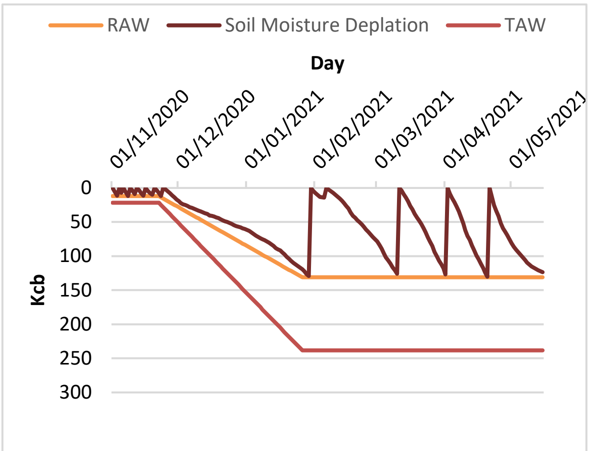
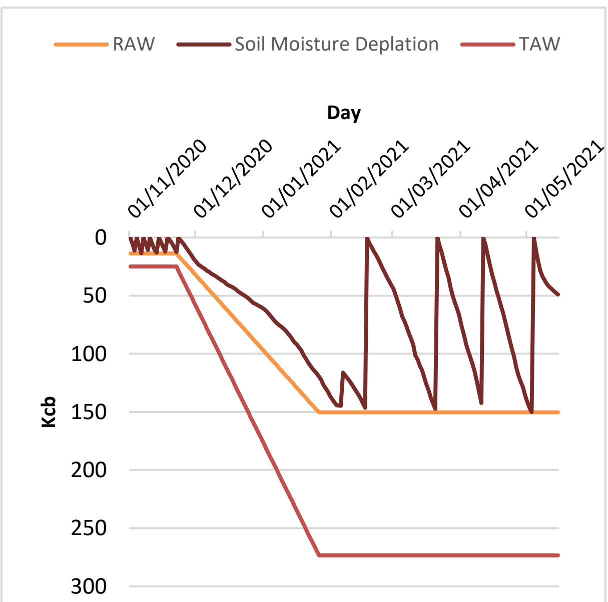


Figure 5. (Wheat crop evapotranspiration (**E c**) for project 1

Where the differences in (TAW) lead to different (RAW) of Fallujah irrigation projects. The Readily Available Water (RAW) is contingent upon the Total Available Water (TAW) and is influenced by the depletion factor of the crop (p) throughout its growth stages.



(a)



(b)

Figure 6. (Wheat daily soil moisture by WEAP) Where (a) represents the daily depletion with daily total and readily available in project 1 and 2 and (b) for project 3 and 4

The water requirements of each project in Figure 7 were calculated according to the cultivated area with the water requirement of crops for each project as in Table 2.

During November, the water demand amounted to 91.7 million cubic meters, aligning with the planting season for critical crops like wheat and barley. However, as temperatures decreased in December, January, and February, the water requirement significantly dropped to 22.5, 57.2, and 40.7 million cubic meters per month.

Conversely, as March, April, May, and June arrived, the water demand increased to 129.0, 170.2, 163.3, and 156.8 million cubic meters per month. This rise was due to the growing water needs of the crops, as shown in Figure 7, where water demand is directly proportional to the crop's water consumption (ETc). As the strategic crops of wheat and barley were harvested in July, the water requirement gradually decreased until it reached 42.2 million cubic meters per month in August, mainly due to the limited cultivated area.

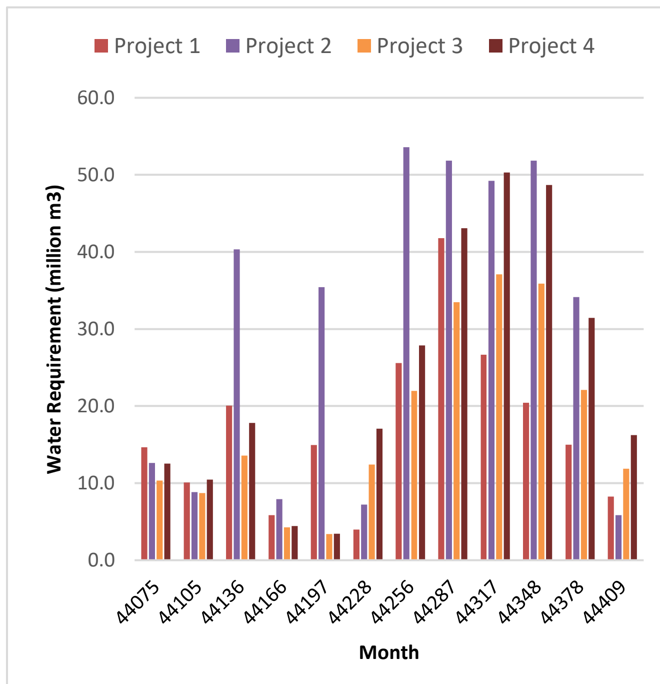


Figure 7 (Total water requirements from river (with all losses))

The Total water supply represents the Water from the river to each project, including the field efficiency of 55% and the conveyance efficiency of the lined canal of 85% [28], as in Table 3. These differences in water requirements among projects were primarily attributed to variations in cultivated areas and soil texture, as depicted in Table 4. Notably, project 2 and project 4 had the largest areas, with 40497 ha and 20253 ha, respectively.

Table 2. (Net and Gross irrigation depth of crops in (mm))

Crops	Project 1		Project 2		Project 3		Project 4	
	dn	dg	dn	dg	dn	dg	dn	Dg
Wheat	663.5	1206.3	663.0	1205.5	728.1	1323.9	729.5	1326.3
Barley	736.6	1339.4	736.1	1338.4	707.4	1286.3	708.9	1288.9
Maize	1343.5	2442.8	1343.6	2442.8	1327.6	2413.9	1327.8	2414.3
Cucumber	1216.4	2211.7	1216.4	2211.7	1213.7	2206.7	1213.9	2207.1
Eggplants	1208.3	2196.9	1199.0	2180.0	1201.8	2185.1	1202.3	2185.9
Kidney beans	864.7	1572.2	864.6	1572.1	863.3	1569.6	863.6	1570.2
Potato Spring	1167.8	2123.2	1167.8	2123.3	1137.4	2068.1	1137.6	2068.3
Sesame	1225.6	2228.3	1225.5	2228.1	1188.2	2160.3	1188.8	2161.4
Sunflower	1282.6	2332.0	1282.6	2332.1	1244.0	2261.8	1244.3	2262.3
Sweet Pepper	1385.3	2518.7	1385.3	2518.7	1351.6	2457.4	1351.8	2457.9
Tomato	1210.1	2200.1	1210.1	2200.1	1186.8	2157.8	1187.1	2158.3
Watermelon	1228.1	2233.0	1228.2	2233.0	1181.1	2147.5	1181.4	2148.0
Berseem	593.7	1079.4	596.9	1085.3	589.0	1070.9	590.0	1072.7
Broad bean	1065.0	1936.5	1064.5	1935.5	1011.5	1839.2	1013.2	1842.1
Cauliflower	681.6	1239.2	681.0	1238.3	664.0	1207.3	660.1	1200.2
Potato autumn	883.9	1607.1	883.3	1606.1	868.5	1579.1	859.8	1563.2
Citrus	2543.5	4624.5	2543.1	4623.7	2507.0	4558.3	2509.0	4561.9
Grape	2013.4	3660.7	2013.3	3660.5	1935.2	3518.6	1936.0	3520.1
Olives	2075.4	3773.5	2075.0	3772.8	1998.0	3632.6	1999.5	3635.4
Palm	3058.0	5560.0	3057.4	5558.9	2968.6	5397.5	2971.0	5401.8

Table 3. (Total water requirements for each project from river in (million m^3/year))

Project	Field losses	Conveyance losses	Net irrigation requirement	Total volume
Project 1	83.1	41.5	152.3	276.8
Project 2	149.6	74.8	274.3	498.7
Project 3	65.1	32.6	119.4	217.1
Project 4	84.1	42.0	154.1	280.2
Sum	**381.9**	**190.9**	**700.1**	**1272.9**

Table 4. (Project cultivated area)

Project	Area (ha)	Cultivated Area			
		Winter Crops %	Summer Crops %	Perennial Crops %	Strategic Crops %
Project 1	17,377	21.09	9.79	8.23	28.08
Project 2	40,497	8.23	16.86	2.22	39.49
Project 3	14,984	10.79	21.59	13.30	21.31
Project 4	20,253	9.05	18.01	11.99	27.98
Sum	**93,112**	**11.31**	**16.55**	**7.25**	**31.93**

3.1 Surface Irrigation

The yearly crop production, as indicated in Table 5, was computed by multiplying the cultivated area of each crop by its yield per hectare, assuming the utilization of the surface irrigation method, as detailed in Table 1. The volume of water production fluctuated based on the soil texture of the projects and was determined by multiplying the total irrigation depth by the cultivated area of each crop.

Project 2 and Project 4 exhibit superior production levels compared to Projects 1 and 3, while greater economic returns are exhibited in Project 1 and Project 2, as shown in Table 6.

Typically, the productivity of surface irrigation systems is relatively lower when compared to other irrigation methods like sprinkler and trickle irrigation, which achieve higher irrigation efficiency levels of 75% and 90%, respectively. In ideal irrigation practices, the initial growth stage experienced frequent irrigation occurrences, with gross irrigation depths ranging from 23 mm to 41 mm, as shown in Figure 6. Nonetheless, shallow irrigation depths pose challenges for surface irrigation systems, whereas sprinkler and trickle systems are better equipped to handle these lighter irrigation depths.

Table 5. (Annual production with water production in (million) by WEAP)

Crops	Project 1		Project 2		Project 3		Project 4	
	Kg/year	Water Vol.	Kg/year	Water Vol.	Kg/year	Water Vol.	Kg/year	Water Vol.
Wheat	10.34	44.88	32.03	138.95	5.66	26.98	11.11	53.03
Barley	1.59	15.01	5.35	50.46	1.41	12.82	0.92	8.33
Maize	0.21	0.93	3.79	17.02	0.86	3.83	5.57	24.69
Cucumber	3.15	17.40	1.80	9.94	3.99	21.99	4.57	25.19
Eggplants	0.84	1.57	1.06	1.96	1.18	2.18	2.29	4.25
Kidney Beans	1.23	1.12	1.55	1.41	1.03	0.94	2.09	1.91
Spring Potato	4.94	10.63	2.66	5.73	8.26	17.31	9.59	20.09
Sesame	2.91	6.44	12.36	27.38	8.46	18.17	4.77	10.25
Sunflower	3.04	4.36	11.10	15.92	10.52	14.63	4.75	6.60
Sweet Pepper	0.26	1.29	0.69	3.44	0.65	3.18	0.73	3.59
Tomato	0.21	5.24	0.61	15.02	0.06	1.40	0.65	15.75
Watermelon	4.12	3.42	27.54	22.87	13.05	10.42	9.81	7.83
Berseem	0.72	3.49	2.74	13.34	0.22	1.04	1.22	5.87
Broad bean	1.63	3.62	5.95	13.22	2.82	5.95	3.18	6.72
Cauliflower	5.03	2.32	22.01	10.15	9.56	4.30	11.76	5.25
Autumn Potato	1.64	1.37	6.56	5.48	5.60	4.60	5.61	4.56
Citrus	44.35	76.27	41.31	71.03	19.01	32.22	22.08	37.46
Grape	20.52	60.37	16.99	49.99	9.41	26.60	9.08	25.69
Olives	1.06	6.91	0.99	6.44	0.38	2.39	0.53	3.32
Palm	1.58	10.19	2.95	18.98	0.99	6.21	1.58	9.86
Sum	**109.37**	**276.84**	**200.04**	**498.72**	**103.12**	**217.15**	**111.88**	**280.23**

Table 6. (Production and economic returns in (million/year))

Project	Production (Kg/year)	Water used in production (m^3/year)	Returns ($/year)
Project 1	109.4	276.8	97.3
Project 2	200.0	498.7	141.7
Project 3	103.1	217.1	76.5
Project 4	111.9	280.2	78.2
Sum	524.4	1272.9	393.6

3.2 Irrigation System Improvements

3.2.1 First Scenario

In this particular situation, a sprinkler irrigation system with an efficiency of 75% was employed for strategic crops like wheat and barley. In comparison, surface irrigation, with an efficiency of 55%, was utilized for other crops, including both summer and winter varieties and trees.

Table 7. (Total water supply from river with all losses in (million /year))

Project	Field losses	Conveyance losses	Net irrigation requirement	Total volume
Project 1	71.1	41.5	164.2	276.8
Project 2	111.7	74.8	312.2	498.7
Project 3	57.2	32.6	127.4	217.1
Project 4	71.8	42.0	166.4	280.2
Sum	**311.8**	**190.9**	**770.2**	**1272.9**

Table 8. (Annual production and water used in production in (million))

Crops	Project 1		Project 2		Project 3		Project 4	
	Kg/year	Water Vol.	Kg/year	Water Vol.	Kg/year	Water Vol.	Kg/year	Water Vol.
Wheat	21.10	44.88	65.35	138.95	11.55	26.98	22.67	53.03
Barley	8.41	15.01	28.28	50.46	7.47	12.82	4.85	8.33

Table 9 (Production and economic return in (million))

Project	Production (Kg/year)	Water used in production (m^3/year)	Returns ($/year)
Project 1	126.9	276.8	103.1
Project 2	256.3	498.7	160.3
Project 3	115.1	217.1	80.4
Project 4	127.4	280.2	83.4
Sum	625.7	1272.9	427.2

Field losses witnessed a 22.5% reduction, decreasing from 381.9 to 311.8 million m^3/year, as highlighted in Table 7. Across all projects, annual wheat production of 104% and barley production experienced a significant 428% increase. Water production signifies the gross irrigation carried out via sprinkler systems multiplied by the cultivated crop area. This increase can be attributed to the higher crop yields achieved under sprinkler irrigation, as outlined in Table 8, with a reduced water input due to the enhanced efficiency of sprinkler irrigation. This decrease in water requirements facilitated an expansion in cultivated areas, as the available water supply became sufficient for a larger area. In the case of the Falluja irrigation project, production increased by 19.3%, rising from 524.4 to 625.7 million m^3/year, consequently leading to an 8.5% boost in economic returns, from 393.6 to 427.2 million $/year, as depicted in Table 9.

3.2.2 Second Scenario

In this suggested scenario, it is advisable to employ sprinkler irrigation for strategic crops like wheat and barley. For other crops grown during both summer and winter, as well as for trees, it is recommended to utilize trickle irrigation, which has a higher efficiency of 90%. Furthermore, the suggestion involves substituting lined channels with pipe channels to enhance conveyance efficiency, elevating it from 85% to 95%. Consequently, field losses witnessed a remarkable 85.2% reduction, plummeting from 381.9 to 116.2 million m^3/year, as depicted in Table 10. Additionally, conveyance losses decreased by

66.7%, resulting in substantial water savings, declining from 190.9 to 63.6 million m^3/year.

Table 10. (Total water supply from river with all losses in million (m^3 / year))

Project	Field losses	Conveyance losses	Net irrigation requirement	Total volume
Project 1	22.8	13.8	240.2	276.8
Project 2	53.3	24.9	420.4	498.7
Project 3	16.8	10.9	189.5	217.1
Project 4	23.2	14.0	243.0	280.2
Sum	**116.2**	**63.6**	**1093.1**	**1272.9**

Table 11. (Annual crop production with water production in (million))

Crops	Project 1		Project 2		Project 3		Project 4	
	Kg/year	Water Vol.	Kg/year	Water Vol.	Kg/year	Water Vol.	Kg/year	Water Vol.
Wheat	21.10	44.88	65.35	138.95	11.55	26.98	22.67	53.03
Barley	8.41	15.01	28.28	50.46	7.47	12.82	4.85	8.33
Maize	0.47	0.93	8.55	17.02	1.95	3.83	12.56	24.69
Cucumber	26.86	17.40	15.35	9.94	34.03	21.99	38.98	25.19
Eggplants	5.44	1.57	6.84	1.96	7.58	2.18	14.78	4.25
Kidney Beans	1.76	1.12	2.21	1.41	1.47	0.94	2.98	1.91
Spring Potato	36.50	10.63	19.67	5.73	61.03	17.31	70.83	20.09
Sesame	0.77	6.44	3.26	27.38	2.23	18.17	1.26	10.25
Sunflower	0.87	4.36	3.16	15.92	3.00	14.63	1.35	6.60
Sweet Pepper	1.81	1.29	4.83	3.44	4.58	3.18	5.16	3.59
Tomato	17.30	5.24	49.61	15.02	4.70	1.40	53.00	15.75
Watermelon	9.49	3.42	63.47	22.87	30.07	10.42	22.60	7.83
Berseem	5.16	3.49	19.62	13.34	1.55	1.04	8.74	5.87
Broad bean	2.33	3.62	8.49	13.22	4.02	5.95	4.54	6.72
Cauliflower	7.21	2.32	31.57	10.15	13.71	4.30	16.87	5.25
Autumn Potato	6.20	1.37	24.89	5.48	21.23	4.60	21.28	4.56
Citrus	10.81	76.27	10.07	71.03	4.63	32.22	5.38	37.46
Grape	31.84	60.37	26.37	49.99	14.60	26.60	14.09	25.69
Olives	5.16	6.91	4.81	6.44	1.85	2.39	2.57	3.32
Palm	2.96	10.19	5.51	18.98	1.86	6.21	2.95	9.86
Sum	**202.44**	**276.84**	**401.92**	**498.72**	**233.12**	**217.15**	**327.43**	**280.23**

Table 12. (Production and economic return in (million / year))

Project	Production (Kg/year)	Water used in production (m^3/year)	Returns ($/year)
Project 1.	202.4	276.8	110.4
Project 2	401.9	498.7	183.3
Project 3	233.1	217.1	115.1
Project 4	327.4	280.2	150.6
Sum	1164.9	1272.9	559.4

maize, cucumber, eggplants, kidney beans, potato spring, sesame, sunflower, sweet pepper, tomato, and watermelon also experienced a remarkable 386%, 183%, 215%, and 437% surge in project 1, 2, 3 and 4 respectively, as documented in Table 11.

In scenario 1, a substantial 104% and 428% increase was observed in wheat and barley production across all projects. Similarly, winter crops, including berseem, broad beans, and autumn potato, recorded a noteworthy 131%, 126%, 122%, and 134% growth in projects 1, 2, 3, and 4 respectively. Furthermore, summer crops such as

The geographical area covered by Falluja irrigation projects expanded by 52%, 47%, 54%, and 52% across projects 1, 2, 3, and 4, respectively. Consequently, production soared by 122%, escalating from 524 to 1165 million m^3/year, while economic returns surged by 42%, increasing from 393.6 to 559.4 million $/year, as detailed in Table 12.

4. Conclusion

The research proposes two scenarios for using modern water irrigation systems in Fallujah. In the first scenario, the proposal suggests using sprinklers for wheat and barley. In contrast, the second scenario recommends using sprinklers for wheat and barley and trickle irrigation systems for other summer and winter crops. Implementing modern water irrigation systems significantly reduces the water required to irrigate the cultivated area.

Under the first scenario, the production of the cultivated area increases from 524.4 million kg/year to 625.7 million kg/year. This production further rises to 1164.9 million kg/year in the second scenario. Similarly, the annual return on investment experiences growth. In scenario 1, it increases from 393.6 million $/year to 427.2 million $/year. In scenario 2, the annual return climbs to 559.4 million $/year.

Furthermore, the field losses of Water during crop irrigation decrease significantly due to the utilization of modern irrigation systems. In the first scenario, these losses decrease from 381.9 million m3/year to 311.8 million m^3/year. The reduction is even more pronounced in the second scenario, with field losses decreasing to 116.2 million m^3/year.

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