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Investigating Water Demand under Different Irrigation Techniques Numerically in Al-Anbar Province - Iraq: A Case Study

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Abstract In terms of the importance of achieving a successful integrated sustainable management to the agricultural sector within the light of the tangible decrease in Euphrates discharge, this research was initiated with the objective of investigating water demand under different irrigation methods, numerically. Primarily, literature in field of modeling and water scarcity was assembled and scrutinized. Anbar in Iraq was selected to be a case study, to which site visits were carried out and data were assembled. WEAP was selected to be implemented to the case study, where it was calibrated and verified against real data sets. Confident with the calibration process and based on previous studies results, WEAP was applied to the study area. 2010 was taken as the base year and simulations were carried out over a span of 30 years (2010-2040). Two scenarios were considered to calculate the water demand and the unmet demand. The 1st scenario considered the present condition (i.e. using traditional irrigation methods), while the 2nd scenario is a virtual condition (i.e. using modern irrigation techniques). The results indicated that the water demand decreased from 5846.59 to 4232.29 MCM, for the 1st and 2nd scenarios, respectively (i.e. decreased by 38%). Accordingly, it is recommended to implement modern irrigation methods to achieve successful integrated-sustainable-management in the agricultural sector.

Keywords WEAP Model, Euphrates, Water Demand, Unmet Demand, Irrigation Techniques

1. Introduction

Iraq is experiencing water scarcity and the agricultural sector demand is 85% of the available water resources, allocated for this sector. This is attributed to fact that there is a simultaneous rapid population increase and individual living-standards elevation. This is twined by the water conflict in the region among Iraqi, Syria and Turkey [1].

Accordingly, contributing to solving such a problem, this research was originated with the impartial of investigating water demand under different irrigation methods, numerically, where Anbar in Iraq was selected to be a case study.

Bashir [2] stated that there is a tangible decrease in the total water resources of Iraq (i.e. Tigris and Euphrates). In addition, Ministry of Water Resources [3] documented that Iraq is implement surface irrigation and intermediate irrigation techniques. However, Hamid [4] advocated that their portions were 60 and 40%, respectively. On the other hand, Arab Organization for Agricultural Development [5] designated that the surface irrigation accounts for 94% of the total irrigation process. Likewise, Central Statistics of the Ministry of Planning [6] signposted that Anbar depends on limited rainfall, where surface irrigation and pumping wells are evident. They further mentioned that within the light of Euphrates supply decrease and the utilization of traditional irrigation methods, innovative methods should be devised to cope with the water demand of the increasing population. However, Report of the Ministry of Planning Central Statistics [7] highlighted the factors affecting such demands in the agriculture sector. They categorized the factors into four clusters (i.e. Climate factors - Soil factors - Agricultural crops type and their water demands - irrigation method). Chartzoulakis et al. [8] Irrigation is defined as the process of adding water into the soil in several different ways to provide water by achieving optimum soil moisture, thus achieving more crop yield.

Based on the scrutinized literature, it was apparent that many researchers investigated this problem numerically. Among these were the following:

Aoun-Sebaiti et al. [9] implemented WEAP to mimic the water supply and water demand in Sibus Valley in Algeria, where they simulated climate change scenarios with increased reuse, while changing the farming patterns to designate the impact of each till 2050. Their results indicated a reduction of 30% in the water supply. In addition, Hamlat et al. [10] applied WEAP to simulate water resource management scenarios in Algerian watersheds, where the watersheds suffer from rainfall insufficiency and drought. Their results underlined that the domestic demand can be met by demand management. Their results obtained from WEAP indicated that water-demand- management "WDM" of the unmet demand scenarios was reduced by 15% and 5% in urban areas and in the irrigation sector, respectively. Moreover, Sameer et al. [11] applied WEAP to investigate the enhancement of water sustainable management in Euphrates. Their results signposted that the total demand of water in 2015 was 100 MCM and it is expected to be 40 MCM in 2035, while it will be reduced by 2 MCM, if modern irrigation methods were implemented. Furthermore, Mohammad et al. [12] utilized WEAP to assess water consumption and future demand in Anbar. Their results emphasized that the demand will increase by 400%, during 2015- 2035. However, in the case of groundwater use and waste water reuse, the deficit will decrease. Where to conduct a study in integrated water management to find ways to get rid of the excessive use of water in the Mara River is located in Kenya. Sarhan [13]. The WEAP model was also used in evaluating the water supply for the urban population of Santiago for the scenario of the local sector and health facilities [14]. The results showed that the sustainability of water for the future 30 years taking into account the number of future residents and residents based on the current demand as of 2019, the demand for water will increase with an increase rate of 8.97%, 17.95% and 28.20% for the years 2030, 2040 and 2050, respectively.

2. Description of the Study Area

2.1. Al-Anbar Province

Several site visits were carried out (figure 1), during which data were assembled and analyzed. Based on the assembled data, clear was the following:

Anbar area is 137,808 km^2 and forms 32% of Iraq (i.e. 434,128 km^2)[15]. It lies between latitudes (34°, 24', 54') and (34°, 11', 6') North. It lies between longitudes (40°, 28', 12') and (41°, 25', 48") East [16].

Anbar is bordered by Nineveh Province at the North. It is bordered by KSA at the South. It is bordered by Babylon, Karbala and Najaf at the East. It is bordered by Jordan and Syria at the West.

Euphrates runs through its administrative units. It is the major water resource for agricultural areas. It is the major artery of Anbar, where its total length from its source in Turkey to its estuary in Iraq is 2,940 km. It enters the area at Al-Qaim district and passes through its administrative units, where Euphrates passes through Syria, Turkey and Iraq. Euphrates runs 450 km in Anbar, where its total length inside Iraq is 1160 km [17].

Anbar encompasses wide agricultural areas with high fertility, along Euphrates banks. Anbar is irrigated by pumping water from Euphrates, where Euphrates witnessed a tangible water supply decrease due to climate changes, rain deficiency and the construction of dams in Turkey [18]. Anbar is not supplied with water that suffices its demand, in the domestic, agricultural and industrial sectors.

3. Theory and Methods

The management of surface water resources passes through several stages, namely: Estimating the amount of water needed for the agricultural sector and estimating the amount of water received each year in the Euphrates River. Two scenarios based on 2010 base year data are used.

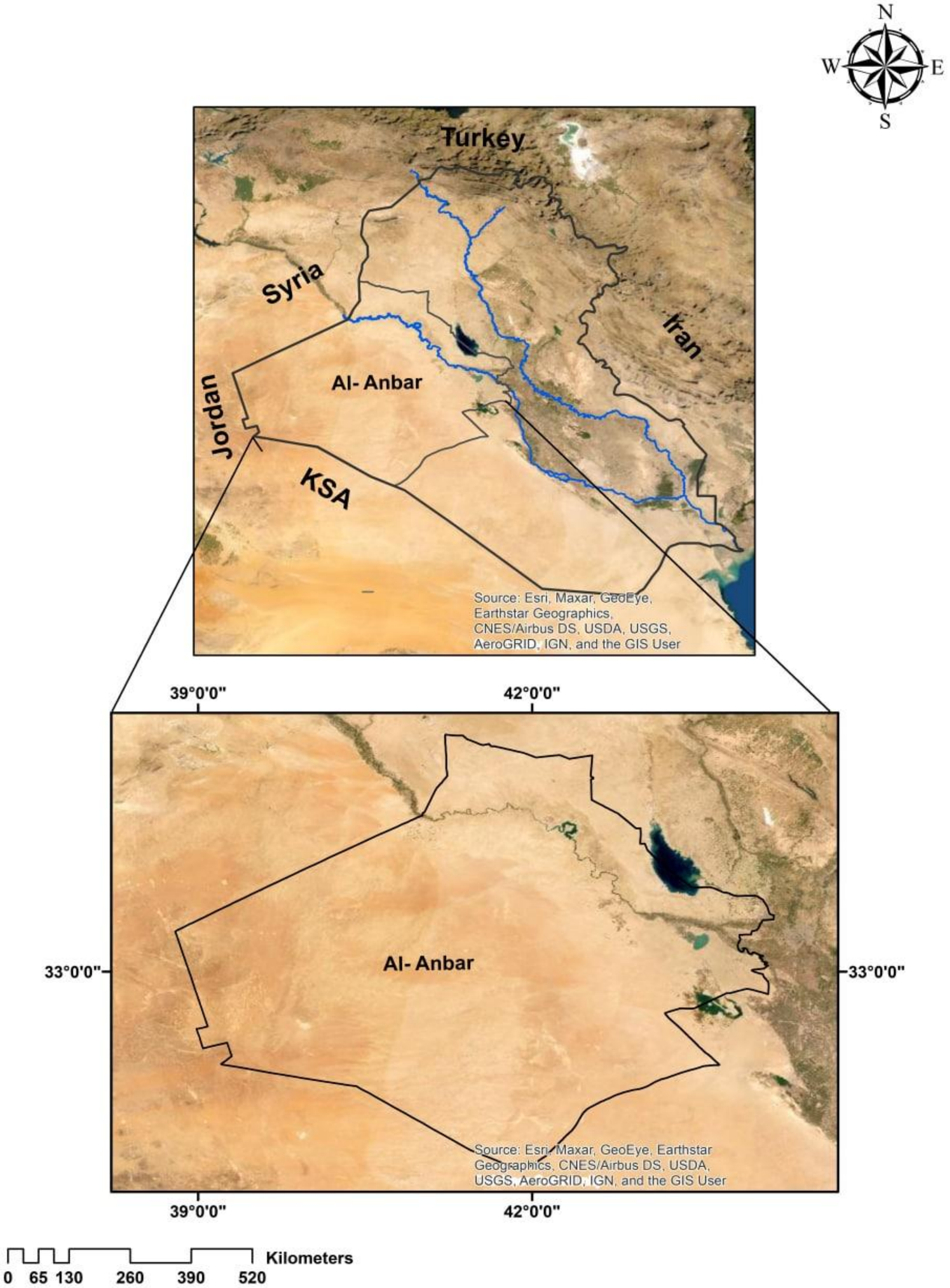

Figure 1. Location of the study area

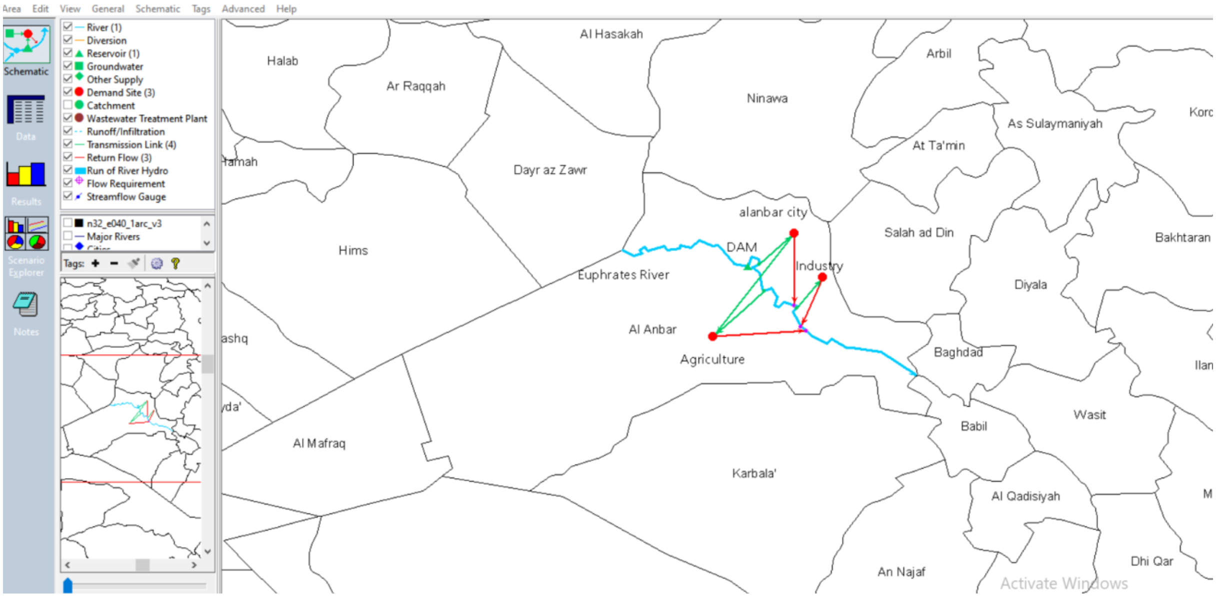

Figure 2. WEAP interface

3.1. Modeling Anbar Numerically

Numerical models (i.e. capable of providing a good picture about surface water management) were reviewed, from which WEAP was selected to predict the yearly water supply for Euphrates. The model was calibrated and verified against real data. Confident with the calibration results, WEAP was applied to simulate Anbar. This is presented, as follows:

3.1.1. Selecting the Implemented Model

Many numerical models that are capable of simulating surface water management are available. They were reviewed, from which it was apparent that WEAP (i.e. acronym of ***W***ater ***E***valuation ***A***nd ***P***lanning) is worldwide accepted. It was applied to several international problems and proven its reliability. In addition, it has a friendly interface; figure (2). Accordingly, it was selected to predict the yearly water supply for Euphrates.

Historically, WEAP was developed in 1988. It is still under enhancement by U.S. Center of Stockholm Environment Institute, at Tufts University in Somerville, Massachusetts.

Theoretically, WEAP links groundwater-flow-model "USGS MODFLOW" and surface-water-quality-model "US EPA QUAL2K". It is based on hypothetical time- step Water Balance, as it considers demand and withdrawal [19]. WEAP is based on an effective algorithm for solving water allocation problems, while considering site demand and integrating hydrological units (i.e. rain runoff and groundwater) [20].

WEAP is utilized in climate change studies and is applied by researchers and planners in many organizations, worldwide. It is a model-building tool for planning water resource and it can achieve a policy-analysis. It simulates water demand, runoff, infiltration and irrigation requirements for crops. This is achieved via varying the policy, climate and technology.

3.1.2. Calibrating and Verifying Weap

WEAP was calibrated against an actual data set. It was then verified against a different actual data set. These data were obtained during the site visits from different governmental authorities and organizations.

3.1.3. The WEAP Algorithm

The amount supplied to a demand site (DS) is the sum of the inflows from its transmission links. (The inflow to the demand site from a supply source (Src) is defined as the outflow from the transmission link connecting them, i.e., net of any leakage along the transmission link)[21].

$$DemandSiteInflowDS = TransLinkOutflowSrc,DS, DS \quad (1)$$

The demand presented by some demand site (*DS*) is computed as the sum of the corresponding demands of all the bottom-level branches (*Br*) of that particular site[20].

$$AnnualDemand_{DS} = \sum_{Br} TotalActivityLevelBr \ x \ WaterUseRateBr \quad (2)$$

Unmet Demand

The amount of each demand site's requirement is not met, when some demand sites are not getting full coverage.

3.2. Applying WEAP to Simulate Anbar

Confident with the calibration so as verification results and previous researchers' findings, WEAP was implemented to predict the water demand of the agricultural sector in Anbar. This was achieved to assess Anbar demand within a time-span of 30 years (2010- 2040), where 2 scenarios were simulated. ***1st scenario*** considered the base case or the reference scenario, while the ***2nd***

scenario considered the utilization of modern irrigation techniques.

3.2.1. Preparing WEAP Input Data

According to previous studies, WEAP input data were prepared. Among these studies were the following:

The unified Arab economic report [22] carried out experiments, in Abu Gharib in Iraq. The experiments assessed 3 irrigation techniques (i.e. conventional-spraying-drip techniques), where traditional, sprinkler and drip techniques efficiencies were 50-60%, 60-75% and 90-95%, respectively. The estimated efficiency included losses and water losses from evaporation and leakage. In addition, Abdul-Razzaq et al. [23] carried out similar experiments in Abu Ghraib, where the sprinkler and drip irrigation systems efficiency exceeded the surface irrigation system by 22% and 43%, respectively. Moreover, Arab Organization for Agricultural Development [24] advocated that this surpass originates from the fact that modern techniques causes relatively smaller amounts of water loss compared to traditional techniques, which was estimated by 23172 billion m^3/year. The Dual-Kc approach by Water Assessment and Planning (WEAP) was applied to calculate the water needs of different soil textures [25]. The results indicate that the net water requirements of wheat are 429 mm and 433 mm for sandy clay and silt, respectively.

Accordingly, the results of Sieber et al. [21], the unified Arab economic report [22] were adopted in the present study. This is attributed to the fact that both studies carried out experiments in Abu Gharib and the study case in hand (i.e. Anbar) is bordered by Abu Gharib. In addition, both have similar climatic conditions and soil nature.

Table (1) is provided to list of the prepared input data to WEAP, which encompassed the crops irrigated by spraying and dripping with their surpassed efficiencies.

3.2.2. Running WEAP to Mimic Anbar Numerically

WEAP was run to mimic Anbar numerically, taking into consideration previous studies results. Among these studies were the following:

Anbar Investment Authority [26] prepared annual and future agricultural plans for arable lands, taking into account population increment and urban expansion to meet the demand of agricultural productivity. The plans reported that the arable areas are 125,000 in Anbar in 2010 and are expected to be 144,000 hectares in 2020.

It advocated that the areas nominated for agricultural investment will be 184,000 and 370000 hectares in years 2030 and 2040, respectively [27].

Taking the above researchers results into consideration, WEAP was run to mimic Anbar, where data from agricultural sector was utilized during calculations. The annual river dischrge rate was considered as a variable and unmet demand was estimated. Based on this, new scenarios to resolve difficulties were put forward.

The computation implemented the available Euphrates dischrge during 2010-2020. However, during 2020-2040, time series method was used to forecast Euphrates discharge based on the data of 2010-2020, where Box-Jenkins method was implemented [28]. The water demand is presented on figure (3).

Table 1. Prepared input data for WEAP (water demand versus irrigation techniques)

Water needs / Crop type	Water requirements (m^3/dunum) Tourist irrigation	Water requirements (m^3/dunum) Sprinkler irrigation efficiency (22%)	Water requirements (m^3/dunum) Drip irrigation efficiency (43%)	Water requirements (m^3/hectare)
1-Wheat	3201.2	2496.9		9987.6
2-Barley	3201.2	2496.9		9987.6
3-Clover	4431	3456.1		13824.4
4-Winter vegetables	2616	2040.8		8163.2
5-Yellow corn	5239	4086.4		16345.6
6-White corn	4607	3593.4		14373.6
7-Sesame	6448	5029.4		20117.6
8-Summervegetables	17065		9727	38908
9-alfalfa	11728		6684.9	26739.6
10-Palm	5306		3024.4	12097.6
11-Fruits	4637		2643	10572

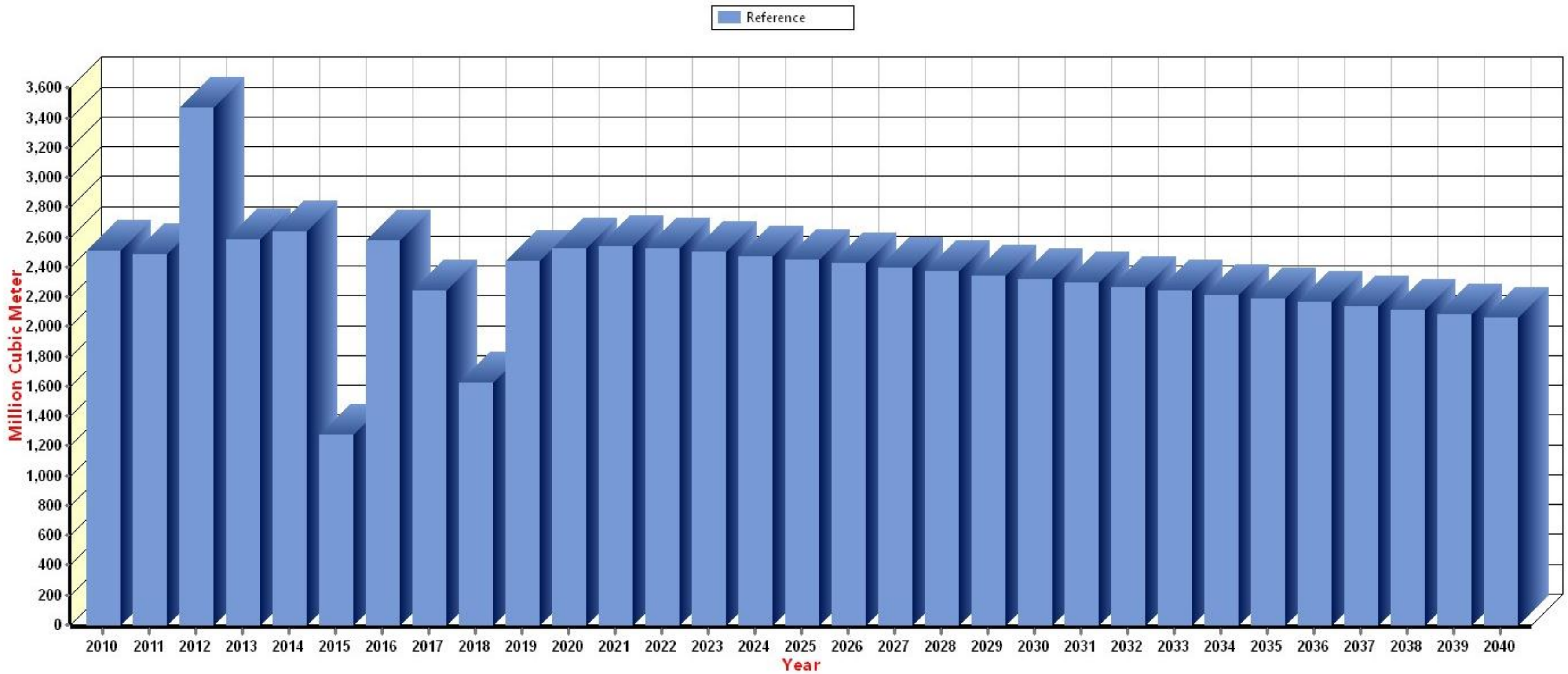

Figure 3. Euphrates annual discharge in Anbar (2010-2040)

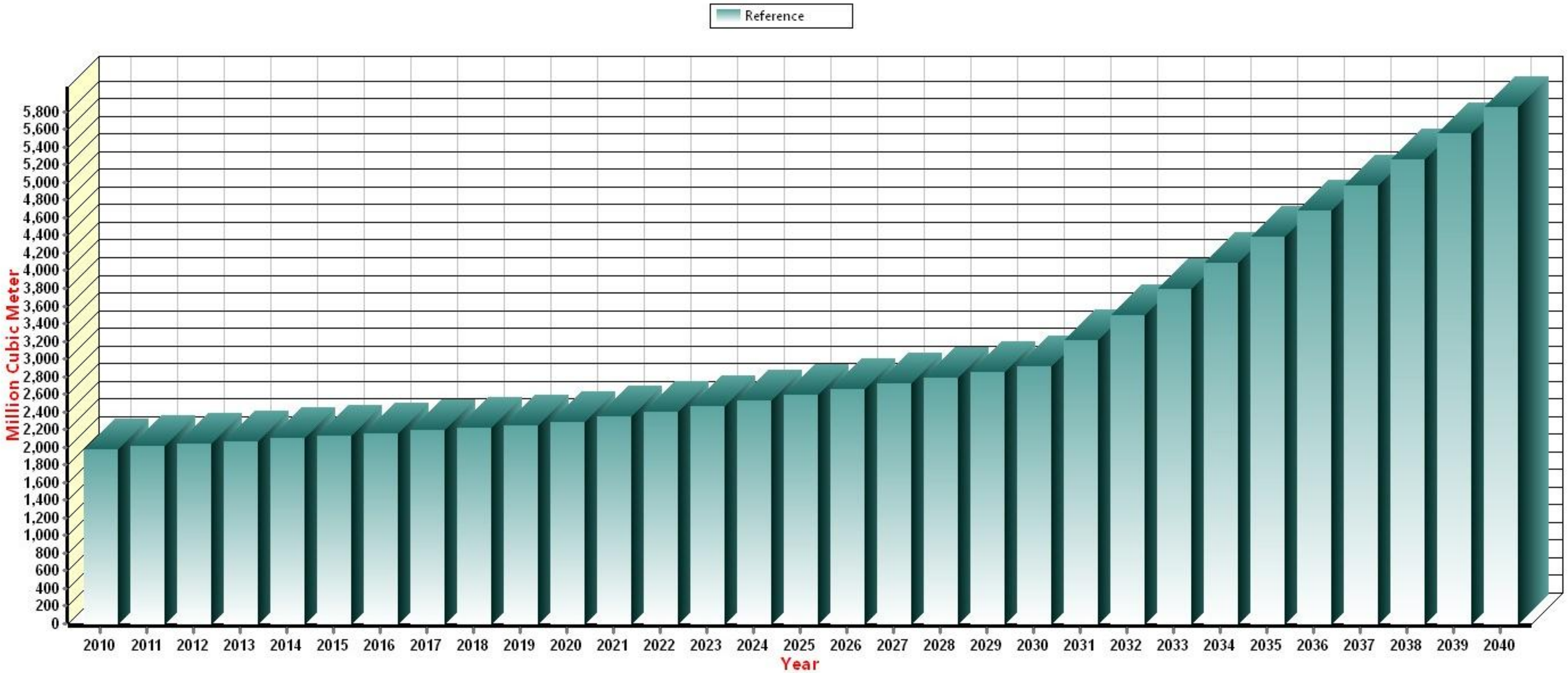

Figure4. Water demand for the agricultural sector for the scenario of the reference from 2010-2040

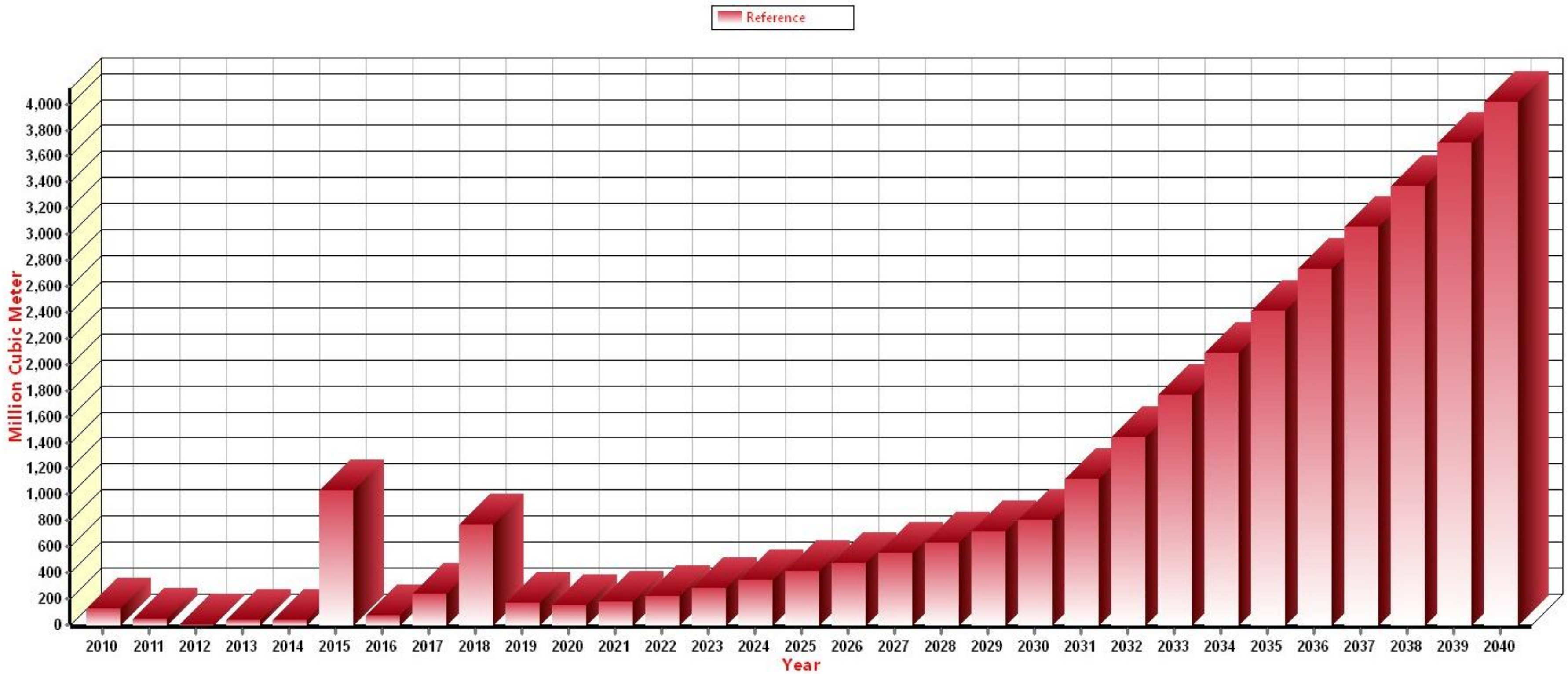

Figure 5. The unmet demand for water for the agricultural sector for the reference scenario 2010-2040

Figure 6. Water demand for the agricultural sector for the scenario of using modern irrigation methods 2010-2040

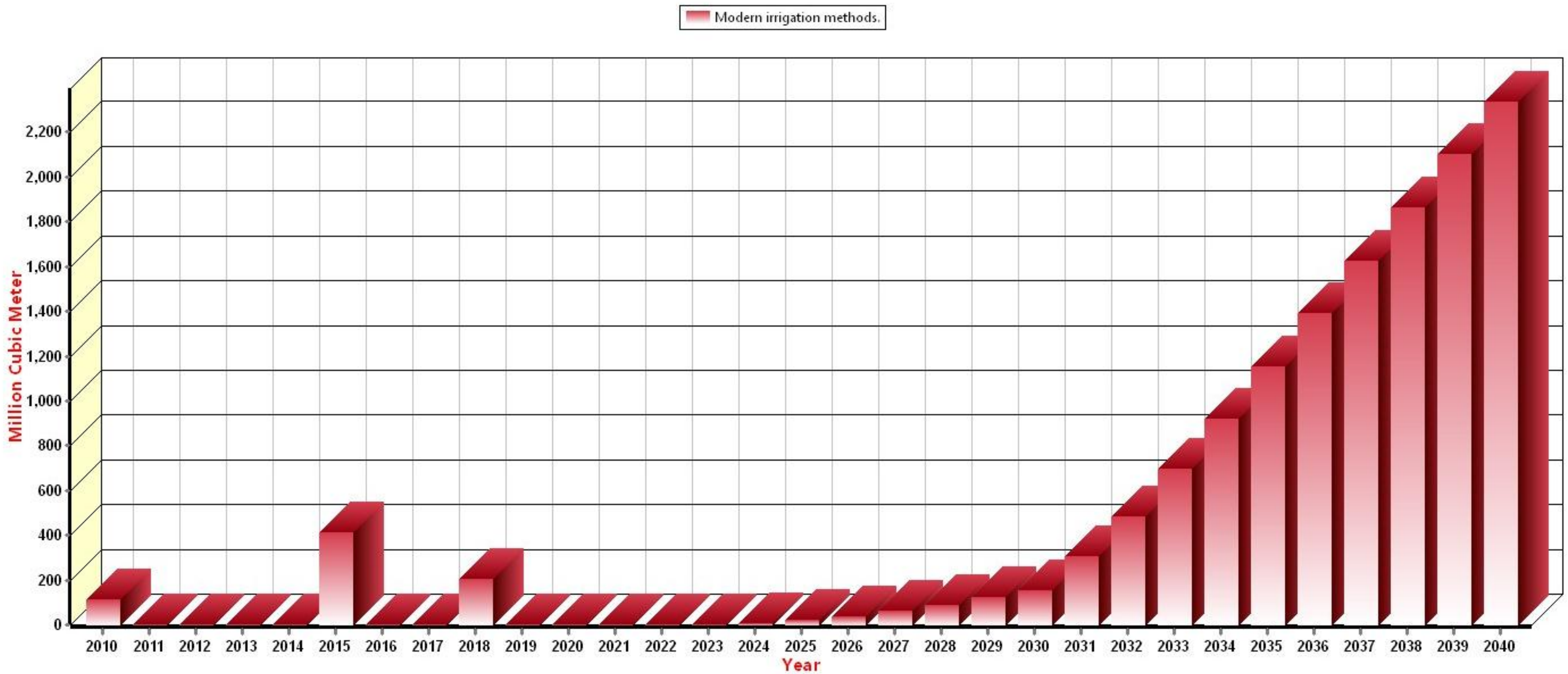

Figure 7. The unmet demand for water for the agricultural sector for the scenario of using modern irrigation methods 2010-2040

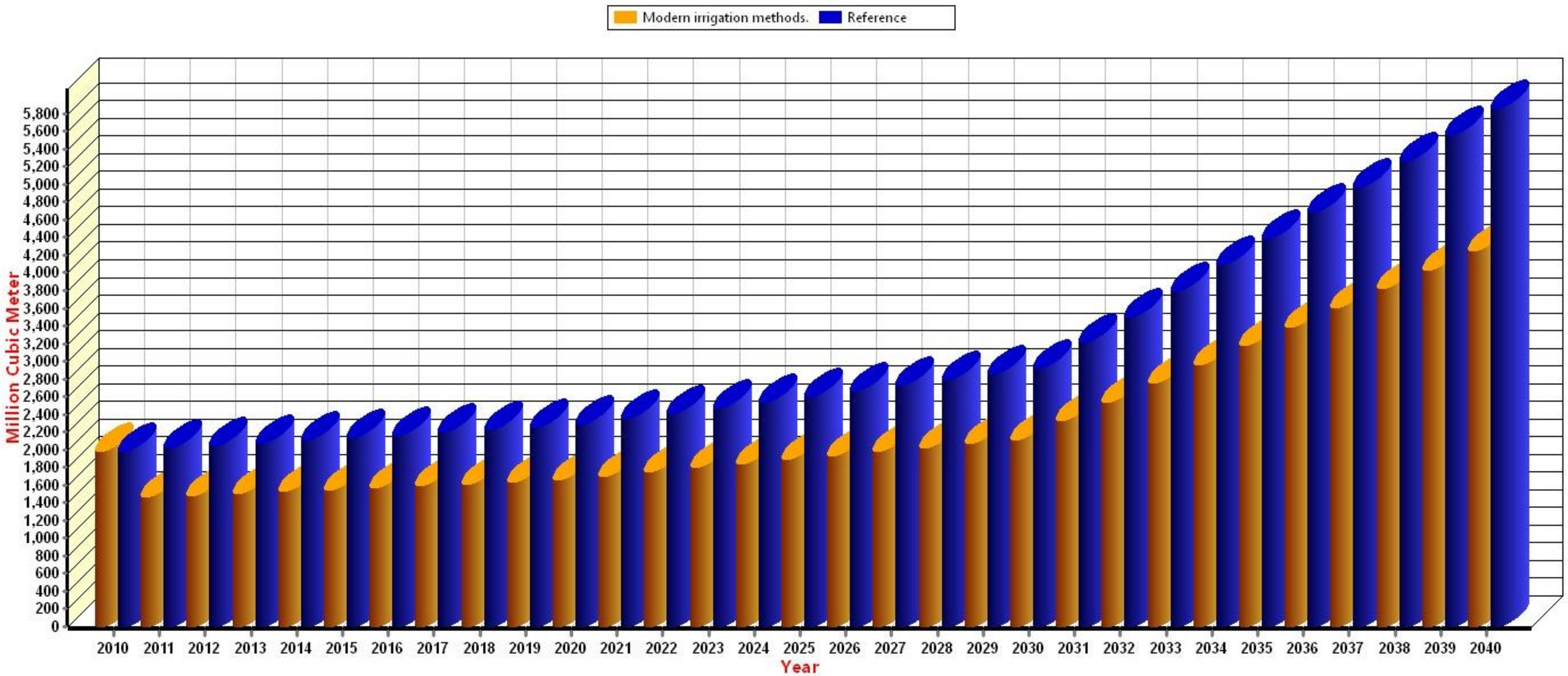

Figure 8. Water demand for the agricultural sector between the two scenarios in Anbar (2010-2040)

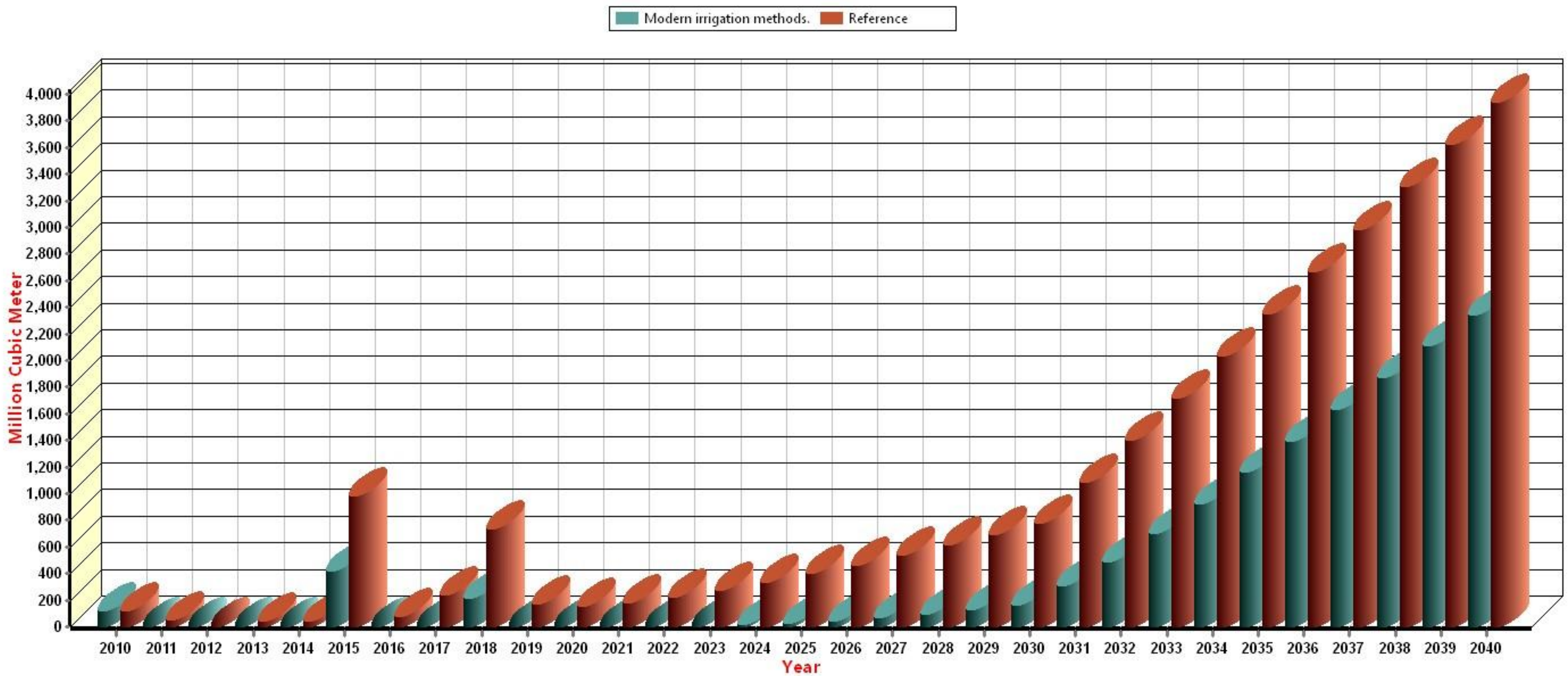

Figure 9. Unmet demand for the agricultural sector between the two scenarios in Anbar (2010-2040)

Table 2. Water demand for both the reference scenario and the scenario of using modern irrigation methods in Anbar Province

Year	Scenario Reference (Million cubic meters)	Scenario Modern irrigation methods (Million cubic meters)
2021	2338.64	1692.92
2022	2401.84	1738.67
2023	2465.05	1784.43
2024	2528.25	1830.18
2025	2591.46	1875.93
2026	2654.67	1921.69
2027	2717.87	1967.44
2028	2781.08	2013.20
2029	2844.29	2058.95
2030	2907.49	2104.71
2031	3201.40	2317.47
2032	3495.31	2530.22
2033	3789.22	2742.98
2034	4083.13	2955.74
2035	4377.04	3168.50
2036	4670.95	3381.26
2037	4964.86	3594.02
2038	5258.77	3806.78
2039	5552.68	4019.53
2040	5846.59	4232.29

Table 3. Unmet demand for both the reference scenario and the scenario of using modern irrigation methods in Anbar Province

Year	Scenario Reference (Million cubic meters)	Scenario Modern irrigation methods (Million cubic meters)
2021	169.42	0
2022	212.07	0
2023	265.33	0
2024	326.95	6.45
2025	389.28	18.73
2026	454.38	37.25
2027	526.42	58.60
2028	603.72	87.29
2029	686.03	119.82
2030	768.53	152.46
2031	1075.60	302.63
2032	1390.13	480.45
2033	1705.58	693.05
2034	2022.34	918.60
2035	2339.64	1152.96
2036	2657.93	1388.53
2037	2976.80	1624.86
2038	3295.89	1861.54
2039	3615.70	2099.10
2040	3935.59	2336.82

4. Analyzing and Presenting the Results

The obtained results were analyzed and represented on graphs and tables, as follows:

- Regarding the ***water demand***, figure (4) is given. The future demand for water for the 1st scenario in Anbar.
- Regarding the ***unmet demand***, figure (5) is given. The future unmet demand for water for the 1st scenario in Anbar.
- Regarding the ***water demand***, figure (6) is given. The future demand for water for the 2nd scenario in Anbar.
- Regarding the ***unmet demand***, figure (7) is given. The future unmet demand for water for the 2nd scenario in Anbar.
- Regarding the ***water demand***, figure (8) is given. It provides a comparison between the results of the 1st and 2nd scenarios.
- As for the ***unmet demand***, figure (9) is given. It provides a comparison between the results of the 1st and 2nd scenarios.
- Concentrating on the ***quantities of water demand*** and ***unmet water demand***, tables (2) and (3) are given to list these quantities for the future agricultural sector in Anbar from 2021-2040, from which clear was the significant difference.

From the above figures and tables, clear was the importance of developing a future plan to reduce the water shortage and reduce water scarcity risks.

5. Conclusions

Based on the present investigation, apparent was the following:

- Euphrates discharge will decrease due to climatic changes and improper water policy, which does not cope with the unmet water demand for agricultural sector under current conditions with agricultural areas expansion.
- Regarding the ***water demand***, it was almost tripled, during a time span of 30 years (i.e. it increased from 1975.20 to 5846.59 MCM). This is due to the increased investment in agricultural areas and future expansion of lands in Anbar. This was apparent from the 1st scenario (i.e. traditional irrigation). On the other hand, the water demand was doubled, during 30 years (i.e. increased from 1975.20 to 4232.29 MCM). This indicated that modern techniques would save 1614.30 MCM of water, which could cultivate 141,000 hectares. This was obvious from the 2nd scenario (i.e. using modern irrigation technique).
- As for the ***unmet demand***, it is almost 35 times as much during 2010-2040 (i.e. it increased from 110.93 to 3935.59 MCM). This was clear from the 1st scenario (i.e. using conventional irrigation). This is due to reduced discharge of Euphrates and expansion of agricultural areas. However, the 2nd scenario designated that unmet water demand is almost 21 times as much, during 30 years (i.e. it increased from 110.93 to 2336.82 MCM) due to modern irrigation.

6. Recommendations

Through this study, we recommend

- The necessity of implementing modern irrigation for successful integrated sustainable management in the agricultural sector.

Use other scenarios, including

- Reuse of agricultural wastewater.
- Uses of saline water from wells and mix it with fresh water.
- Use salinity-resistant crops such as some trees to resist wind and dust and stabilize soils.

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