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Optimising water resources management by Using Water Evaluation and Planning (WEAP) in the West of Iraq

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Abstract: Iraq has been suffering from decreasing Euphrates discharge due to the construction of dams within upstream countries and the use of surface irrigation systems. The country is facing a problem with meeting the increasing demand for water as a result of population growth and development in the industrial and agricultural sectors. Therefore, a simulation modelling was applied for western Iraq (Ramadi city as a case study) using the Water Evaluation and Planning System (WEAP) for the period 2018–2035. This research follows a four-step approach that involves: (i) evaluating the available water of the Euphrates River under declined water imports caused by the construction of dams in Turkey and Syria, (ii) assessing present and future water demands of the domestic, industrial, and agricultural sectors, (iii) improving water productivity (WP) by means of saving more water, (iv) estimating the economic returns under improved water use. The results showed that Iraq would face a serious problem in the coming years, represented by the limited storage of Haditha Dam, which is considered the strategic water storage site for the central and southern regions of Iraq. The study indicated the necessity of finding alternative sources of water supply by adopting new water management strategies to reduce the water deficit.

Keywords: dual K_c approach, water management, water productivity, WEAP-model

INTRODUCTION

In view of climatic and environmental changes, it is necessary to adopt new water management strategies for domestic, industrial, and agricultural purposes. The global population is expected to increase from 7.3 bln to 9.8 bln between 2015 and 2050 [Walker 2016], causing an increase in demand for freshwater. Demand for food is expected to be higher in developing countries, where the population is predicted to increase by more than 80% [Seckler *et al.* 1998]. Globally, water consumed for irrigation accounts for 70% of the available freshwater resources. In some developing countries, it can account for up to 95% of freshwater resources [FAO 2017]. This will make it necessary for these countries to find ways to increase food production while using less water. The main sources of water supplies in Iraq are the Tigris and the Euphrates Rivers. The amount of water in the Tigris and Euphrates rivers has dropped to less than a third of their capacity in recent years. The decrease in the flow of rivers is due to limited precipitation, increasing desertification, and the construction of dams by upstream countries. Iraq's average annual rainfall is equivalent to 216 mm per year [Noon *et al.* 2021; Sulaiman *et al.* 2019a; UN 2013].

In Iraq, agriculture is the top water consumer, which uses up to 85% of the water obtained from the Tigris and Euphrates rivers. Adopting new irrigation methods, such as sprinkler and drip irrigation, is important for reducing water consumption in agriculture in the future. The Water Evaluation and Planning (WEAP) is a software tool developed by Stockholm Environment Institute's U.S. Center in 1999. It is used for the evaluation and management of water resources with a set of tools representing water supply and demand. It deals with demand priorities and supply preferences and it evaluates the available present and future water demand. The WEAP model was used in the simulation of the water supply and demand in the Aral Sea within Russia [Raskin *et al.* 1992]. It was applied as an integrated model in planning water resources at a regional, local, and basin-scale [Demertzi *et al.* 2014; Groves *et al.* 2008; Purkey *et al.* 2007]. Since 2008, the model has been adjusted and tested within Central Asia and West Africa under different ecological and hydrological conditions. The WEAP model was used in estimating water resources in the Jordan River [Hoff *et al.* 2011], as well as raising the water productivity of agriculture in Palestine by using wastewater in the Nar River [Almasri, Hindi 2008]. The WEAP was applied in various studies in China [Gao *et al.* 2017], South Africa [Slaughter, Mantel 2018], and the United States [Brown *et al.* 2019].

In this study, the sprinkler irrigation method was used for strategic crops such as wheat and barley, while the trickle irrigation was used for trees and for winter crops during the summer. The economic returns obtained for surface, sprinkler, and trickle irrigation methods were subsequently compared. The impact of groundwater and capillary rise on crops was ignored within the irrigation project because the groundwater is present at great depths. The dual K_c approach was applied because it renders more accurate results than the single-K_c approach, where the dual approach divides the crop coefficient (K_c) into the "Basal" crop coefficient (K_b) and the evaporation coefficient from the soil (K_e). The dual approach is more suitable in arid and semi-arid regions, where there is a need to estimate the water requirements of crops in real-time.

MATERIALS AND METHODS

STUDY AREA

The study area is located between 33°26'84" N to 33°22'15.46" N latitude and 43°35'36.63" E to 43°57'59.50" E longitude (Fig. 1). It extends from Abu Tayban west of Ramadi on the right of the Euphrates River and ends at Al-Malahma to the left of the Euphrates River, east of Ramadi.

The city has an important strategic location 108 km west of Baghdad and is considered the capital of Anbar governorate. It is bordered by Salah Al-Din governorate in the north and northeast, Karbala governorate in the south and southwest, Hit city in the west, and Fallujah city in the east [Al-Dulaimy 2018].

The study area has several water bodies, including Tharthar Lake to the north and Habbaniyah Lake to the east of Ramadi city. These lakes are used in periods of water shortages. Al-Warar stream to the west of Ramadi is used to transport water from the Euphrates River by Al-Warar regulator to Habbaniyah Lake.

EUPHRATES RIVER

The Euphrates Basin is shared by several countries. Turkey has 28% of the length of the river, 17% is located in Syria, 40% in Iraq, 15% in Saudi Arabia, and 0.03% in Jordan [UN-ESCWA, BGR 2013]. Turkey is the main water contributor; it contributes 89% of the total flow, while 11% is contributed by Syria [Glass 2017].

Irrigation, hydropower, domestic uses, and agriculture are the main uses of water from the Euphrates River in Iraq, Syria, and Turkey. The agricultural sector has the highest share in the water demand, which exceeds 70%.

The average annual precipitation within the Euphrates River Basin is 335 mm, with varying levels across the basin regions [New *et al.* 2002]. Usually, the annual rainfall in the Mesopotamian Plain does not exceed 200 mm, while in other regions of the basin it exceeds 1045 mm [Haleem, Al-Muhyi 2016]. The summer season is characterised by hot and dry weather, with temperatures reaching 50°C, while the relative humidity during the day is less than 15% [Jaber *et al.* 2020]. These climatic trends indicate that in Syria, about 60% of the basin gets less than 250 mm of precipitation per year, while in Iraq 70% of the basin has an average precipitation of 400 mm per year [UNDP 2013]. Due to its geographic location, Turkey is the dominant country within the Tigris and Euphrates basins where

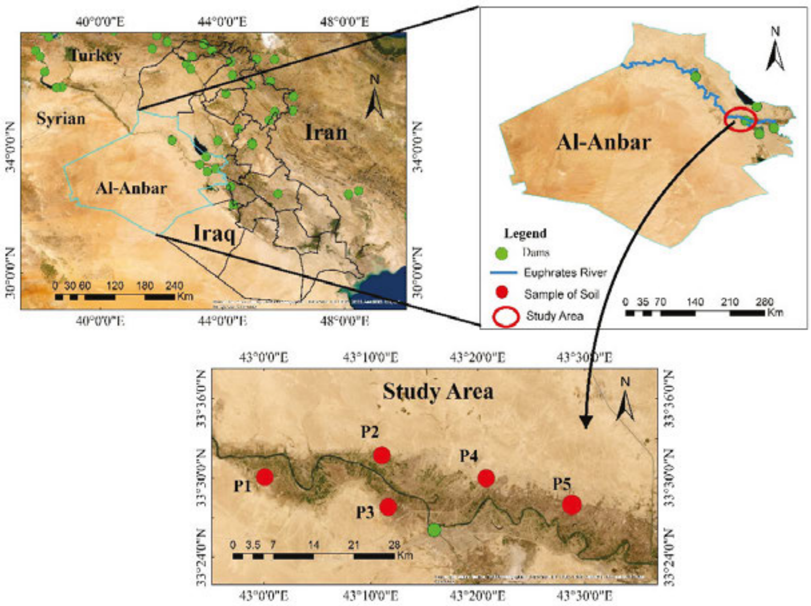

Fig. 1. Map of the study area with water dams obtained by using ArcGIS 10.8; source: own elaboration based on Google Maps

it possesses ample freshwater supplies [Al-Ansari 2013; 2016; Al-Ansari *et al.* 2021]. Syria depends heavily on the water of the Euphrates River, while Iraq relies on the water of the Tigris and Euphrates Rivers.

Most of the water used in Turkey is intended for hydropower generation and irrigation. The return flow from irrigation in Turkey is directly disposed into the Euphrates River. Accordingly, the quality of the water deteriorates further downstream toward Syria and Iraq [Al-Ansari 2013; 2016; Al-Ansari *et al.* 2021]. In the 1960s, Syria started to use the Euphrates' water for irrigation and hydropower generation. The Tabqa Dam on the Euphrates was built in 1973, and the purpose of this large dam was to supply water and energy to Syria. The Bath Dam, constructed in 1986, was the second Syrian dam on the Euphrates River. The Bath Dam features a small hydropower station for electricity production and provides some water for irrigation. The Tishreen Dam is the third Syrian dam on the Euphrates. This dam was built primarily for the generation of hydropower [Glass 2017; Yousuf *et al.* 2018]. Turkey started building the first dam on the Euphrates River in the mid-1960s. The first dam known as the Keban Dam near Keban Strait was completed in 1973. The Karakaya Dam was completed in 1988 and has been considered the second dam on the Euphrates.

The Karakaya and Keban Dams are mainly used to generate hydropower (Tab. 1). The third dam on the Euphrates River, built in 1992, was the Ataturk Dam, which is considered the most important dam within the GAP program. It stores water for irrigation and hydroelectricity generation [Balciogullari 2018].

Table 1. Major dams on the Euphrates

Name	Rated capacity (MW)	Storage capacity (km^3)	Irrigation
Keban	1240	31.0	–
Karakaya	1800	9.58	–
Ataturk	2400	48.7	use
Birecik	672	1.22	use
Karkamis	180	0.157	–
Tishreen	630	1.88	–
Tabqa	880	14.16	use

Source: Tilmant *et al.* [2009], modified.

DEMAND SITES

The population growth rate in the Middle East, particularly in Syria and Iraq, is considered to be high [Al-Ansari *et al.* 2021; Drake 2007] (Fig. 2). This implies a continuous future increase in water demand for the daily household uses such as drinking, watering the garden, bathing, preparing food, cleaning the house, and other uses, with an average person's share being 392 dm^3 per day [UN 2013]. The study area has a growth rate of about 2% according to data provided by the Anbar Statistics Directorate in 2018.

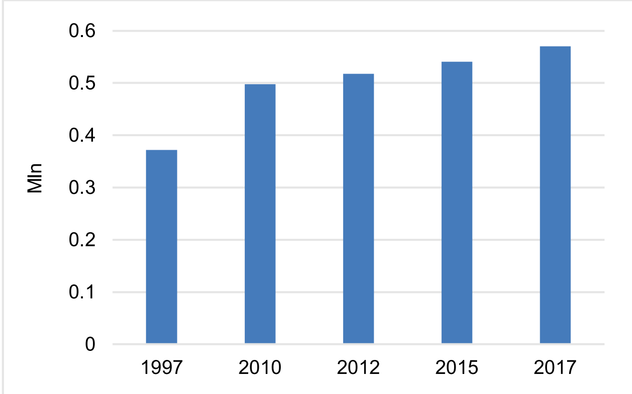

Fig. 2. Population census for study area; source: own elaboration based on unpublished data of the Central Statistical Organization (Iraq)

The industrial establishments are classified into small, medium, and large and characterised by different water demand levels. The sand and gravel washing facilities are based on the banks of the river and have water consumption of 0.0075 $m^3 \cdot s^{-1}$. They rely on the Euphrates River for washing their materials, which are discharged into the river and cause an increase in its salinity. Car wash sites are also located near the river. The water from these sites is often contaminated with oil, which is discharged into the river. There are small factories manufacturing materials such as aluminium, block, and concrete. The daily water consumption at these factories is 0.005 $m^3 \cdot s^{-1}$. The largest consumers of water are the glass and ceramic factories with a consumption rate of 0.4 $m^3 \cdot s^{-1}$.

The water of the Euphrates River is the primary source of water for the irrigation of crops. The irrigation efficiency is about 55%. The reduction in the water flow of the Euphrates River leads to the shrinking of the cultivated areas. At the same time, the relatively high population growth rate contributes to higher water demand. The irrigated lands that are suitable for agricultural purposes cover an area of 28,342 ha. The annual water budget available from the Euphrates River is 326 mln $m^3 \cdot y^{-1}$. The cultivated area is limited (Tab. 2), where 35% is allocated to winter crops, 3.46% to summer crops, and 0.39% is used for growing permanent crops. This requires achieving true water management without affecting the agricultural water budget.

Table 2. Project area and cultivated area for 2018–2019

Project	Area (ha)	Cultivated area		
		winter crops	summer crops	perennial crops
		%		
1	3,667	27.6	1.7	0.34
2	2,675	66.2	6.5	0.47
3	2,500	58.0	4.5	0.75
4	8,250	44.2	3.18	0.34
5	11,250	18.1	3.29	0.34
Sum	28,342	35.0	3.46	0.39

Source: own study.

WEAP MODEL – GENERAL INFORMATION

The Water Evaluation and Planning (WEAP) model was used in this study to model the water demand for industrial, domestic, and agricultural purposes with an estimate of the future water requirements, taking into account the expected increase in population. The data of the surface water resources represented by the Euphrates River and the population census with growth rate and industrial establishments were collected from government departments within the study area and the data published by researchers.

The productivity per hectare under surface irrigation and unit price for winter crops, such as wheat, barley, berseem, and summer crops, such as sweet pepper, spring potato, cucumber, sesame with other crops, as well as trees, such as palm, olives, and citrus, was collected from data published by the Central Statistical Organization of Iraq in 2018. The climate data were collected from the Iraqi Meteorological Organization and Seismology for 2019, as shown in Figure 3. The productivity per hectare under the sprinkler and trickle irrigation was collected from published research results [ABRISQUETA, AYARS 2018; DANESHNIA *et al.* 2015; EL-WAHED *et al.* 2015; ISODA *et al.* 2006; KUŞÇU *et al.* 2009; OSUNLA, OKOH 2017; PATIL, GADGE 2016; ROLBIECKI, SENYIGIT 2011; SAMPATHKUMAR *et al.* 2013; TAYEL *et al.* 2008].

For the soil texture, several samples were taken from different locations, as shown in Figure 1, to represent the soil texture for each irrigation project of the five irrigation projects in the study area (Tab. 3). Standard Test Method for Particle-Size Analysis of Soils [POPESCU *et al.* 2015] was used in the laboratory tests performed in the Upper Euphrates Basin Developing Center.

Table 3. Soil textures for Ramadi Irrigation Project

Project	Clay	Silt	Sand	Soil texture
	%			
1	18.8	24	57.2	sandy loam
2	20.8	42	62.8	sandy clay loam
3	16.8	42	41.2	loam
4	30.8	32	37.2	clay loam
5	20.8	50	29.2	silt loam

Source: own study.

WEAP MODELLING PROCESS

The population in future years can be estimated with the application of the WEAP model, using the "Growth Form" function, the population growth rate, and data from the last population census. A 2% growth rate was adopted for the purposes of the present calculation. The WEAP model requires annual water use per unit of activity with the water consumption from the water supply to the demand site. It was assumed that the water consumption from the water supply in developing countries was 20% [OSUNLA, OKOH 2017]. As for the annual water demand for industrial and domestic uses, the WEAP model calculates the annual water demand with this expression:

$$Tm = \sum (Ta \cdot Wq) \tag{1}$$

where: Tm = annual demand, Ta = total activity, Wq = water quota.

The agricultural sector is represented by the catchment node for each irrigation project within the study area as in Figure 4, and relies on the (FAO 56, dual K_c, daily) approach outlined in the FAO-56 paper [ALLEN *et al.* 2005]. It divided the crop coefficient K_c value to a "Basal" crop coefficient K_b, and evaporation soil coefficient K_e. The WEAP relies on the Penman-Monteith method to calculate the reference evapotranspiration (ET_o).

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} U_2\ (e_s - e_a)}{\Delta + \gamma\ (1 + 0.34U_2)} \tag{2}$$

where: ET_o = the reference evapotranspiration (mm·day^{-1}), R_n = the net radiation at the surface of the crop (MJ·m^{-2}·day^{-1}), G = the density of the soil heat flux (MJ·m^{-2}·day^{-1}), T = the average daily air temperature at the height of 2 m (°C), U_2 = the speed of wind at 2 m height (m·s^{-1}), e_s = the vapor pressure of the saturation

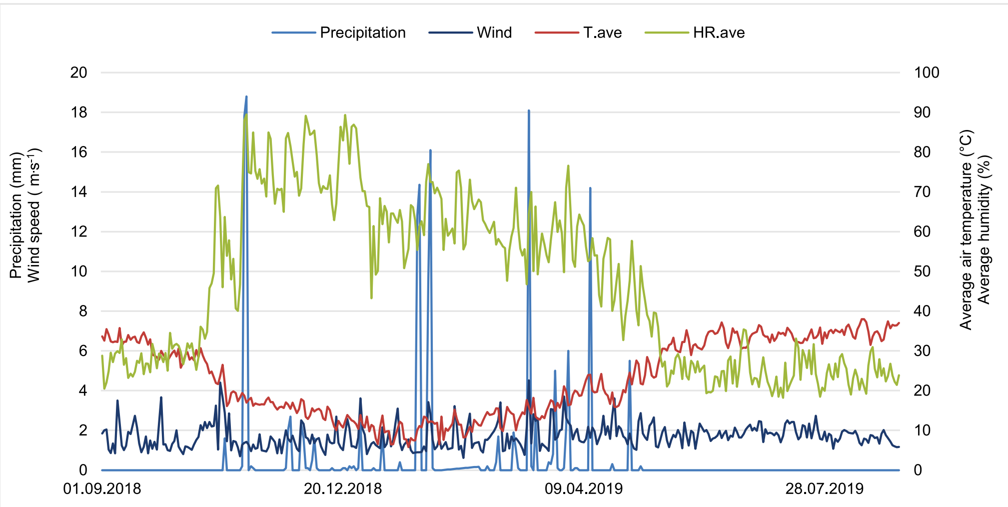

Fig. 3. Daily climate data for the period (2018–2019); source: NAJM *et al.* [2020]

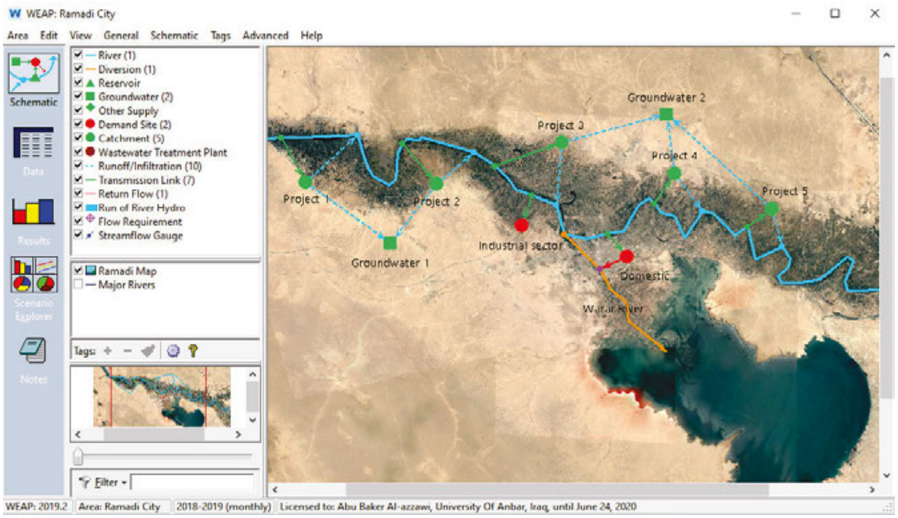

Fig. 4. Map of the demand sites with water supply by the WEAP Model; source: own study

(kPa), e_s = the actual vapor pressure (kPa), $e_s - e_a$ = saturation vapour pressure deficit (kPa), Δ = the slope vapor pressure curve (kPa·°C^{-1}), γ = the psychometric constant (kPa·°C^{-1}).

The purpose of irrigation is to supply crops with the required amount of water when the rainfall is not sufficient to provide the necessary moisture to the root zone with readily available water [CHARTZOULAKIS, BERTAKI 2015]. Therefore, the WEAP model supplies water to crops before it exceeds the (RAW) [SIEBER; PURKEY 2011]. The water balance of the soil surface layer was used to estimate the water requirement of each soil texture for each irrigation project.

$$D_{e,i} = D_{e,\,i-1} - (P_i - RO_i) - \frac{I_i}{f_w} + \frac{E_i}{f_{ew}} + T_{ew,\,i} + DP_{e,\,i} \qquad (3)$$

where: $D_{e,\ i-1}$ = the cumulative depletion depth at the end of the previous day (mm), $D_{e,\ i}$ = the depth of cumulative depletion at the end of day (mm), P_i = the precipitation on the day i (mm), RO_i = the amount that exceeds the infiltration of soil and causes runoff on a day i (mm), I_i = irrigation depth on day i (mm), E_i = the evaporation on day i (i.e. $E_i = Ke{\cdot}ET_o$) (mm), T_{ew}, i = the transpiration from the wetted and exposed soil surface layer fraction on day i (mm), DP_e, i represents the deep percolation loss from topsoil layer on the day i in the case where the soil water content is exceeding the field capacity (mm), f_w = the soil surface which is moistened with the rain or irrigation (0.01–1.0), and f_{ew} = the exposed soil and wetted soil which is subjected to solar radiation (0.01–1).

RESULTS

CURRENT WATER DEMAND

The irrigation water demand (Fig. 5) differed among the five irrigation projects according to different soil textures and the percentage of the cultivated area of each project as shown in Table 2 and Table 3.

There was a limited water demand of about 0.8 mln m^3 during September and October, where most crop planting takes place in November. This applies especially to strategic crops such as wheat and barley, which have a water demand of 8.6 mln m^3. The water demand decreased from December to mid-January due to low temperatures and low rainfall. It was increasing after that from February until it reached 22 mln m^3 in April with increasing temperature as shown in Figure 5 of reference evapotranspiration (ET_o). The total water demand in the agricultural sector was 111.5 mln m^3 per year, which equals 34% of the water budget of 326 mln m^3 per year allocated to the agricultural sector. Therefore, the unused water accounted for 66% of the water budget, and this

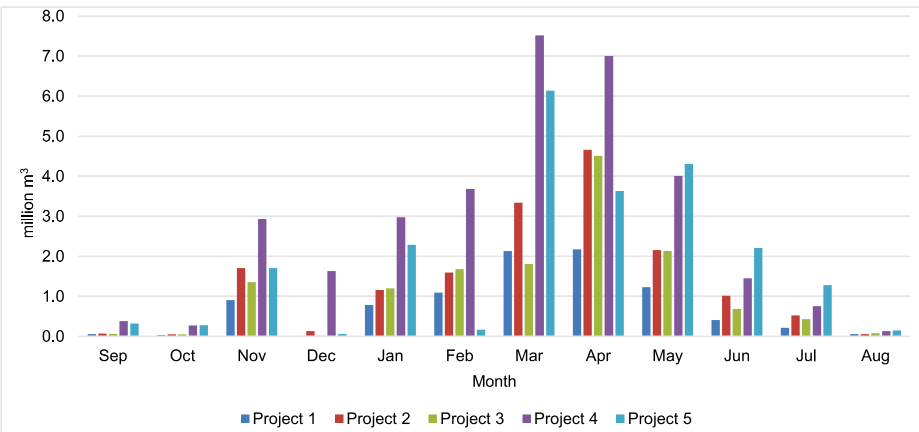

Fig. 5. Water demand of the five projects by WEAP; source: own study

occurred with the loss of proper water management, where there was 61% uncultivated area from the total irrigation project area as shown in Table 2.

The estimated consumption of water for domestic purposes was 392 dm^3 per capita per day. It exceeds the international norm of 200 dm^3 per capita per day, which is combined with the lack of understanding of the water shortage problem [UN 2013]. The annual domestic water demand was 63.6 mln m^3 per year, with the annual water use rate per unit of activity being 143.1 m^3 per year. In developing countries, studies indicated that 80% of the domestic water supply returns to the river as wastewater without treatment [Osunla, Okoh 2017]. Therefore, the amount of water that can be treated and reused for agriculture equals 51 mln m^3 per year.

The water consumed by the industrial sector within the study area is consumed by the sand washing, gravel and block factories, or car washing, while the largest water consumption is driven by the glass and ceramic factory with a demand of about 0.4 $m^3 \cdot s^{-1}$. The annual water demand generated by the industrial sector is about 15.77 mln m^3 per year, which corresponds to 7% of the total demand (Fig. 6).

CALIBRATION OF WEAP RESULTS

The water demand per hectare, which is calculated by the WEAP model, was compared with the results of the study of Al Dulaimy [2018]. The water demand for trees was taken from the Agricultural Directorate of Anbar in 2019. There was convergence from 1–12% for wheat with 22–27% for barley. It was 1–5% for sunflower, while the demand for trees was converging from 1–12% for palm and citrus as in Table 4.

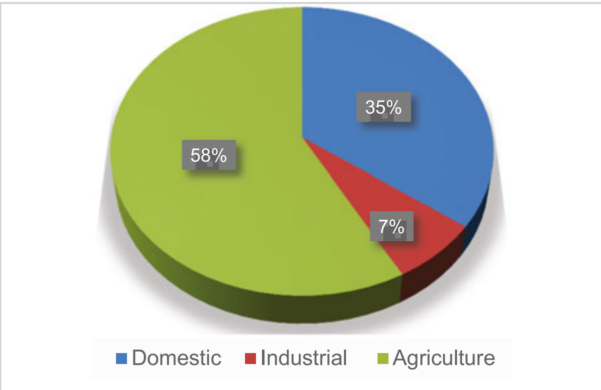

Fig. 6. Percentage of water demand per sector, calculated using the WEAP model; source: own study

FUTURE WATER DEMAND

The flow of the Euphrates River started to decrease due to the construction of dams by upstream countries (e.g. Keban Dam by Turkey in 1973 and Tabqa Dam by Syria). These dams affected the quantity and quality of the water coming to Iraq from the Euphrates River. The flow of the river decreased by 16.7% from the annual flow of 30 BCM at the Syrian-Turkish border to reach 25BCM in 2009 [UN-ESCWA, BGR 2013].

Haditha Dam is one of the most important dams in Iraq on the Euphrates River, and the second-largest dam after the Mosul Dam. It is used to generate electricity and store water to be used for domestic, industrial, and agricultural purposes in the central and southern parts of Iraq. The decrease in the water flow of the Euphrates River leads to limited water releases of the Haditha Dam and reduces the storage as shown in Figure 7, in addition to reducing the water share of the study area, particularly for agricultural purposes.

There was a convergence between releases from Haditha Dam and water imports at Hussaybah station (Fig. 8). This difference increased to a point where the outflow from the dam was greater than the inflow that entered the dam in the period from 2013 to 2018. This means more consumption from the dam storage with limited inflow entering its reservoir, where the storage in the period 2009–2011 reached 1546, 1649, and 3361 BCM respectively, and the dead storage of the dam was 2.4 BCM. In addition, the reservoir of Haditha Dam suffers from annual net evaporation of about 2078 mm. The Anbar Governorate, situated in the western part of Iraq, has a water share from the outflow of Haditha Dam estimated to be about 15% for the agricultural sector, which equals 70 $m^3 \cdot s^{-1}$. The total water demand of the industrial sector does not exceed 4 $m^3 \cdot s^{-1}$ [Sulaiman *et al.* 2019b], with various domestic demand levels depending on the growth rate. The irrigation project of the study area, the Ramadi irrigation project, has a water demand that reaches 326 mln m^3 per year, estimated considering 15% of the water demand generated by the agricultural sector of the Anbar Governorate.

Table 4. Water demand under surface irrigation ($m^3 \cdot ha^{-1}$)

Crops	Project 1	Project 2	Project 3	Project 4	Project 5	Reference demand
Wheat	8.6	8.2	8.0	7.7	7.5	8.6
Barley	6.2	6.3	6.6	6.4	6.7	8.6
Maize	17.8	18.1	18.0	18.1	18.3	15.0
Sesame	15.8	16.6	16.2	16.5	17.2	14.6
Sunflower	16.6	17.2	16.4	17.2	16.3	14.2
Potato autumn	7.2	7.8	7.2	7.4	7.2	8.6
Citrus	33.1	34.0	34.2	34.3	33.0	32.6
Palm	36.9	36.8	36.4	37.1	37.2	32.6

Source: own study based on unpublished data of Anbar Agriculture Directorate.

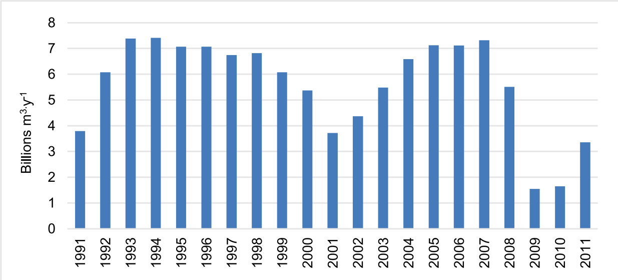

Fig. 7. Water storage of Haditha Dam (1991–2011); source: own study

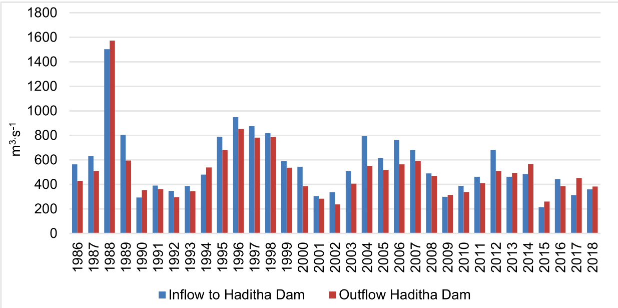

Fig. 8. Inflow and outflow Haditha dam from Euphrates River (1986–2018); source: own study

The industrial sector in the study area requires 0.5 $m^3 \cdot s^{-1}$ representing 12.5% of the water demand generated by the industrial sector of the Anbar Governorate. The population percentage of the study area was estimated at 25% of the figure obtained from the population census of the Anbar Governorate using the population census for the previous year from 2009–2018. Studies indicated that the available water resources within the Anbar Governorate are insufficient to meet the demand of the sites in the future. It is expected that the quantity of water entering from the Syrian-Iraqi border will continue to decline, with reduced storage of the Haditha dam [SULAIMAN *et al.* 2019b]. By estimating the available water for the study area from the water available for the Anbar Governorate, it can be concluded that the deficit will amount to 48 mln m^3 per year by 2025 and will reach 159 mln m^3 per year by 2035 (Tab. 5).

IMPROVING WATER MANAGEMENT

The difference between the available water supply and demand is usually met by using alternative water sources such as groundwater, which is considered essential for irrigated agricultural areas in most arid and semi-arid regions. The available amount of renewable and non-renewable groundwater in the west of Iraq is estimated at 2.5 bln m^3 [SULAIMAN *et al.* 2021; 2019b], where it can be invested by applying plans and strategies correctly to meet part of the agricultural sector's water demand. Agricultural water demand can be reduced by applying new irrigation technologies to minimise water losses. Irrigation technologies involve various trade-offs between crop production, water used in production, and financial costs. Irrigation systems such as sprinkler and trickle irrigation are relatively expensive but provide a better capacity to reduce run-off and evaporation from the soil, and to increase the productivity of crops. The surface irrigation method, meanwhile, is less costly and easy to apply, but it is less effective, allowing more water loss by evaporation, run-off, and percolation. Increasing water productivity is essential to provide more food for the population by reducing stress on natural water resources. Agricultural water demand can be improved by:
- increasing crop productivity per unit of water by using sprinkler and trickle irrigation instead of surface irrigation;
- improving water transport efficiency to the field by using pipe canals instead of lined and soil canals;
- using scientific irrigation schedules to supply water at the appropriate time and in the appropriate amount, where the WEAP-model considers the best choice in this state with the dual K_c.

The WEAP-model was applied to propose two scenarios to improve irrigation management for the Ramadi irrigation project with increasing economic returns. In the first scenario, sprinkler irrigation was considered with strategic crops, such as wheat and barley, and basin irrigation with other summer and winter crops in addition to trees. In the second scenario, sprinkler irrigation was considered with wheat and barley, and trickle irrigation with winter and summer crops, such as cucumber, watermelon, sesame, sunflower, potato, and pepper, in addition to trees, such as palm, grape, and olives. In both scenarios, pipe canals were considered instead of the lined canal. In the first scenario, the field losses declined by 56% from 42.7 mln to 18.9 mln $m^3 \cdot y^{-1}$. Moreover, the conveyance losses decreased by 76% from 16.7 mln to 3.97 mln $m^3 \cdot y^{-1}$ when using pipe canals which reduced water supply by 29% from 111.52 mln to 79.43 mln $m^3 \cdot y^{-1}$ (Fig. 9). The production increased by 43% with an increase in the economic returns by 37% from 16.04 mln \$ per year to 21.9 mln \$ per year. In the second scenario, where sprinkler and trickle irrigation were used, water consumption was reduced by 38%, from 111.5 mln to 69.1 mln $m^3 \cdot y^{-1}$ (Fig. 9). In addition, the conveyance losses decreased by 80%, from 16.7 mln to 3.4 mln $m^3 \cdot y^{-1}$ when using pipe canals for all irrigation projects. The productivity improved by 68% from 39.3 mln to 66.1 mln $kg \cdot y^{-1}$, while economic returns increased by 66%.

Table 5. Available water with water demand for period (2020–2035)

Year	Population (thous.)	Available water [SULAIMAN *et al.* 2019b]	Water demand				Difference
			domestic	industrial	agricultural	total	
		mln $m^3 \cdot y^{-1}$					
2020	454	445	64.92	15.77	326	406.7	+38
2025	501	365	71.67	15.77	326	413.4	–48
2035	611	270	87.37	15.77	326	429.1	–159

Source: own study.

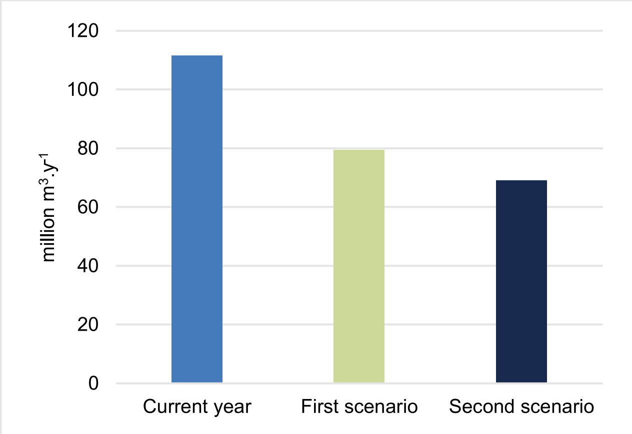

Fig. 9. Comparison of total water supply from river; source: own elaboration

IMPROVING WATER PRODUCTIVITY

Water productivity is defined as the ratio between crop yields (kg·ha^{-1}) on the total amount of water applied during the crop season. Improving irrigation productivity is important for reducing water demand and saving more water resources. Irrigation efficiency was measured at 55% for surface irrigation with 75% for sprinkler irrigation and 90% for trickle irrigation. The water productivity was calculated according to the following formula [Paredes *et al.* 2017]:

$$WP = \frac{Y_a}{TWU} \tag{4}$$

where: Y_a = the yield of the crop (kg·y^{-1}), TWU = the water volume used in production, which includes effective rainfall and gross irrigation (m^3).

In Iraq, the water productivity of surface irrigation is considered low, as in southern Iraq the water productivity of strategic crops is 0.13 kg·m^{-3}·with 0.09 kg·m^{-3} for wheat and barley [Al-Furaiji *et al.* 2016]. The study area does not differ much from that in the southern part of Iraq where the average water productivity is 0.28 kg·m^{-3} with 0.17 kg·m^{-3} for wheat and barley, respectively (Tab. 6). The sprinkler and trickle irrigation can increase the water productivity of crops by reducing the irrigation losses that reach 45% when surface irrigation is used. Irrigation technologies achieve more economic returns and save more water, due to their ability to increase the cultivated area, and thanks to irrigation technologies, droughts can be counteracted with lower water reserves.

Table 6. Water productivity (kg·m^{-3}) under different irrigation systems for each irrigation project by WEAP

Crops	Surface irrigation method					Sprinkler for wheat and barley, and trickle irrigation for others crops				
	P1	P2	P3	P4	P5	P1	P2	P3	P4	P5
Wheat	0.28	0.27	0.28	0.28	0.31	0.57	0.55	0.58	0.57	0.56
Barley	0.19	0.16	0.17	0.18	0.17	0.88	0.91	0.90	0.86	0.92
Maize	0.30	0.30	0.30	0.29	0.30	0.76	0.74	0.78	0.75	0.79
Cucumber	0.75	0.67	0.63	0.68	0.74	3.00	2.43	2.75	2.53	2.77
Eggplants	1.33	1.30	1.29	1.31	1.40	6.50	6.33	6.25	6.40	6.67
Kidney beans	0.50	0.57	0.75	0.59	0.69	4.00	3.00	4.00	3.10	3.25
Potato spring	1.75	1.83	1.88	1.75	1.77	6.00	5.29	4.80	5.41	5.50
Sesame	0.05	0.08	0.06	0.06	0.07	0	0.14	0.20	0.17	0.20
Sunflower	0.20	0.14	0.13	0.14	0.14	0.50	0.29	0.40	0.33	0.33
Sweet pepper	0.60	0.50	0.45	0.50	0.47	2.00	2.11	2.17	2.13	2.00
Tomato	1.75	1.69	1.67	1.67	1.70	6.00	5.29	3.00	5.06	5.13
Watermelon	1.25	1.23	1.11	1.18	1.27	5.00	3.88	2.20	4.11	4.13
Berseem	1.00	1.00	1.00	0.98	1.00	1.50	1.67	1.50	1.32	1.35
Broad bean	1.00	0.75	1.00	0.76	0.75	2.00	2.00	2.00	2.33	2.67
Cauliflower	1.00	0.80	0.75	0.76	0.82	7.00	5.50	7.00	5.87	6.82
Potato autumn	4.00	3.25	4.00	3.61	3.44	14.00	10.50	14.00	12.85	11.83
Citrus	0.09	0.09	0.13	0.12	0.13	0.20	0.17	0.25	0.25	0.24
Grap	0.50	0.50	0.50	0.44	0.46	1.00	1.00	1.00	0.80	0.85
Olives	0.63	0.56	0.67	0.60	0.59	1.25	1.00	1.14	1.09	1.23
Palm	0.25	0.25	0.28	0.26	0.24	0.43	0.43	0.50	0.47	0.43

Explanations: P1, P2, P3, P4, P5 = project 1, 2, 3, 4, 5 respectively.
Source: own study.

CONCLUSIONS

The decrease in the flow of the Euphrates River from Turkey, combined with the limited storage capacity of the Haditha Dam, is significantly affecting the available amount of water. During certain periods, the outflow from the dam is greater than the inflow entering the reservoir of the dam, as was the case in the period from 2013 to 2018. This means more consumption from the dam storage with limited inflow, where the storage reached during the period 2009–2011 amounted to 1546, 1649, and 3361 BCM respectively (the dead storage of the dam is 2.4 BCM). In addition, the reservoir of Haditha Dam suffers from annual net evaporation that reaches about 2078 mm.

The total water demand of the agricultural sector in the study area was 111.5 mln $m^3 \cdot y^{-1}$, which equals 34% of the water budget of 326 mln $m^3 \cdot y^{-1}$ allocated to the agricultural sector. Therefore, the unused water (66%) occurs as a result of the lack of proper water management, where there was 61% of uncultivated areas from the total irrigation project area. The annual domestic water demand was 63.6 mln $m^3 \cdot y^{-1}$, with the annual water use rate per unit of activity of about 143.1 $m^3 \cdot y^{-1}$. Also, the annual water demand in the industrial sector was about 15.77 mln $m^3 \cdot y^{-1}$, which equals 7% of the total demand.

The WEAP model showed convergence of 1–12% for wheat with 22–27% for barley. It was 1–5% for sunflowers, while the demand for trees ranged between 1% and 12% for palm and citrus trees. By estimating the available water for the study area from the water available for the Anbar Governorate, the deficit will be 48 mln $m^3 \cdot y^{-1}$ by 2025 and is expected to reach 159 mln $m^3 \cdot y^{-1}$ by 2035.

In the first scenario involving the use of sprinkler and surface irrigation systems, the field losses were reduced by 56% from 42.7 mln to 18.9 mln $m^3 \cdot y^{-1}$. Also, the conveyance losses decreased by 76% from 16.7 mln to 3.97 mln $m^3 \cdot y^{-1}$. Moreover, the production increased by 43% with the increase of the economic returns by 37% from 16.04 mln $ per year to 21.9 mln $ per year.

In the second scenario involving the use of sprinkler and trickle irrigation systems, water consumption was reduced by 38%, from 111.5 mln to 69.1 mln $m^3 \cdot y^{-1}$. In addition, the conveyance losses decreased by 80% from 16.7 mln to 3.4 mln $m^3 \cdot y^{-1}$. Furthermore, the production increased by 68% from 39.3 mln to 66.1 mln $kg \cdot y^{-1}$, while economic returns went up by 66%.

RECOMMENDATIONS

The results of this work suggest the following recommendations to improve the management of water resources within the studied area.

1. Applying the correct irrigation schedule to reduce waste and provide the required amount of water to the crops at the specified time. The WEAP-model is considered a useful tool, which uses the dual K_c approach that deals with daily climate data, soil texture, and characteristics of crops such as planting and harvesting periods, effective root depth, and the height of the crop. These determinants contribute to achieving a good irrigation system.
2. Using irrigation methods with low irrigation losses, such as sprinkler and trickle. These technologies provide an increase in water productivity and economic returns, as well as ensure that more water can be used to reclaim new agricultural lands or reached for during drought periods.
3. Using other water resources, such as wastewater treatment, to reduce river pollution and recycling it for the agricultural sector. Also, using the groundwater besides the Euphrates River to meet the water demand of crops.
4. Imposing restrictions on domestic water use, where the per capita share of 392 $dm^3 \cdot day^{-1}$ is considered high compared to the international standard of 200 $dm^3 \cdot day^{-1}$, with little vegetation cover within the residential neighbourhoods in the region. This requires following the awareness and rationalisation system to reduce water waste.

The study recommends making comprehensive economic feasibility assessments by using dynamic programming to include the initial costs of applying irrigation technologies such as sprinklers and trickle with all financial returns, and the costs of establishing treatment plants to recycle wastewater for the agricultural sector. In addition to this, we recommend comprehensive studies to assess the suitability of drainage water and groundwater for agricultural purposes in the study area.

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