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Estimation of The Different Aspects of Water Demand for Selected Regions in The Lower Reach of Euphrates River

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ABSTRACT

This research aimed to estimate and analyse the water demand for the Muthanna and Thi-Qar provinces in Iraq's lower Euphrates River Basin. WEAP, CROPWAT model, and statistical forecasting methods were used to estimate agricultural, municipal, and industrial water demand. The results showed that the municipal demand for Muthanna reaches a maximum of 211.4 MCM in 2059 and a minimum of 98 MCM in 2022, while the demand for Thi-Qar is higher at 377.2 MCM and a minimum demand of 174.8 MCM in the same year. This difference is due to the larger population of Muthanna compared to Thi-Qar. The agricultural water demand for the two provinces also exhibits a significant difference, with Muthanna experiencing a maximum demand of 1579 MCM in 2059 and a minimum water demand of 1443.4 MCM in 2022, compared to a maximum water demand of 347.8 MCM and a minimum water demand of 317 MCM for Thi-Qar over the same period. This difference is due to the larger irrigated area in Muthanna compared to Thi-Qar. The findings from the comparison between the different methods suggest that demand can be accurately forecasted and planned in the future. The research highlights the need for effective water resource management in the face of the challenges posed by climate change, population growth, and industrialization in the lower reach of the Euphrates River.

Introduction

Climate change, population growth, and shifts in water usage are making long-range water planning increasingly complex in the 21st century (Nielsen-Gammon et al., 2020). Heat waves are also expected to occur ten times more frequently over extended periods (Max-Planck-Gesellschaft, 2016). The Euphrates-Tigris basin has increased the frequency and severity of floods due to changing rainfall variability and increasing snow melt (Waha et al., 2017). These climate change impacts are likely to negatively affect water security in the region, reducing water supply in most parts of the basin (Gleick et al., 2020). Droughts, such as the one experienced in 2007-2011, have already shown the vulnerability of agricultural and livestock production systems in Turkey, Syria, and Iraq, as well as the potential impact of extreme weather events on food security and livelihoods in the region (Voss et al., 2013). Water shortages, mainly due to poor water quality, have significantly impacted agriculture in the area, resulting in some of the highest rates of water-related loss of livelihoods and displacements in Iraq (World Bank, 2018). The Climate Change Knowledge Portal (CCKP) presents the latest climate model intercomparison project (CMIP) data, which has been used by researchers such as Lar et al. (2018); Haque and Khan (2022); Boluwade (2021) to project climate change data. The IPCC-6 used five SSPs, including SSP1-1.9, SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5, to present future climate scenarios with varying levels of socioeconomic development. These scenarios predict global radiation forcing levels by 2100 and present five temperature scenarios ranging from "extremely low" (SSP1-1.9) to "very high" (SSP5-8.5) (IPCC,2021).

The CROPWAT model calculates the total crop water use based on meteorological data such as rainfall, temperature, wind speed, sunshine, and humidity, as well as soil and crop characteristics (AbdulHasan et al., 2017). This model was also used to estimate the rate of reference evapotranspiration (ETo), evapotranspiration of the crop (ETc), and irrigation water requirements (IWR) (Moseki et al., 2019).

The Water Evaluation and Planning (WEAP) model has the necessary tools to operate reservoir systems (Klari, 2016). This model has been used to simulate the basin and evaluate the effects of different scenarios on the upstream and downstream of the basin (Avarideh et al., 2017). Sameer et al. (2021) utilized the WEAP model to develop a sustainable water resource management approach in the upper Euphrates River Basin (UERB) up to 2035. Noon et al. (2021) applied the WEAP model to manage water resources in the Euphrates River, using Anbar Province as a case study to examine past trends in water resource management and simulate current demand scenarios. Abdulhameed et al. (2022) also used the WEAP model to optimize water resource management in the western region of Iraq, using a simulation modelling approach for the city of Ramadi as a case study for the period 2018-2035.

Several studies have examined water management in Iraq's Tigris and Euphrates Basins. However, they have yet to specifically focus on assessing water management in the lower reach of the Euphrates River. This study aims to estimate the water demand in the Iraqi provinces of Muthanna and Thi-Qar within the lower reach of the Euphrates River.

Materials and Methods

Study Area

Muthanna is a governorate in southern Iraq with a capital city of Al-Samawa located at approximately 31.31° N, 45.28° E. The land area of the Muthanna province is approximately 51740 km2. Thi-Qar is another governorate in southern Iraq with a capital city of Nasiriyah located at approximately 31.05° N, 46.26° E. The land area of the Thi-Qar province is approximately 12900 km^2 (JICA, 2016). Figure 1 shows the layout map for the Muthanna and Thi-Qar provinces. The Haditha Dam feeds both the Thi-Qar and Muthanna provinces. The Haditha reservoir is located on the Euphrates River about 270 km northwest of Baghdad, near Haditha, Iraq. The coordinates in UTM WGS 84 are X= 257241.412 and Y= 3788898.705. The dam is a 9.4 km long earth-fill structure with a powerhouse containing six Kaplan turbine units with a maximum capacity of 660 MW. The maximum discharge of the spillway is 11,000 m3/s at the maximum pool level (El. 147.0). The design storage capacity of the reservoir is 8.2 cubic km (NIMP, 2006).

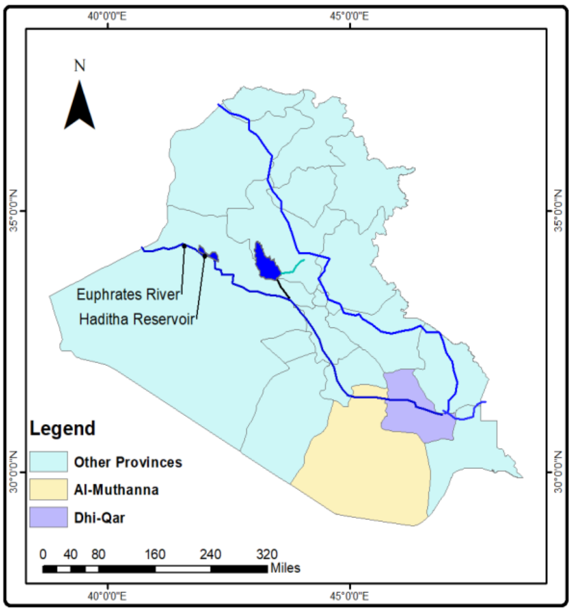

Figure 1. Layout map for the study area.

Projections of Future Climate Data

The CROPWAT model was used to calculate the irrigation demand of crops in Muthanna and Thi-Qar based on three climate change scenarios. The first scenario, the reference period (RP), is based on historical data collected from 1995 to 2014. The second and third scenarios, SSPs 2.6 and 4.5, represent climate change data for 2020-2039 and 2040-2059, respectively. Figures 2 and 3 show the minimum and maximum temperature, relative humidity, and precipitation data for the Muthanna and Thi-Qar province's RP scenario. The data was sourced from the Climate Change Knowledge Portal (CCKP).

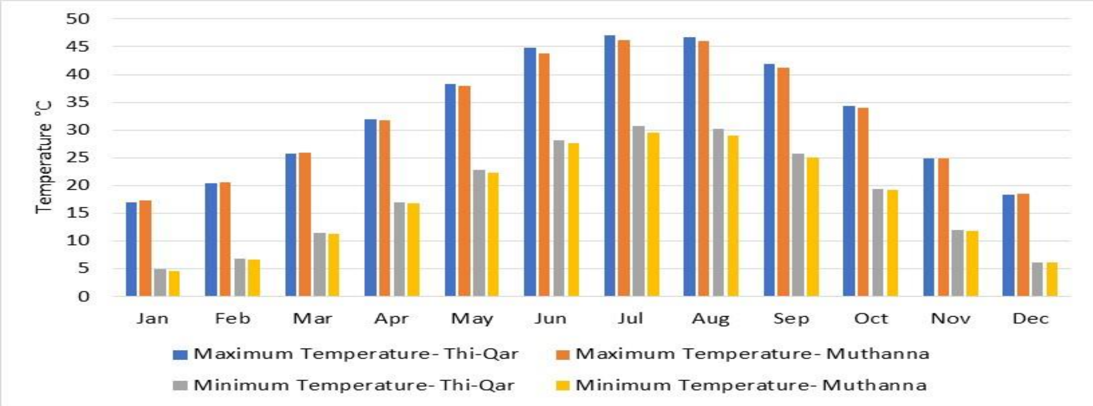

Figure 2. The maximum and minimum temperatures of the RP scenario.

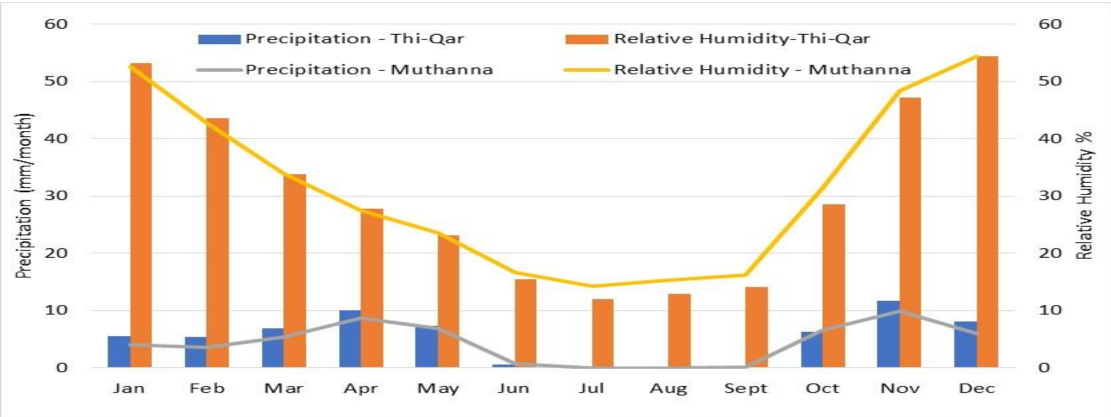

Figure 3. The precipitation and relative humidity of the RP scenario.

Estimation of Agricultural Water Demand

Figure 4 shows the flowchart of the methodology for estimating agricultural water demand. Many software packages already use the Penman-Monteith equation to assess the reference evapotranspiration. One of the outputs of the CROPWAT Model is irrigation scheduling. The Penman-Monteith method can be adapted to calculate the reference surface evapotranspiration (ETo). ETo expresses as:

$$\mathrm{ETo} = \frac{0.408\Delta(R_n - G) + \gamma\left(\frac{900}{T+273}\right)u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (1)$$

Where ETo is the reference evapotranspiration (mm/day), R_n is the net radiation at the crop surface (MJm^2/day), G is the soil heat flux density (MJm^2/day), T is the daily air temperature at 2 m height (°C), u_2 is the wind speed at 2 m height (m/s), e_s is the saturation vapor pressure (KP_a), e_a is the actual vapor pressure (KP_a), $(e_s - e_a)$ is the saturation vapor pressure deficit (KP_a), Δ is the slope vapor pressure curve ($KP_a/°C$), γ is the psychrometric constant ($KP_a/°C$).

$$\mathrm{Etc} = \mathrm{Kc} \times \mathrm{ETo} \quad (2)$$

Where Etc is the crop evapotranspiration (mm/day), Kc is the crop coefficient (Allen et al.,1998). Net irrigation water requirements (NIWR) were evaluated by using the equation:

$$\mathrm{NIWR} = \mathrm{Etc} - \mathrm{Re} \quad (3)$$

Where Re: is the effective rainfall (Naidu and Giridhar,2016). The net irrigation area in Muthanna and Thi-Qar is 125235 and 23556 hectares, respectively. These areas grow seasonal and annual crops, including wheat, barley, vegetables, rice, and citrus (JICA, 2016). The crop coefficient, which reflects the difference in evapotranspiration between field crops and a reference grass surface, varies throughout the growing period as the ground cover changes with crop development stages. The crop coefficient curve, which has three values, illustrates typical trends during the growing season. The crop coefficient, maximum crop height, and lengths of crop development stages for various planting periods were collected from the study of Allen et al. (1998).

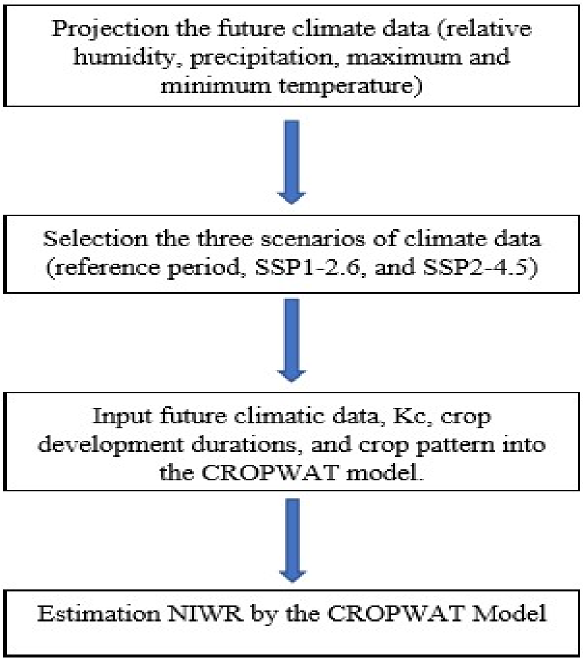

Figure 4. Flowchart of the methodology for estimation the NIWR by CROPWAT Model

Estimation of the Municipal and Industrial demand

The United Nations has created population growth projections for countries, including Iraq, using fertility rates in each region. These projections can be used by the United Nations to forecast municipal water demand in these countries (United Nations, 2019). Figure 5 shows the annual percentage rate of change of population growth in the Muthanna and Thi-Qar provinces. In 2013, the Republic of Iraq Ministry of Planning (RIMP) estimated the population in 2009 based on the 1997 Census. The number of residents in the Muthanna and Thi-Qar provinces in 2009 was 683126 and 1744398, respectively (RIMP,2013). Figure 6 shows the number of residents in the Muthanna and Thi-Qar provinces throughout the development manager. Table 1 shows the actual capacity of water treatment plants (WTPs) and water consumption units (CU) in the Muthanna and Thi-Qar provinces (Al-janabi, 2018). The water demand per capita data can be calculated by dividing the actual capacity of WTPs and CU data by the resident number for the provinces. The data in Table 2 can also be used to project the annual growth of industrial water demand (Al-janabi, 2018).

Table 1. The actual capacity of water treatment plants (WTPs) and water consumption units (CU) in the Muthanna and Thi-Qar provinces (Al-janabi, 2018)

The actual capacity of water treatment plants (m^3/d)			
Province	WTB	CU	Total
Muthanna	245920	198773	271962
Thi-Qar	502408	188531	486322

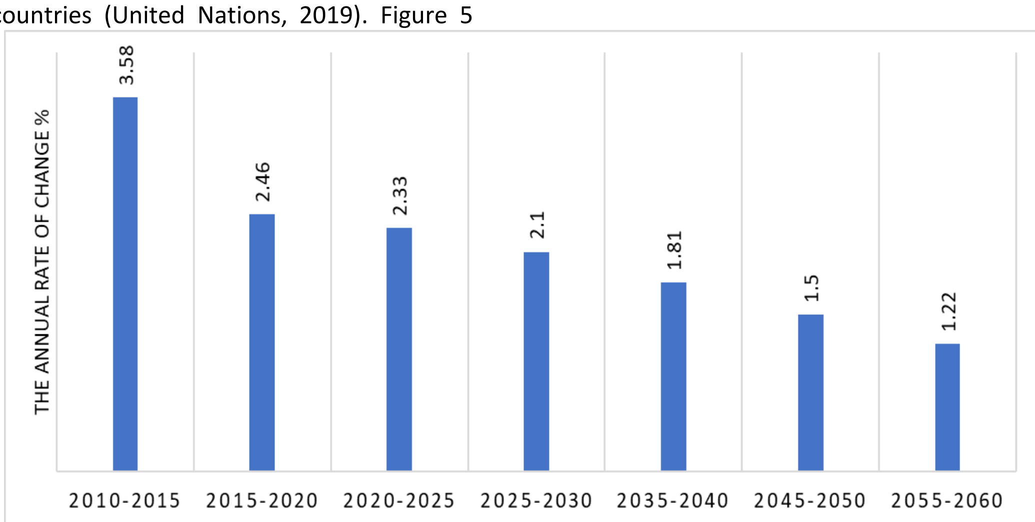

Figure 5. The annual percentage rate of population growth from 2010 to 2060 (United Nations, 2019)

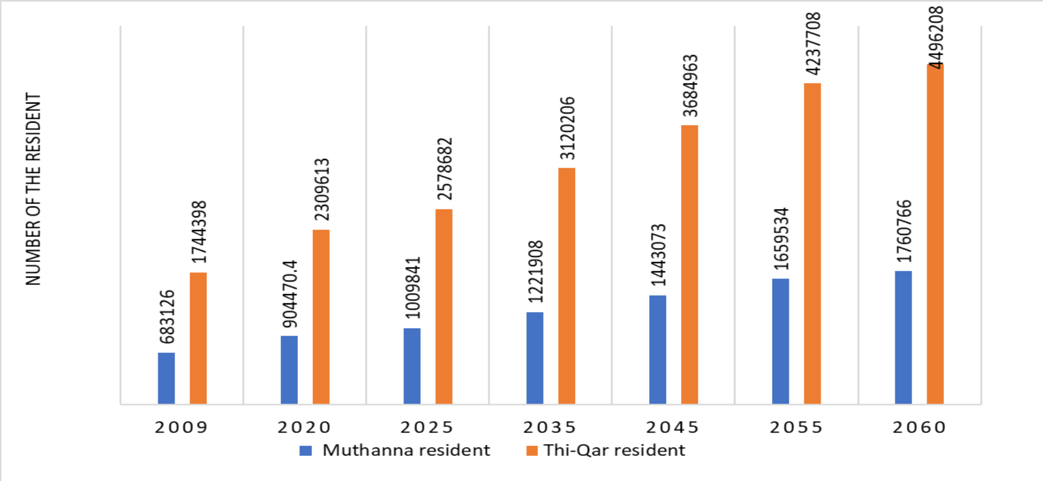

Figure 6. Projection of the residents in the Muthanna and Thi-Qar provinces

Table 2. The industrial water demand from 2010 to 2035 (m^3/d) (Al-janabi, 2018)

Governorate	2010	2015	2020	2025	2030	2035
Muthanna	19781	29672	39563	49453	59344	69235
Thi-Qar	1713	2.569	3425	4282	5138	5994

Evaluation Criteria

The last step will be to evaluate the performance of a measurement system after estimating the water demand by CROPWAT, WEAP, and other statistical methods. Some of the fundamental statistics for Validation are as follows:
1-Coefficient of determination (R^2): describes the proportion of the variance in measured data explained by the model. R^2 ranges from 0 to 1, with higher values indicating less error variance, and typically values greater than 0.5 are considered acceptable (Moriasi et al. 2007). (R^2) is used to evaluate the results of the calibration and validation of the model (Khazaipoul et al. 2019). from 0 to 1, with higher values signifying less error variance, and typically values greater than 0.5 are considered acceptable (Moriasi et al.,2007). The formula for computing R^2 between bivariate data, X_i and Y_i values are:

$$R^2 = \frac{\left[\sum_{i=1}^{n}(X_i-\bar{X}_i)(Y_i-\bar{Y}_i)\right]^2}{\sum_{i=1}^{n}(X_i-\bar{X}_i)^2 \sum_{i=1}^{n}(Y_i-\bar{Y}_i)^2}$$
(4)

$\bar{X}_i$ and $\bar{Y}_i$ are the sample means of the X_i and Y_i values, respectively.

Results and Discussion

Projection of the Climate Change Data

Figures 7 and 8 show the time series of maximum and minimum temperature projections for the Muthanna and Thi-Qar Provinces. Also, Figures 8 and 9 show the time series of precipitation and relative humidity projection. The projected temperature, precipitation, and relative humidity under three scenarios of climate change: RP, SSP-2.6, and SSP-4.5. The results showed that the projected temperatures in both provinces are consistent with global climate change, with an increase in the maximum temperature ranging from 1.14 to 0.53 for Muthanna and 1.07 to 0.53 for Thi-Qar. The increase in the minimum temperature ranged from 1.21 to 0.43 for the Muthanna and Thi-Qar Provinces, respectively. The annual precipitation in Muthanna fluctuated between a maximum of 76.6 mm and a minimum of 39.75 mm. At the same time, Thi-Qar ranged from a maximum of 94.53 mm to a minimum of 45 mm.

The annual decrease in relative humidity was 0.114% and 0.119% for Muthanna and Thi-Qar, respectively.

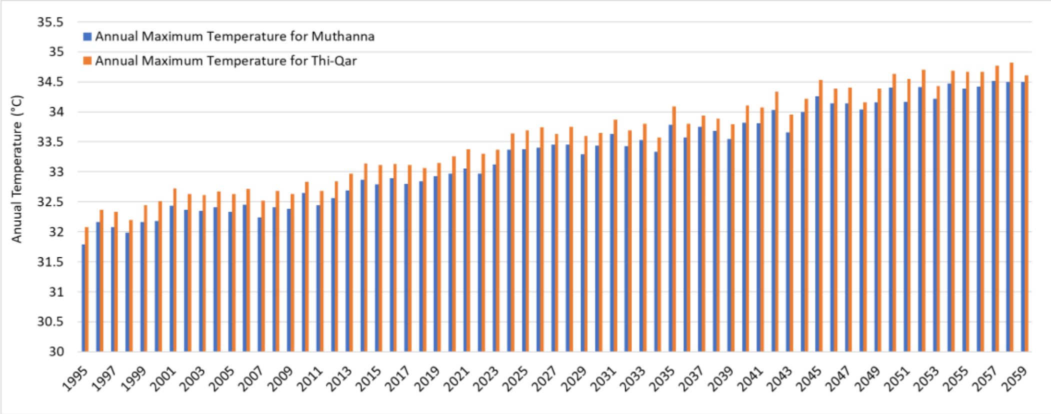

Figure 7. The Maximum Temperature Projection Time Series for Muthanna and Thi-Qar provinces.

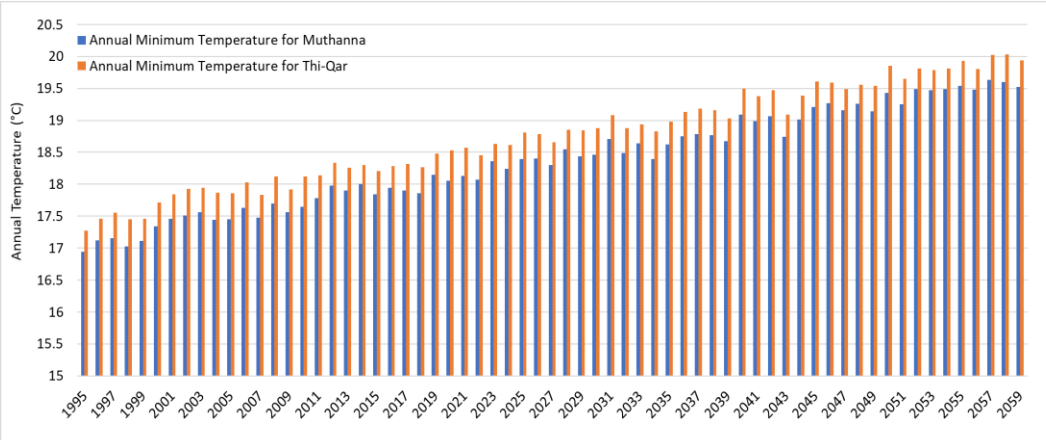

Figure 8. The Minimum Temperature Projection Time Series for Muthanna and Thi-Qar Provinces.

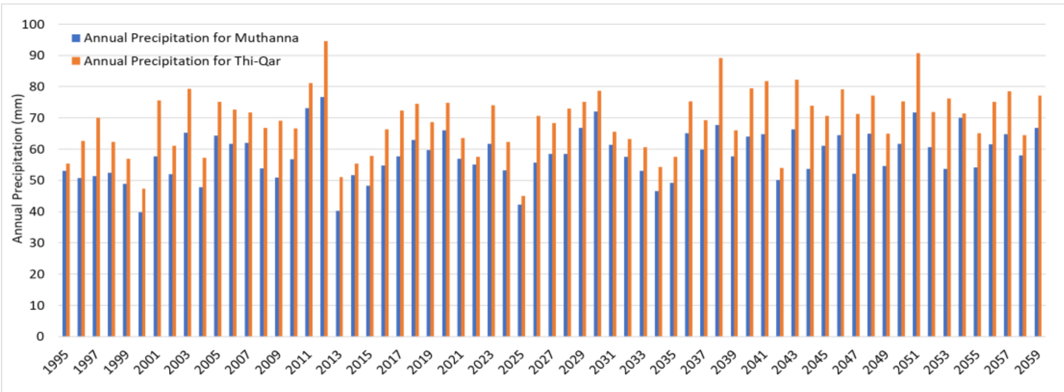

Figure 9. The Time Series of Precipitation Projection for Muthanna and Thi-Qar Provinces

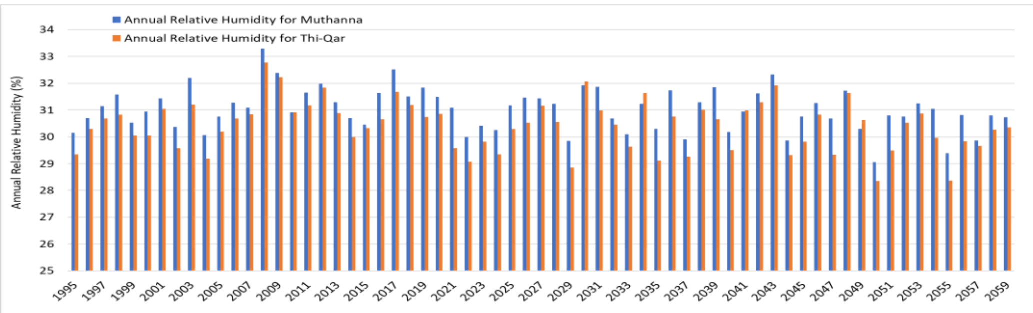

Figure 10. The Time Series of Relative Humidity Projection for Muthanna and Thi-Qar Provinces.

Projection of Agricultural, Municipal, and Industrial Water Demand

Figure 10 shows the agricultural water demand for the Muthanna and Thi-Qar provinces from 2020 to 2059. The data shows that the agricultural water demand for both provinces exhibits an increasing trend over time, with demand increasing by 9.2 and 0.65 million cubic meters (MCM) per year in both provinces. The agricultural water demand in Muthanna is consistently higher than in Thi-Qar, with the difference between the two provinces widening over time. Figure 11 shows the municipal water demand for the Muthanna and Thi-Qar provinces from 2022 to 2059. The data shows that the municipal water demand for both provinces exhibits an increasing trend over time, with an average increase in the demand of 2.73 MCM per year in Muthanna and 4.89 MCM per year in Thi-Qar. The municipal water demand in Thi-Qar is higher than in Muthanna, with the difference between the two provinces over time. Figure 12 shows the industrial water demand for the Muthanna and Thi-Qar provinces from 2022 to 2059. The data shows that the industrial water demand for both provinces exhibits an increasing trend over time, with an average increase in the demand of 0.2 MCM per year in Muthanna and 0.22 MCM per year in Thi-Qar.

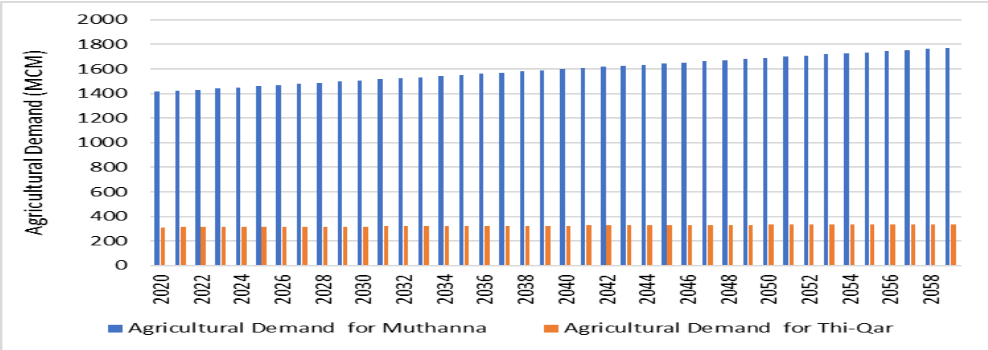

Figure 11. The projected agricultural water demand

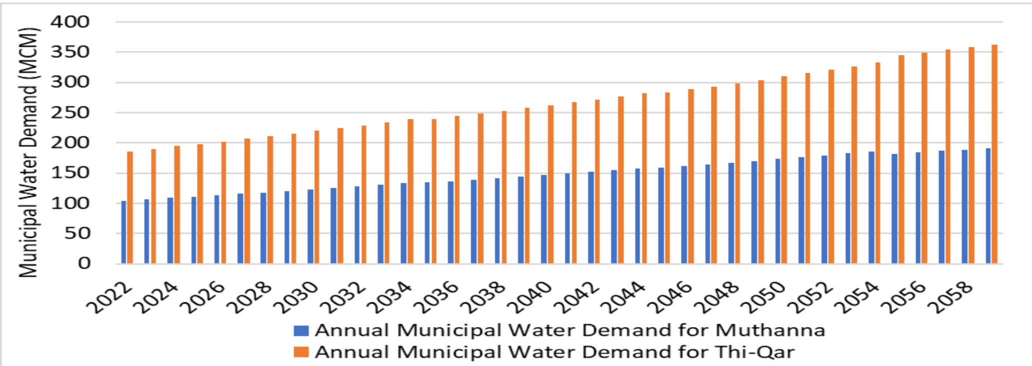

Figure 12. The projected municipal water demand

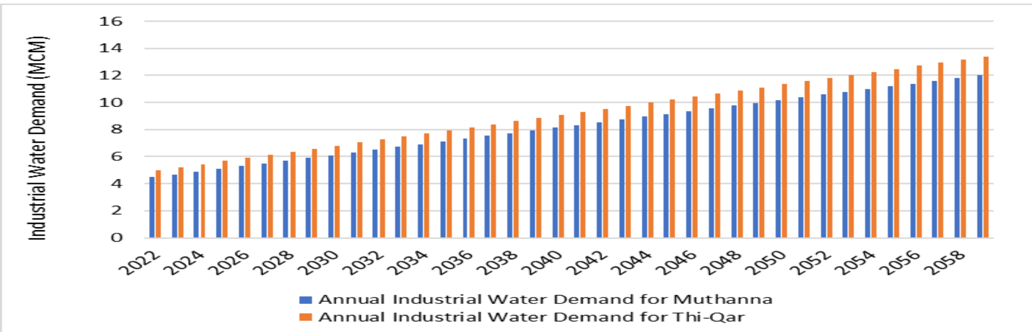

Figure 13. The projected industrial water demand

Prediction of the Water Demand by WEAP Model

The WEAP model was used to simulate annual demand projections for the Muthanna and Thi-Qar provinces. The results, shown in Figure 14, indicate that the municipal demand for Muthanna reaches a maximum of 211.4 MCM in 2059 and a minimum demand of 98 MCM in 2022, while the demand for Thi-Qar is higher at 377.2 MCM and a minimum demand of 174.8 MCM in the same year. This difference is likely because the population of Thi-Qar is more significant than that of Muthanna.Figure 15 shows the agricultural demand for the two provinces also shows a significant difference, with Muthanna experiencing a maximum demand of 1579 MCM in 2059 and a minimum demand of 1443.4 MCM in 2022, compared to a maximum demand of 347.8 MCM and a minimum demand of 317 MCM for Thi-Qar over the same year. This difference is likely due to the larger irrigated area in Muthanna compared to Thi-Qar.Figure 15 illustrates that the industrial demand for the two provinces also exhibits some variation over time, with Muthanna experiencing a maximum demand of 7.66 MCM in 2059 and a minimum demand of 3 MCM in 2022, while Thi-Qar has a maximum demand of 6.48 MCM in 2059 and a minimum demand of 2.65 MCM in 2022.

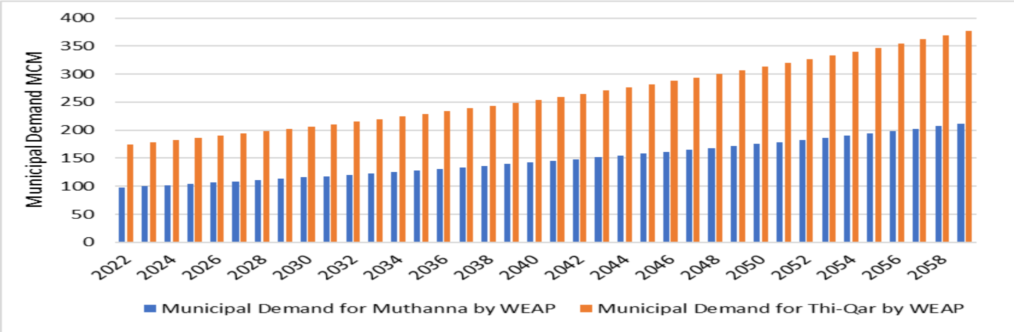

Figure 14. The estimation of the municipal water demand by WEAP model

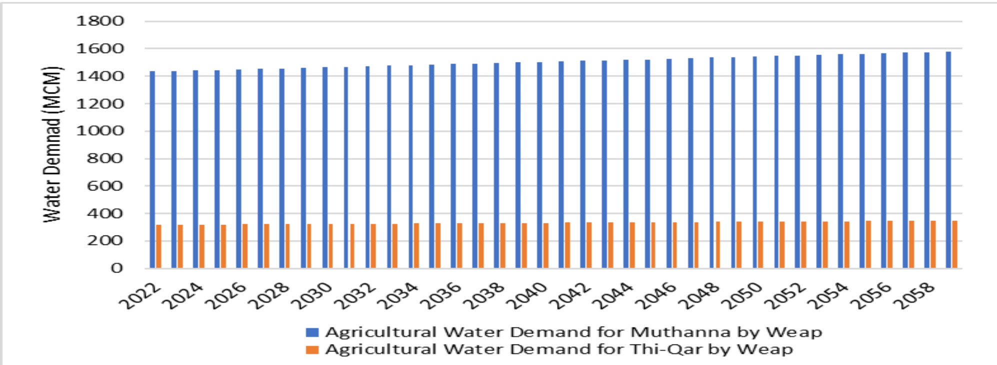

Figure 15. The estimation of the agricultural water demand by WEAP model

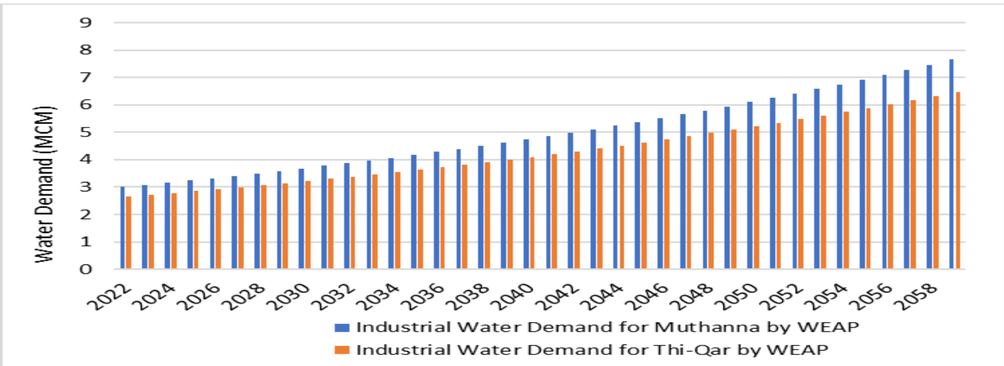

Figure 16. The estimation of the industrial water demand WEAP model

Validation of the Estimated Water Demand

In this study can be used the coefficient of the determination (R^2) to validate the estimated water demand of the agricultural, municipal, and industrial sectors by using CROPWAT, and the methods described in section 2.4 concerning the estimation made by the WEAP model. The results of the validation parameter R^2 show a high degree of correlation between the estimation made by the different methods. For the industrial sector, the R^2 values are 0.985 and 0.986 for the Muthanna and Thi-Qar provinces, respectively. For the agricultural sector, the R^2 value is 0.999 for both provinces. For the municipal sector, the R^2 values are 0.985 and 0.997. These results suggest that the demand for water in the Muthanna and Thi-Qar provinces is highly predictable and follows a strong linear trend.

Conclusion

The projections for temperature, precipitation, and relative humidity in the Muthanna and Thi-Qar provinces have significant implications for water demand, particularly in the agricultural sector. The annual precipitation and relative humidity in both provinces are expected to fluctuate, with a more significant range of fluctuations in the Thi-Qar province. The maximum and minimum temperature are also expected to increase annually under all three climate change scenarios. These changes are likely to lead to an increase in evapotranspiration rates and water consumption for the agricultural sector.

The agricultural water demand for Muthanna is higher than that of Thi-Qar; there are a few potential explanations for these trends. The main reason is that the irrigated areas in Muthanna are larger than in Thi-Qar. Another possibility is that the agricultural water demand in Muthanna may be influenced by factors such as soil type, crop types, or irrigation practices that differ from those in Thi-Qar. Further analysis, such as comparing the agricultural sector characteristics or irrigation practices in the two provinces, could shed light on the underlying drivers of these trends.

The municipal demand for Thi-Qar is higher than that of Muthanna. The main reason is that the residents in Thi-Qar are larger than in Muthanna. It is important to note that the demand for all three sectors (municipal, agricultural, and industrial) shows an increasing trend over time in both provinces, indicating that the water resources in the region will face increasing pressure from population growth and economic activity.

The findings from the comparison between the different methods suggest that demand can be accurately forecasted and planned for in the future. The research highlights the need for effective water resource management in the face of the challenges posed by climate change, population growth, and industrialization in the lower reach of the Euphrates River. The simulation results provide vital information for water resource management in the region and can be used to inform decision-making and planning for the future.

Conflict of interest

The author declare there is no conflict of interest.

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