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Impact of Climate Change on Integrated Management of Water Resources in The lower Basin of Diyala River, Iraq

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Abstract

Climate change could affect the world's water resources system, especially at the level of the basin. Climate change would impact streamflow and corresponding future water resources. The lower basin of the Diyala River is currently experiencing water shortage and contamination issues. This study aims to use Water Evaluation And Planning (WEAP) model to create an integrated modeling system for evaluating the effects of climate change on water supply and demand within the lower Diyala River basin. The WEAP model was calibrated and verified employing monthly streamflow data from the Diyala River outflow station. Following that, the calibrated model was loaded with various future scenarios ranging from 2020-2045. Future scenarios used included the reference scenario, the high population growth rate scenario, and the climate change scenario. The results indicated that the WEAP model accurately predicted the basin's water supply and demand, with RMSE, NSE, and R^2 values of 0.85, 0.91, and 0.867, respectively, throughout the validation period. Furthermore, Water demand and supply were found to be unmet in all projected future scenarios, showing that sustainable water management in the lower basin of the Diyala River is highly required.

Keywords: Integrated water resources management, WEAP model, climate change

الخلاصة : يؤثر تغير المناخ على نظام الموارد المائية العالمي ، وخاصة على مستوى الأحواض. سيؤثر تغير المناخ على تدفق مجاري المياه و بالمقابل على موارد المياه في المستقبل. يعاني الحوض الأسفل لنهر ديالى حاليا من نقص في المياه وقضايا التلوث. الهدف من هذه البحث هو تطوير إطار نمذجة متكامل لتقييم تأثير تغير المناخ على إمدادات المياه والطلب عليها في حوض نهر ديالى الأسفل باستخدام نموذج تقييم المياه والتخطيط (WEAP). تمت معايرة النموذج والتحقق من صحته باستخدام بيانات التدفق الشهري من محطة منفذ نهر ديالى. بعد ذلك ، تم تحميل النموذج المعاير سيناريوهات مستقبلية مختلفة تتراوح بين 2020-2045. تضمنت السيناريوهات المستقبلية المستخدمة السيناريو المرجعي ، وسيناريو معدل النمو السكاني المرتفع ، وسيناريو تغير المناخ. أشارت النتائج إلى أن نموذج WEAP تنبأ بدقة بإمدادات المياه في الحوض والطلب عليها ، حيث بلغت قيم RMSE و NSE و R^2 (0.85 و 0.91 و 0.867)على التوالي خلال فترة التحقق. علاوة على ذلك ، لوحظ أن العرض والطلب على المياه لم يتم تلبيتهما في ظل جميع السيناريوهات المستقبلية المقترحة ، مما يعني أن هناك حاجة ملحة لإدارة المياه المستدامة في الحوض الأسفل لنهر ديالى.

1. INTRODUCTION

The effects of climate change on water supplies have recently emerged as a key issue that world must address. Climate change has the potential to significantly alter hydrological cycles, primarily by changes in precipitation and evapotranspiration.[1], [2], [3]. The accessibility of potential water resources in various areas will undoubtedly be impacted by climate change, economic development, and population increase.

Although the consequences of climate change are a worldwide issue, researchers are most impressed by the regional effects at the catchment level. The fact that Climate change will have an impact on the hydrological cycle and availability of water globally is one of the most important conclusions of relevant studies [4]. Researchers and policymakers may limit the harmful effects of climate change by applying proper water management practices and understanding the relationship between water resources and climate change. Multiple studies on the impact of climatic changes on the hydrological systems reveal that fluctuations in streamflow are related to temperature and rainfall changes [5], [6], [7], [8]. As a result of global warming, enhanced rapid urbanization, industrial fields, population increase and increased demand for natural resources, the lower basin of Diyala River has recently experienced significant water management challenges. To present, climate change studies and policy formulation have not sufficiently addressed water challenges in the Diyala basin [9]. As a result, the primary goal of this research was to analyze the impact of projected future climate changes on the lower Diyala River's water resources. Water Evaluation and Planning (WEAP) has evolved as a useful technique for allocating water resources in a variety of socioeconomic and climate change scenarios [10], [11]. The WEAP model has gained widespread acclaim for assessing numerous water-related projects and has been applied in numerous nations. For example, Kerim et al., [12] evaluated existing and future water accessibility in Ethiopia's Upper Awash sub-basin under the effect of climate change scenarios till 2031. The findings imply that water consumption will rise, but there will be enough water to fulfill the need in the future. They recommended prioritizing the irrigation sector, which is at the forefront, followed by livestock, and at last industrial plants. Amin et al. [13] evaluated future and current water needs in Pakistan's Upper Indus Basin within IPCC climate-change scenarios and created various scenarios (population increase, urban growth, and standard of living) employing the WEAP methodology. According to the findings, water demand would rise in 2050, with unmet demand depending on the user scenarios. Kishiwa et al., [14] investigated the dynamics of accessible present and future streamflow for various users inside the upper Pangani Watershed due to climate change. They used the SWAT and WEAP models to predict river flow during climate change scenarios in order to estimate future water availability during various socioeconomic activities up to the 2060 s. They anticipated that by the 2060s, the unmet water demand will have risen to 51.5%, with irrigation being the most affected. Sithiengtham [15] studied water demand and supply in the Nam-Ngum river basin, Laos under climate change. The study concluded that the current water demand is less than the availability of water which means there are more quantities of water in all types of years (wet, dry, and very dry) but need good management is recommended to ensure that water resources in this region are not wasted to 2030. Lastly, Mena et al. [16] took the Guali River Basin in Colombia as a study area to determine the impact of climate change on water and the rising demand for it. The researcher combined the Hydro-Bid model with a WEAP model taking 2012 as the base year and the prediction until the 2100s.They used three scenarios to find a solution to minimize the amount of unmet water demand within basin by reducing the quantities of losses in the system (network system for each node in the basin). It was found that the most period of scarcity and unmet demand is 2071-2100, as the population will increase and increase with it industrial and agricultural activity, which leads to an unmet demand rate of 100%. The present study investigated water demand and availability in the Diyala River's lower basin during the coming years (2020-2045).It manages allocation of water resources in the face of climate change, which is a source of social and economic growth as well as a human activity. I′n order to achieve this, the monthly streamflow at the Diyala River outflow gauge station was utilized to calibrate and verify the WEAP model. This calibrated model was then used to evaluate three major future scenarios: the reference scenario, the high-rate population growth scenario, and the climate-change scenario.

2. MATERIALS & METHODS

2.1. Study area

Diyala river basin lies within the latitude (33° 10′ 44″ - 35° 50′ 43″) N, and longitudes (44° 30′ 34″ and 47° 50′ 33″) E. It is bordered to the east by the Karon River basin, to the north and northwest by the Lesser Zab Basin, but to the west by the AL-Udaim River Basin and to the south and southwest by the Tigris River. The basin is shared by Iraq and Iran (59% in Iran and 41% in Iraq) [17]. After the Tigris and Euphrates rivers, the Diyala River is Iraq's third-largest international river in terms of basin area at 32,600 km², and it has a total length of about 445 km [18]. The river basin is split into two sections the feeding basin, which extends from the Iranian mountains to the Strait of Hamrin in Mansouriat al-Jabal in Diyala province. The drainage basin is the second section, which extends from the Strait of Hamrin to its mouth in the Tigris River south of Baghdad. The research focuses on the drainage basin, which represents the lower part of the basin; the basin area (based on SRTM-DEM) is 2930 km², and the river length is approximately 184 km.

Demand sites in the WEAP model for the study area are represented by red color nodes and are classified into three categories, with four nodes representing domestic demand sites, five nodes representing agricultural demand sites, and one node representing industrial demand sites as shown in figure 1.

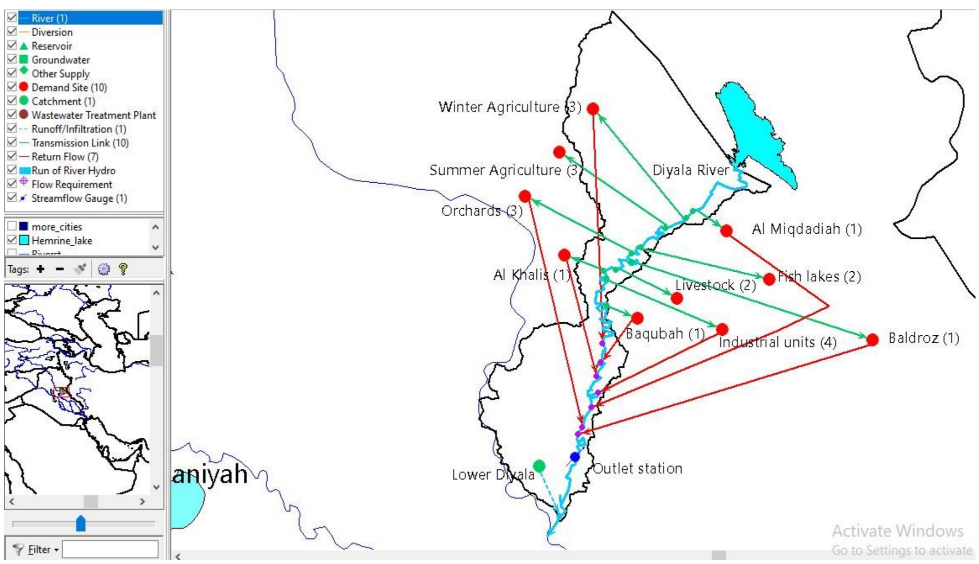

Figure 1: Diyala River consumption water nodes in the lower basin

The population of the study area districts is listed in Table I, which was acquired from Iraq's Central Statistical Organization. The population is estimated to be 1,495,548 in 2020, with a growth rate of about 2.55%, which represents the normal growth rate, making the future population expected to be 2,806,674 in 2045. Also, the amount of water used by each person was estimated to be 350 L/day by the Diyala Governorate Water Directorate.

Table1: The population of the lower basin of Diyala River/2020

Lower basin	Population
Baqubah	663,181
Al Khalis	387,267
Al Miqdadiah	281,425
Baladroz	163,675
Sum	1,495,548

2.2. Input data

Various data were used as inputs to the WEAP model in this paper to estimate the demand and supply of water in the lower basin of the Diyala River. The following categories implement to these data:

2.2.1. Climate data

The Ministry of Transportation/Iraq Meteorological Organization and Seismology provided observed climate data such as rainfall, temperatures, humidity, wind speed, as well as evaporation for the period between 2000 and 2020, and these data represent annual or monthly observations. Table 2 illustrates the statistical properties of the climate data in the lower Diyala River basin.

Table 2: The statistical properties of the study area's average annual climate data (2000- 2020)

Climate Data	Max.	Min.	Mean
Rainfall (mm)	147.6	0	14.8
Temperature (C °)	44.1	3.6	22.7
Relative humidity (%)	72	28	48
Wind speed (m/s)	3.6	1.8	2.7
Evaporation (mm)	412	53.8	208.6

The majority of the lower basin's annual precipitation falls between October and May. The rainfall distribution across the study area is also not uniform, but Al-Khalis station is the only station inside the lower basin. According to the 20 years of monthly data available for Al-Khalis station from 2000 to 2020, 50% of rainfall occurs in the winter, 25% occurs in the spring, and 25% mostly in autumn. [19], which mean that during the summer dry season, a substitute source could be necessary to meet demand. As a result, the lower basin of the Diyala River highly depends on Diyala River water instead of rain to meet its needs.

2.2.2. Diyala River flow

The head flow for the Diyala River's lower basin is represented by monthly and annual discharge data for the Diyala River downstream of Hamrin dam from (2000- 2020). The Iraqi Ministry of Water Resources/National Center for Water Resources Management provided this data [21]. The river flows through the Diyala province before joining with the Tigris River just south of Baghdad which is considered the end of the lower basin this joining point is called the outlet gauge station. This station's observed streamflow data was used for streamflow analysis as well as model calibration and validation.

2.2.3. Agricultural area

For the year (2020-2021), the cultivated land area in the Lower Diyala Basin is approximately 150303 ha. This study included the agricultural areas that rely on the Diyala River for irrigation, which were divided into three categories as follows:

- Winter agriculture: All crops planted during the winter season were included in this category. The water quantity for winter crops was calculated using the average amount of water required to produce an agricultural crop during the planting season (each plant requires about 8572 m3/ha), as well as the area available for various types of crops, which is estimated to be approximately 114,306 hectares [20].
- Summer agriculture includes all crops grown during the summer season. The amount of adequate water for winter crops was calculated in the same way as in the winter agriculture, taking into account the difference in water quantities for summer crops (The yield of these crops ranges from 11500- 17000 m3/ha for each plant) .These areas are estimated to be around 10,212 hectares [20].
- Orchards: These are considered constant in terms of water consumption (about 22860 m3/ha) and include Citrus and Palm, with a total area of 25,785 hectares [20].

2.2.4. Livestock Data

According to data from the Diyala Province Directorate of Agriculture/Department of Animal Wealth Services for 2020, there are approximately 734,973 heads of animals within the study area, and based on the annual consumption rates of each species, their total water consumption is 8,583,381 cubic meters, as shown in Table 3.

Table3 : Livestock needs within the study area /2020

Livestock	**Head**	**Annual water consumption per head m3/year**	**Total annual water consumption m3/year**
Cow	204934	20	4098680
Buffalo	18905	50	945250
Sheep	369133	8	2953064
Goat	140296	4	561184
Camel	1643	15	24645
Horses	62	9	558
Sum	734,973		8,583,381

2.2.5. Fish lakes

There are 34 officially licensed lakes, the majority of which are located in the Al Khalis district, with areas ranging from (1-38) Donem [22]. A number of fish ponds that are not deemed legal by the government consume large amounts of water from the Diyala River. Only officially licensed fish lakes were considered in this paper.

2.2.6. Industrial units

Water consumption by industrial facilities tends to vary by industry, with some industries consuming a large amount of water, such as sugar, paper, and fertilizers, while other institutions, such as the Baquba industrial complex, consuming small amounts of water. Table 4 shows how industrial and commercial facilities have been accounted for in the lower basin [23].

Table 4: Industrial and commercial water consumption/2020

Industrial and commercial type	Number	Water consumption (m^3/day)	Water consumption (m^3/year)
Ice factory	9	100	328500
Wash and lubricate	30	40	438000
Production factory	65	90	2135250
Big workshop	55	15	301125
Small workshop	40	7	102200
Hotel	8	7	20440
Restaurant	100	20	730000
Casino	70	15	383250
Service shop	2192	6	4800480
Sum			9,239,245

3. WEAP MODEL

Water Evaluation And Planning Approach is known as WEAP. It offers a thorough, adaptable, and simple framework for policy analysis. Among water specialists, the WEAP is becoming more and more well-liked as a useful addition to their collection of models, databases, spreadsheets, and some other tools [24]. A system for processing information on water demand and supply is provided by WEAP as a database. As a prediction tool, WEAP models water demand, supply, flows, storage, treatment, and discharge. As a tool for policy analysis, WEAP considers all available development and management alternatives for water options as well as various and conflicting uses of water sources [25]. WEAP is suitable for complex trans-border river systems, single watersheds, and municipal and agricultural systems. It works on the fundamental idea of a water balance. WEAP is also capable of handling a wide range of challenges, such as sectoral demand studies, water conservation, prioritizing water rights and distribution, modeling groundwater and streamflow, running reservoirs, producing hydropower, monitoring pollution, determining the needs of ecosystems, determining vulnerability, and performing benefit-cost analyses for projects. The Stockholm Environment Institute was primarily responsible for developing WEAP [25]. More than a hundred countries have used WEAP for water assessments. WEAP model calculates water demand in the study region using some equations, such as equation.1, which is shown below:

$$\text{Water Demand} = A.W \times A.L \tag{1}$$

A.W = annual stage of activity (like agricultural land, domestic water use, or industrial units) that drives demand.

A.L = yearly water consumption per unit of activity.

4. FUTURE SCENARIOS DEVLOPMENT

Because the data for 2020 were complete and could serve as a starting point for the future scenario, that year was chosen as the reference year for data covering overall water demand for different sectors, including domestic, industrial and agricultural demand. In the lower basin of Diyala River, the potential of the water supply and demand was evaluated using three scenarios from 2021 to 2045, and as follows:

1) Reference Scenario (S1): with a population growth rate of 2.55% (2021-2045), agricultural areas increased by 69%, and other driving factors (climatological, water uses, etc.) remain constant; this depicts the water resources' current state.
2) High rate population growth (S2): This reflects the scenario in which the rate of population growth rises from 2.55% to 4% by 2045.
3) Climate change scenario (S3): This scenario assumes a gradual increase in temperature by 5.4% during (2021-2045) and Gradual decrease in rainfall by 20% during the study period, and this will be reflected on the surface imports of the river and its tributaries.

5. WEAP model evaluation

Three statistical criteria were applied in this paper to evaluate the WEAP model's performance. These were the Root Mean Square Error (RMSE), the Nash-Sutcliffe Coefficient, and the coefficient of determination (R^2). These coefficients are represented by the following equations:

$$\mathrm{RMES} = \sqrt{\frac{\sum_{i=1}^{N}(Oi-Yi)^2}{N}} \quad (2)$$

$$\mathrm{NSE} = 1 - \frac{\sum_{i=1}^{N}(Yi-\mu)^2}{\sum_{i=1}^{N}(Oi-\delta)^2} \quad (3)$$

$$R^2 = \frac{\sum_{i=1}^{N}(Oi-\delta)(Yi-\mu)}{\sqrt{\sum_{i=1}^{N}(Oi-\delta)^2 \sum_{i=1}^{N}(Yi-\mu)^2}} \quad (4)$$

Where: Oi Observed Streamflow, Yi Simulated Streamflow, μ the mean of Simulated stream flow, δ the mean of Observed stream flow.

6. RESULTS & DISCUSSION

6.1. Calibration and validation

WEAP integrates the hydrological process with water allocation; hydrological parameters that can be calibrated for the WEAP model include those that simulate the impact of integrated water resource management and have a significant effect on availability. Manual calibration was used, with trial and error in parameter adjustment through the use of multiple simulations. The observed stream flows at the outlet station from 2014 to 2016 were used to calibrate the model, and the model was validated in 2017 and 2018. The calibration process is supported by sensitivity analysis to achieve the best model accuracy. The sensitivity analysis method was terminated once it was determined that it was feasible, and the optimal parameter values selected are shown in table 5.

Table 5: Optimum parameter value

Parameter	**value**
Initial relative storage (Z1)	20%
Relative storage (Z2)	80%
Deep Conductivity (DC)	60 mm/month
Deep Water Capacity (DWC)	800 mm

Root Zone Conductivity (RZC)	50 mm/month
Resistance Runoff Factor (RRF)	2
Preferred Flow Direction (PFD)	0.7
Soil Water Capacity (SWC)	600 mm

It is evident that the observed and simulated streamflow were consistent and in good agreement throughout the two periods, despite the fact that there were slight variations between the peak discharge from the observed and modeled data even throughout the calibration period. The results of RMSE, NSE, and R^2 values, however, were 0.72, 0.88, and 0.67 for calibration and 0.85, 0.91, and 0.867 for validation, respectively as shown in Table 6. For both the calibration and validation processes, low variations between the simulated and observed values of stream flow data are indicated by the values of the Nash-Sutcliffe Coefficient (NSE), Coefficient of determination (R^2), and Root Mean Square Error (RMSE). The model performs well in reproducing the outputs needed for analyzing the scenarios' results, according to the statistical calibration and validation results as shown in figure 2 and figure 3.

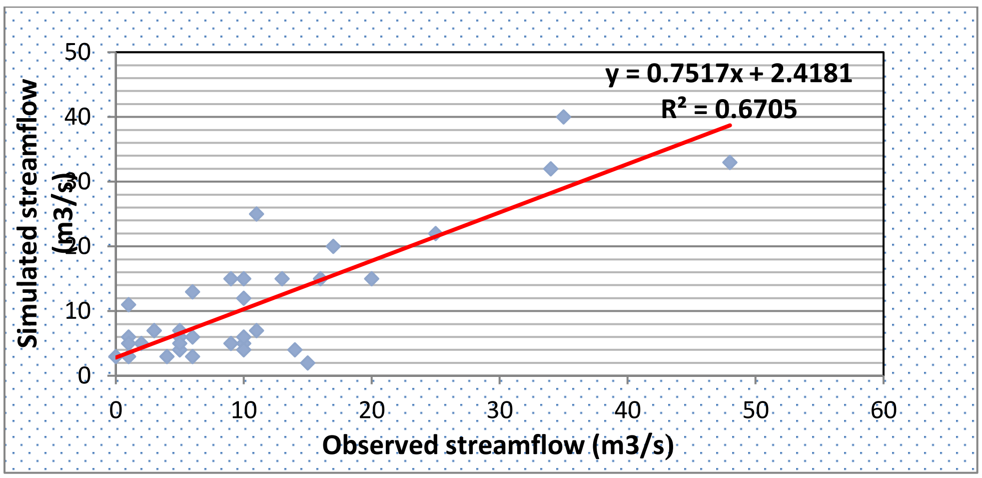

Figure 2: The calibration relationship between the monthly observed and simulated streamflow for (2014-2016) in the lower basin of the Diyala River.

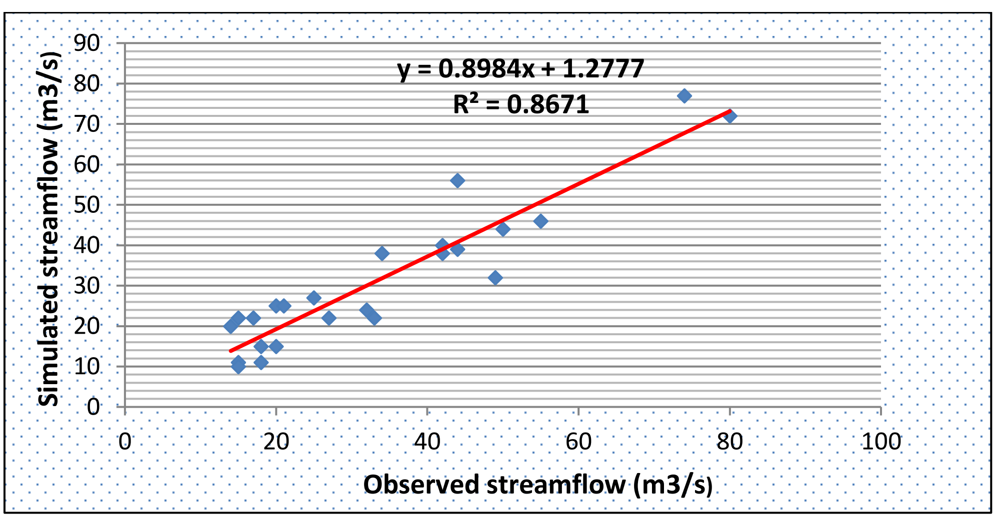

Figure 3: The validation relationship between the monthly observed and simulated streamflow relationships for (2017-2018) in the lower basin of the Diyala River.

Table 6: Model Calibration and Validation Results

Statistical Coefficient	Calibration value	Validation value
RMSE	0.72	0.85
NSE	0.88	0.91
R^2	0.67	0.867

6.2. Future scenarios

6.2.1. The reference Scenario (S1)

The calibrated WEAP model was used in conjunction with the reference scenario to assess the potential future actions of the water system in the lower basin of the Diyala River. The reference scenario; which serves as a guideline for the other scenarios in the system data, extends the current data over the full-time frame with no significant changes. This model's input conditions included a population growth rate of 2.55% (2021-2045), an increase in agricultural land of 69%, and an evaporation rate of 1.7% [26]. The research results indicated that the water demand for the agricultural and domestic sectors would raise to 2.77 billion cubic meters (BCM) and 358.55 MCM, respectively, by 2045. The demand for water in agriculture increased by 58%. Similar to this, domestic water demand increased to approximately 87% in 2045. According to the results, the lower basin of the Diyala River has enough water to satisfy all demands in all sectors through 2028. However, from 2029 to 2045, there will be an unmet demand as shown in figure 4. The supply requirements for the reference scenario show that the domestic sector will be the largest, followed by the industrial sector, and then the agricultural sector as shown in figure 5.

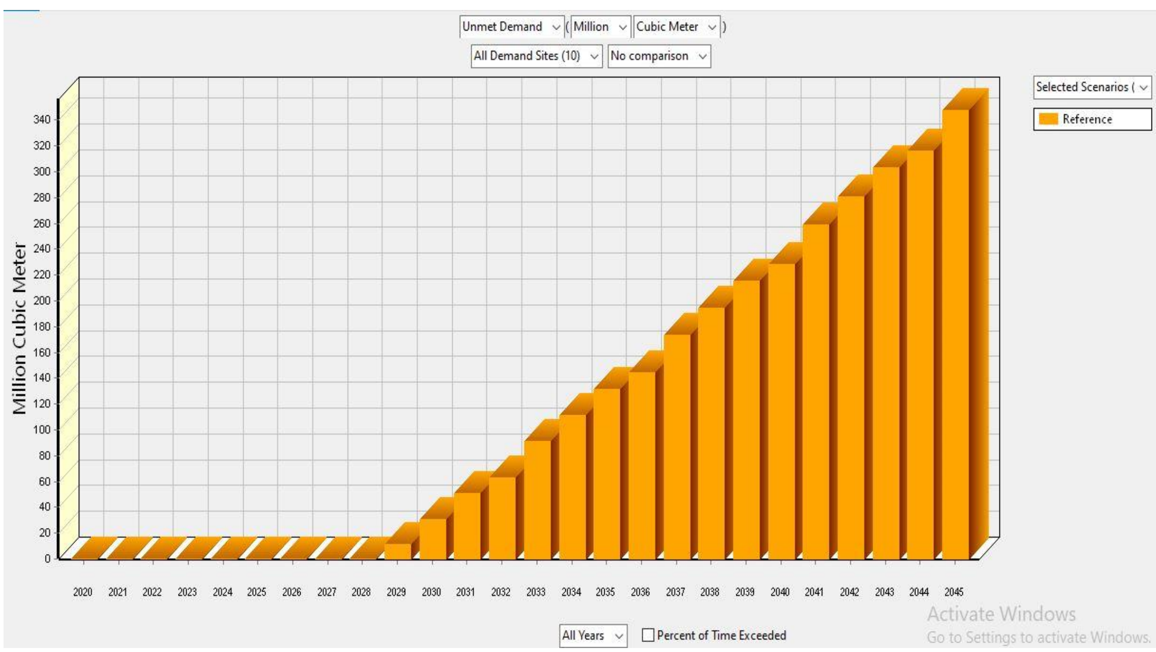

Figure 4: The unmet demand for the reference scenario

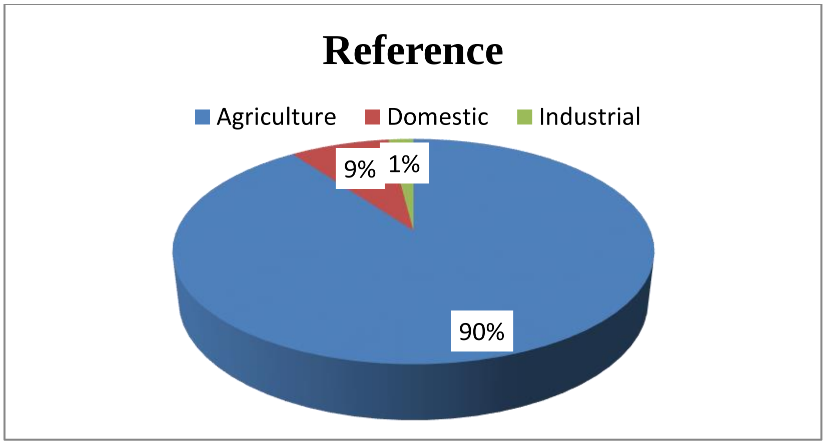

Figure 5: Percentage of future water supply for each sector for S1

6.2.2. High rate population growth (S2)

For this scenario, the rate of population expansion would be increased from 2.55% (as in the reference scenario) to 4%. However, the other input data will be identical to the data in the reference scenario. This was done to ensure what would happen if population growth rates increased. Figure 6 demonstrates the demand for this scenario as well as the demand for the reference scenario. The agriculture sector will have the highest water demand in this scenario, followed by the domestic sector and finally the industrial sector, as represented in Figure 7. The previous results show that the cumulative difference in water demand between the two scenarios reaches 12% over the next 25 years. The annual increase is estimated to be around 0.47%. Also, as shown in Figure 8, the results show that after 2026, there will be an unmet demand from 2027 to 2045. As seen in the bar chart, the maximum unmet demand is in 2045, while the minimum is in 2027.

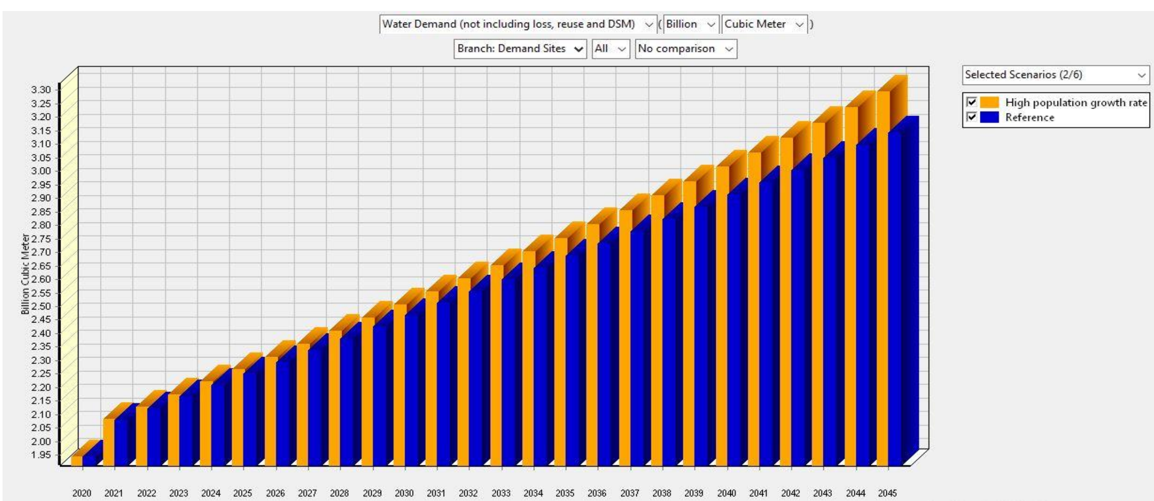

Figure 6: The water demand for S2 along with S1

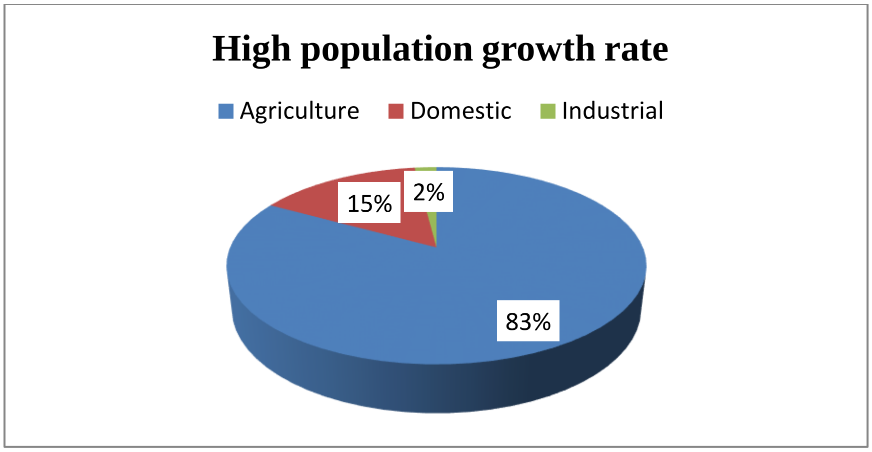

Figure 7: Percentage for the future water demand for each sector for S2

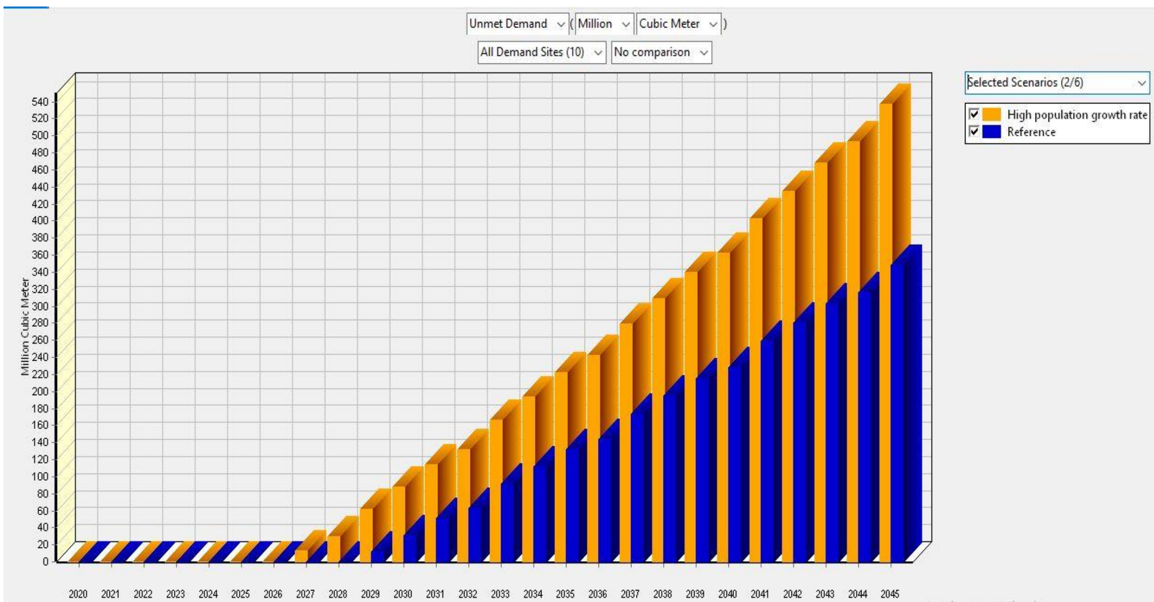

Figure 8: The unmet demand for S2 along with S1

6.2.3. Climate change scenario (S3)

According to Global Climate Models (GCMs), precipitation will decline over the eastern Mediterranean, Turkey, Syria, Iraq, and northern Iran. Adamo et al.(2018 b) state that The average yearly precipitation in the Diyala River basin will decline by (17% - 26%) under two different future scenarios [27]. Furthermore, Wasimi (2010) estimates that Iraq could have a yearly temperature rise of less than 0.05°C. It is anticipated that the annual precipitation will drop by 1.5 millimeters [28]. Based on the studies mentioned above, the following was authorized in this scenario:

1. Gradual increase in temperature by 5.4% over the study period.

2. Rainfall gradually decreased by 20% during the study period, and this will be reflected in the surface imports of the river and its tributaries.

The results show that the water supply and demand requirements in this scenario will be similar to those in the reference scenario, but unmet demand will be larger than in the scenario with a high population growth rate from 2021 to 2045. According to this scenario, unmet demand will increase to 819.14 MCM in 2045, and total unmet demand in the future will be around 10.97 BCM, as shown in figure 9. Figure 10 illustrates the WEAP model's approach to allocating water resources to meet the demand for domestic use first, followed by (livestock and fish farms), then agricultural and industrial sectors. The highest unmet demand is for winter agriculture, as shown by this figure, and the lowest is for industrial units for S3.

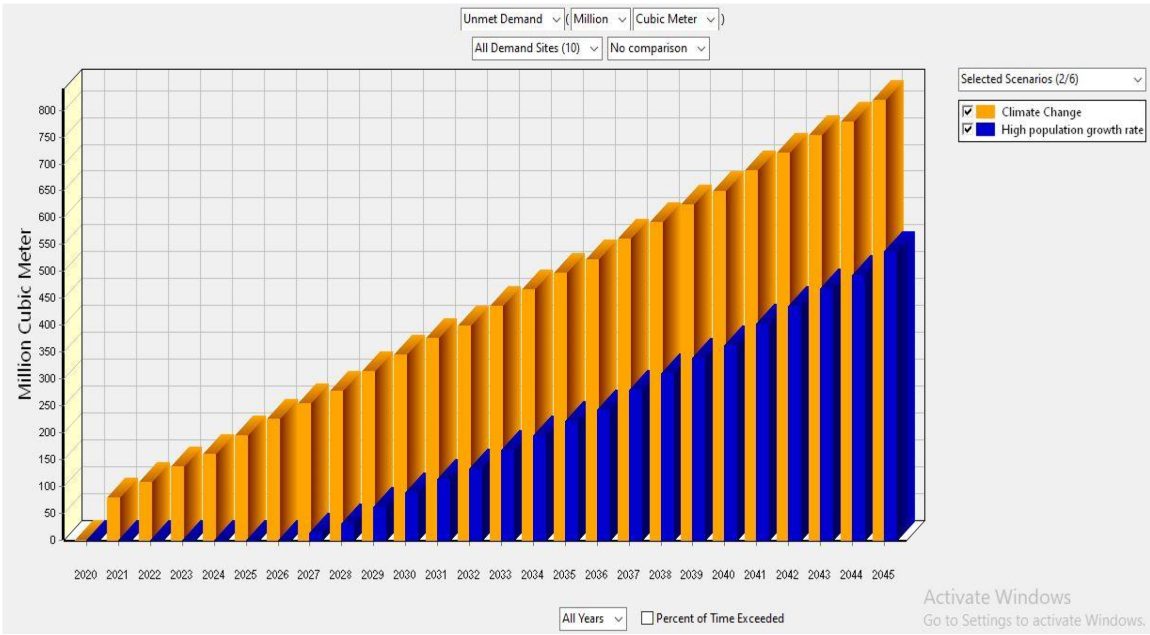

Figure 9: The unmet demand for S3 along with S2

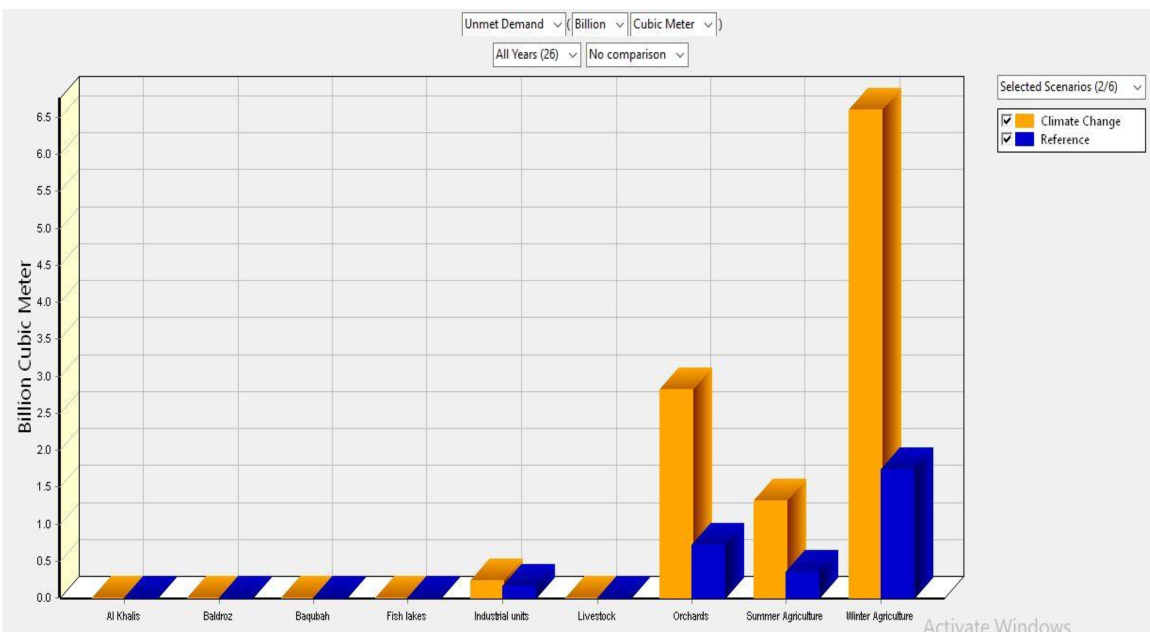

Figure 10: The unmet demand in all demand nodes along the period (2020-2045) for S3 and S1

7. Conclusion

By merging multiple methods and data and taking into consideration the effects of climate change on both water demand and supply, this study provides a consistent methodology for establishing integrated water management in a basin with limited data. WEAP model is a decisions support system's principal tool for simulating current and future projected water balances. Although the model was calibrated and verified using monthly streamflow data gathered at the outlet station, from 2014 to 2018, it was fed data from 2000 to 2020. Three different statistical metrics, including the Root Mean Square Error, the NSE efficiency and the determination coefficient, were employed to assess the model's performance. This model was effective in simulating water use in the three separate sectors (domestic, industrial and agricultural). The future unmet demand will vary, but it will occur in different percentages and years. Water demand and supply were found to be unmet in all three future scenarios, with climate change having the largest unmet demand percentage of around 16.4%, the high population growth rate scenario having 7.3%, and the reference scenario having 4.4%.

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