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Implementing Management Practices for Enhancing Water-Food Nexus Under Climate Change

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Abstract

The current investigation aims to develop a management strategy to enhance the relationship between water and food in the Euphrates River Basin, Iraq. The research methodology utilized the LARS-WG model to generate weather data for the future period (2020–2050) for the CanESM2 model. The weather data was subsequently employed in the CROPWAT model to estimate crop water requirements. Finally, the Water Evaluating and Planning (WEAP) model analyzed the great-inhabitant growth rate scenario (5%), climate change scenarios (i.e., RCP2.6, RCP4.5, and RCP8.5), and management scenarios. The WEAP model was initially calibrated and validated utilizing several statistical metrics, viz., the root mean square (RMS), Nash-Sutcliffe coefficient efficiency (NSE), and the coefficient of determination (R2). Results revealed a superior performance of the WEAP model in terms of the statistical metrics utilized. The findings illustrate that the projected water demand under RCP 2.6, RCP4.5, and RCP8.5 scenarios and the inhabitants growth scenario increased by 49%, 54%, and 56%, respectively, in the year 2050 compared to the reference scenario. In addition, the findings indicate that the water demand would decrease by 59% under the considered management scenario. Accordingly, the investigation recommends implementing water management practices, especially adaptation measures for climate change.

Keywords: Climate Change; CROPWAT; WEAP; Water Security; Nexus; Euphrates River Basin.

1. Introduction

Implementing management practices for enhancing the water-food nexus under climate change requires integrated approaches considering the interlinkages between land, water, and food resources. Nexus techniques, such as optimization models, can help effectively allocate scarce resources like water and land for irrigation and crop production [1]. These models consider uncertainties in the system and provide decision-makers with strategies for sustainable agricultural development [2]. Additionally, analyzing climate change influences on the water, energy, and food resource nexus can inform the development of effective management strategies. For example, in a bioeconomy-based industrial complex, the influence of climate change on water accessibility and sugarcane yield can be assessed to ensure a secure supply of feedstock [3]. Furthermore, precision agriculture practices can play a crucial role in preventing food insecurity under climate change scenarios by monitoring the food supply chain and managing agricultural products [4]. A comprehensive understanding of the nexus and implementing appropriate management practices are essential for enhancing the water-food nexus under climate change [5].

Adopting an ecosystem services approach to integrated water resources management (IWRM) can contribute to long-term food security and ecosystem health by ensuring more efficient and effective water management for agroecosystems, natural systems, and all its other uses [6]. Additionally, the governance structure plays a crucial role in implementing

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the water-food-energy nexus concept, as fluctuations in food production are influenced by governance rather than water accessibility [7]. Future socio-economic changes will have a stronger influence on the water-food-energy nexus than climate change, highlighting the need for systemic transformations and actions to achieve sustainable development goals [8].

"Nexus" means "connection" and stands for the meeting of multiple elements or sectors [9]. The close connection between food and water resources has created the need for a nexus approach. For instance, water is needed to irrigate land for food production. As a result of this interconnectivity, a comprehensive approach is needed to create policies and choices in each management area that will benefit the other sector and ensure the security of all resources [10, 11]. Most nations on the globe will face water scarcity problems in 2025 [12]. Global rivers and reservoirs, which are water resources, will dry up in the future [13], leading to water scarcity in the domestic and agricultural sectors, which is an important global issue because it has an influence on water resources; additionally, the accessibility of clean drinking water for the population [14]. Urbanization, economic development, and population expansion pressure the hydrologic cycle and water accessibility [15, 16]. Climate change has a considerable influence on the hydrologic cycle in addition to the above factors [17]. The changes in the hydrological cycle will lead to a rise or drop in river flow [18].

The country's two major rivers, the Tigris and Euphrates River Basins, provide the basis for Iraq's hydrology. The Euphrates River is the focus of this investigation and is considered the investigation zone. The Euphrates River travels through three different countries (Turkey, Syria, and then finally Iraq), and it enters the territory of the investigation zone at the hamlet (Western Husaybah) that is situated inside the district of Al-Qaim in the AL-Anbar region [19]. The Euphrates River is subjected to significant evaporation since it passes through a dry environment where rain rarely increases due to high temperatures [20]. The geological structure, topography, soil type, climate, native vegetation, region, and other features of the basin also influence the amount of water that flows through the river. The annual flow of the Euphrates River varies in volume from year to year because of various factors affecting the upstream water supply area [21]. In addition, due to climate change and Turkey's activation of the GAP project, which involves roughly 22 dams, the Euphrates River's flow has begun to fall steadily in recent years [22]. As a direct consequence, Iraq's household, industrial, and agricultural water supplies are decreasing, and Iraq is suffering from severe water scarcity. Consequently, integrating water management has emerged as an important option for Iraq.

In terms of employing different management practices, many researchers have studied water management modeling. Perera et al. [23] investigated water management utilizing "REALM" ("the Resource Allocation Model"). REALM is a computer model utilized to distribute the sources of water supply. Similarly, Omar [24] employed "RIBASIM" (River Basin Planning and Management) to evaluate strategies for managing water shortages. Likewise, Cai et al. [25] utilized "CaWAT" ("Catchment Water Allocation Tool") for planning water resources; this model is principally based on balanced water allocation between sectors. Similarly, Cutlac & Horbulyk [26] utilized "WRMM" (the Water Resources Management Model) for resource allocation. Moreover, Inam et al. [27] utilized the "SAHYSMODEL" ("Spatial Agro Hydro Salinity Model"), which is based on a combined socioeconomic, physical, and hydrological approach. Furthermore, Yates et al. [28] proposed the concept of demand priorities and supply preferences to solve the water allocation problem instead of a rule-based logic approach.

The convergence of underground aquifers, lakes, and rivers in various regions facilitates the fulfillment of agricultural, industrial, and domestic water requirements. The issue at hand is further compounded by the influence of climate change, which alters the distribution of precipitation, intensifies evaporation rates, and diminishes the accessibility of freshwater resources [29]. As a result of the adverse influences of climate change, the diminishing water resources in Iraq have a significant influence on the agricultural sector, thereby exacerbating the issue of food insecurity [30].

As a result of the adverse influences of climate change, the energy sector in Iraq is encountering significant challenges. Energy consumption in the region is experiencing a notable surge due to the escalating population and the advancement of economic activities. As the field of energy production continues to evolve, it is becoming increasingly intricate and costly due to the diminishing quality and accessibility of traditional energy sources. The heightened dependence on foreign energy sources gives rise to significant economic and political considerations, as highlighted in the works of Edenhofer et al. [31] and Guler & Kumar [32]. Due to the influence of climate change, the Middle Euphrates region is currently experiencing significant challenges in ensuring food security. In environmental engineering, it is crucial to acknowledge the influence of altering rainfall patterns, the emergence of water scarcity, and soil degradation. These factors have been observed to have adverse influences on agricultural production, thereby intensifying the risk of potential food shortages. The challenges are further compounded by the rapid growth in population within the region, resulting in increased pressure on food resources.

Due to the adverse influences of climate change, namely reduced precipitation and heightened evaporation rates, the water supply situation in the Middle Euphrates region has become a pressing concern from an environmental engineering perspective. The observed phenomenon results in a depletion of both surface and groundwater resources, thereby exacerbating the difficulties associated with meeting the escalating water requirements of the local area. The diminishing accessibility of water poses a significant challenge for nations grappling with acute water scarcity issues. The agricultural sector in the study area is significantly impacted by climate change's consequences. The fluctuations in precipitation and temperature patterns profoundly influence the duration and timing of growing seasons, consequently leading to a reduction in food production. Consequently, the region experiences food security challenges due to declining agricultural yields [33].

This research aimed to optimize the water allocation of the Euphrates River Basin in Iraq, considering the water-food nexus, and examine the influence of climate changes and future population growth on water demand in the river basin. This study is considered the first to study the effect of climate change on water demand along the Euphrates River Basin. This investigation will help in understanding and planning how to use existing water resources in the future in all sectors, considering the potential influences of climate change and rising populations on the country's water resources, to contribute to the improved management of food and water. Analyzing great population growth and climate change scenarios is important for water supply stakeholders and management.

2. Material and Methods

2.1. Investigation Zone

The Euphrates River, renowned for its length and historical significance, is a prominent waterway in Western Asia. In conjunction with the Tigris River, it serves as one of the two defining watercourses of the Mesopotamian region. The Euphrates River, originating from its source in Turkey, traverses through the countries of Syria and Iraq, ultimately converging with the Tigris River in the Shatt al-Arab waterway. This confluence then leads to the discharge of water into the Persian Gulf. The Euphrates River, spanning approximately 2,780 kilometers, proudly holds the esteemed title of the fifteenth-longest river in Asia. It is the longest river in Western Asia, illustrating its remarkable length and significance. With a vast drainage area encompassing 440,000 square kilometers, this mighty river gracefully traverses six countries, leaving an indelible mark on the region. The Euphrates River in Iraq is the boundary for the research area, which encompasses eight different districts: Anbar, west of Baghdad; Babil; Kerbala; Najaf; Diwanya; Semawa; and portions of Nasiryia (Figure. 1). Figure 1 shows the hydrological and contour maps. The investigation zone lies in the longitude of 41 22′ 3″–47 8′ 52″ E and the latitude of 34 40′ 5″–30 016″ N. The total population of all eight districts is 9,674,715. The climate of the investigation zone is a dry environment with low rainfall and high temperatures [22].

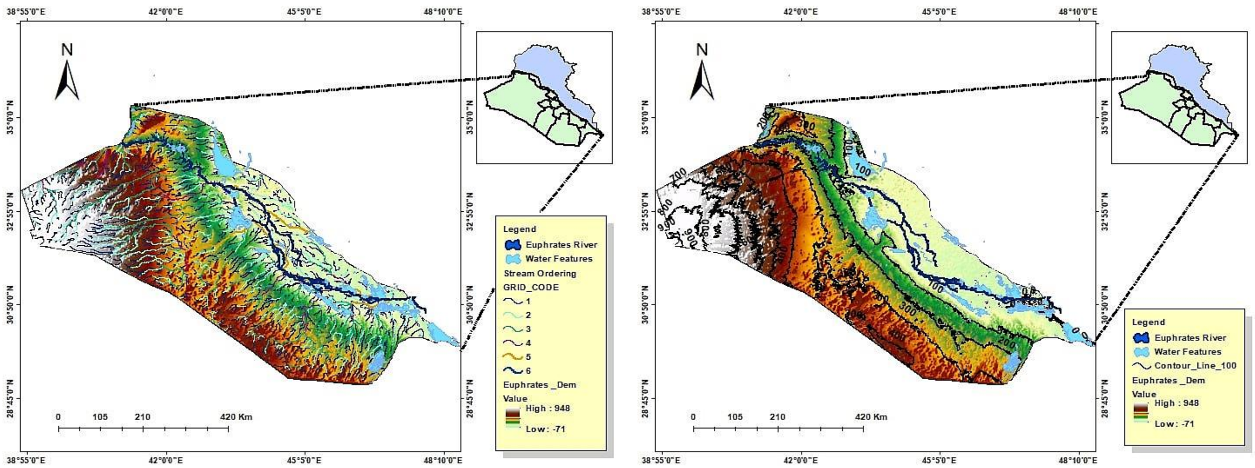


Figure 1. Location of the investigation region

2.2. Methodology

Initially, CROPWAT was utilized to determine irrigation requirements in the current year. Then, Long Ashton Research Station Weather Generator (LARS-WG) version 6 was utilized to forecast weather data for the Canadian Earth System Second Generation Model (CanESM2). Output data involving the min and max temps, solar radiation, and precipitation for future periods for the eight designated metrological stations under RCP 2.6, RCP 4.5, and RCP 8.5 scenarios. Then, forecasted data is inserted into CROPWAT8 to calculate irrigation requirements for the future. Subsequently, future climate data were utilized to compute the standard precipitation index to calculate dry and wet years, which was then entered into the Water Evaluating and Planning (WEAP) model to predict the flow of the river by utilizing the "water year technique." Water demand for all sectors (agriculture, domestic, livestock, and fishponds) for the year 2020 was input into the WEAP model to simulate future demand for water by developing the hypothesized scenarios. These scenarios included the reference, great inhabitants, and climate change scenarios utilized to predict future water demand and the management scenario.

Calibration and validation of the model are necessary to minimize errors and assure the validity and dependability of the model's findings [34]. The WEAP model presents "five" techniques to calibrate the model: "the rainfall-runoff technique, the simplified coefficient technique, the soil moisture technique, the MABIA technique, and the plant growth technique." This investigation chose the soil moisture technique for the calibration process due to its ability to characterize the influences of soil types and land use on these processes [35–37].

2.3. Data Collection

The following data were utilized in this investigation:

- Climate data for the period 1990–2020 from eight stations distributed across the investigation zone were obtained from the Iraqi Meteorological Department (IMD).
- The historical and current river discharge of Haditha dams (34° 12′ 25″ N, 42° 21′ 18″ E) was collected from the Ministry of Water Resources (MOW).
- Demographic information, including the population, growth rate, rates of water consumption, and domestic usage, was collected from the Ministry of Planning (MOP).
- Agriculture data relating to planting dates and harvesting dates of crops, soil data, fish ponds, agriculture areas, and livestock populations were gained from the Ministry of Agriculture (MoA) and the Ministry of Water Resources.
- Weather data from CanESM2, including temp and precipitation under the RCP 2.6, RCP4.5, and RCP8.5 scenarios for 2021–2050, were acquired utilizing the LARS WG 6 model**.**

2.4. Descriptions of LARS-WG

LARS-WG is a stochastic weather generator that uses a set of daily-scale climatic variables to extract high-resolution spatial data information from low-resolution general circulation models (GCMs) based on observed climatic patterns and data. To provide input to the model, four daily data series of information on the lowest and maximum temperatures, precipitation, and evaporation are required [38]. The LARS-WG stochastic weather generator generates a lengthy sequence of synthetic data spanning three distinct periods, namely 2011–2030, 2046–2065, and 2080–2099. Furthermore, it has been meticulously engineered to assess the ramifications of climate change. Furthermore, extensive testing has been conducted on multiple global sites, yielding results demonstrating the model's capability to accurately simulate climatic factors with a commendable level of proficiency [39]. According to the findings of Semenov [39], it has been determined that the time frame spanning from 1980 to 2010 can be considered a suitable baseline period to generate future climatic factors.

Furthermore, numerous esteemed civil engineering scholars have embraced this time frame in their research endeavors [40, 41]. The LARS-WG model, in its construction, employs semi-empirical distribution (SED) to estimate the durations of the daily precipitation, daily solar radiation, and wet and dry day series' probability distributions, in addition to utilizing the Markov chain model to determine monthly precipitation [42]. Additionally, the finite series three-order Fourier series represented the seasonal cycles of the means and standard deviations, and a normal distribution was utilized to approximate the residuals.

2.5. The CROPWAT Model

The CROPWAT model is a program developed by FAO that is utilized for managing and planning irrigation. CROPWAT was developed to serve as a practical tool for carrying out conventional computations for reference evapotranspiration, crop water requirements, and irrigation requirements, and, more specifically, for designing and operating irrigation systems [43]. CROPWAT uses the Penman-Monteith equation (Equation 1) for calculating the reference evapotranspiration. This evapotranspiration can be approximated according to the product of the reference evapotranspiration (ET_0) and the crop coefficient (KC).

$$ET_{\circ} = \frac{0.408\Delta\,(Rn-G)+\Upsilon(\frac{900}{T_a+273})U_2(e_s-e_a)}{\Delta+\Upsilon(1+0.34U_2)} \tag{1}$$

where ET_o (mm/day) is the reference evapotranspiration, Rn (MJ.m^2/day) is the net radiation at the surface of the crop, and G (MJ.m^2/day) is the density of the soil's heat flow, T_a is the average daily air temperature (degrees Celsius), U2(m/sec) is the average wind speed at a two-meter height, e_s is the saturation vapor pressure (kPa), e_a (kPa) is the mean actual vapor pressure, Δ (kPa/°C), is the slope of the relation curve between saturation vapor pressure and temperature , and γ is psychometric constant.

The crop coefficient (KC) is multiplied by the reference evapotranspiration to determine the evapotranspiration of crops, as illustrated in (Equation 2) [44]:

$$Et_c = ET_{\circ} \times KC \tag{2}$$

where KC is the coefficient of crop and ET_o is the control evapotranspiration. The quantity of water an irrigation system must provide to ensure that a crop meets its full water requirements is referred to as NIWR when irrigation water appears to be the only supply for plants. The demand for irrigation water is lower than the crop's water needs if it receives some of its water from other sources (such as deep seepage, rain, etc.). As a result, the NIWR was determined utilizing (Equation 3):

$$NIWR = CWR - Effective\ rains \quad (3)$$

where: CWR is the crop water requirement

2.6. The WEAP Model

In the past decade, a comprehensive approach to water development has surfaced, wherein water supply projects are considered within the broader framework of demand-side considerations, water quality, and the preservation and protection of ecosystems [45]. The Water Evaluating and Planning (WEAP) framework effectively integrates these core principles into a pragmatic water resource planning tool [46]. The distinguishing factor of WEAP lies in its integrated methodology for simulating water systems and its strong emphasis on policy orientation. In civil engineering, WEAP effectively considers the equation's demand and supply aspects. It is important to consider factors such as patterns of water usage, machinery efficiency, possibilities for reuse, cost, and allocation. These elements are given equal weight alongside the supply factors and encompass streamflow, groundwater accessibility, reservoir capacities, and water transfers. The Water Evaluation and Planning (WEAP) tool serves as a valuable laboratory for analyzing and evaluating various water development and management strategies. The Water Evaluation and Planning System (WEAP) is a comprehensive tool designed to be straightforward and user-friendly. Its purpose is to aid the skilled planner in their work rather than replace their expertise. WEAP is a comprehensive tool for managing and maintaining water demand and supply data in its capacity as a database. WEAP serves as a valuable forecasting tool by comprehensively simulating various aspects of water management. It encompasses the simulation of instream water quality, discharge, treatment, pollution generation, storage, stream flows, runoff, supply, and water demand. As a policy analysis tool, WEAP conducts a comprehensive assessment of various water development and management alternatives while duly considering water systems' diverse and conflicting applications.

Water allocation and resource management were undertaken using the WEAP system platform. WEAP21 uses linear programming heuristics to solve the issue of water allocation, taking into account supply and demand preferences as an alternative to multi-criteria weighing or rule-based reasoning techniques. Utilizing a scenario-based methodology, it presents a transparent set of model objects and techniques that may be utilized to assess all of the problems encountered by water managers. These problems involve climate change, the conditions of the watershed, expected demand, ecological requirements, the legal environment, operational goals, and the available infrastructure [47]. A WEAP model was developed for the Euphrates River. The demand for livestock, agriculture, and domestic demand was allocated to all districts (i.e., Al-Anbar, West of Baghdad, Babylon Karbala, Najaf, Diwaniya, Semawa, and Nasiriya districts). Fishpond demand was selected for all districts except Kerballa and West of Baghdad, with no fishpond.

2.7. Developed Scenarios

A scenario explains how the future could unfold base on coherent assumptions about significant linkages and driving factors [48]. External influences (great population growth, climate change projections) were utilized to develop scenarios. Figure 2 illustrates the scenarios' workflow.

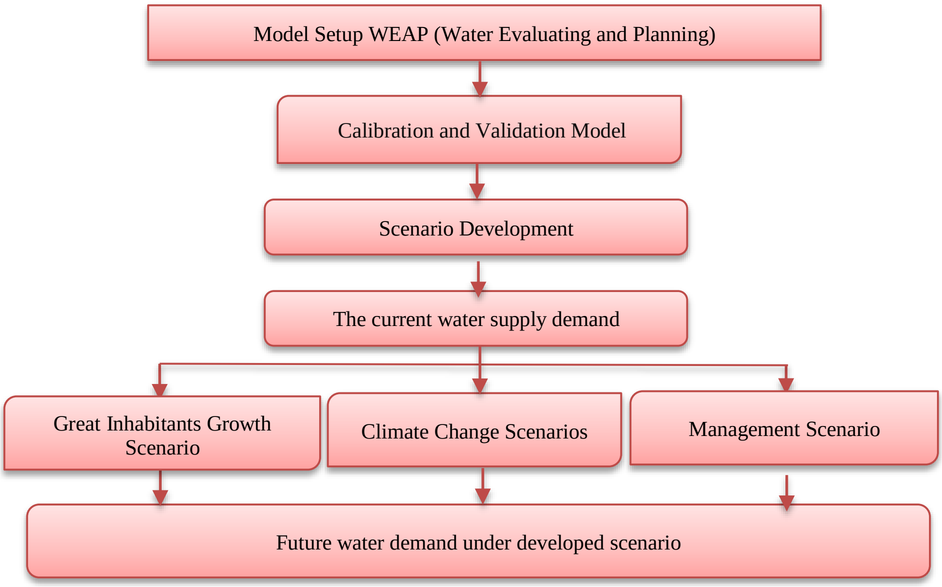


Figure 2. Model development scheme

2.7.1. Reference Scenario

The Reference Scenario illustrates the actual scenario, simulated and predicted under current situations/conditions in this article, which is 2020. Taking into consideration the following assumptions:

- The rate of population growth is 2.58%.
- Domestic usage: 190 litters per day.
- Agriculture areas and fish ponds for this scenario will be constant as in the current year.

2.7.2. Great Inhabitants Growth Scenario

This scenario assumes a 5% population growth rate. This factor influences water consumption; domestic water demand is projected to rise at the same population growth rate (5%) while maintaining the same level in all other sectors as in the reference scenario.

2.7.3. Climate Change Scenarios

The climate change scenario was constructed by utilizing LARS -WG to create a climate change scenario (RCP 2.6, RCP 4.5, and RCP 8.5); these scenarios assumed:

- Decreased flow of the river, which was simulated by utilizing the water year technique;
- Increasing irrigation water demand.

2.7.4. Management Scenario

This scenario is created by reducing the demand for domestic water, increasing irrigation efficiency from 35% to 70%, reducing the agricultural area for wheat and barley to 50%, and reducing the cultivation of rice, which requires much water to grow in most of the governorates of the investigation zone, except Najaf, where it must be preserved as a national identity as admitted by the Iraqi government.

3. Results and Discussions

3.1. Projection Stream Flow

Climatic data of RCP2.6, RCP4.5, and RCP8.5 were utilized to determine the standard precipitation index for calculating dry and wet years, and then "the water year technique" utilized in the WEAP model was utilized to project stream flow. The technique first involves defining how different climate regimes (for example, very wet, dry, very dry, and normal) compare relative to a current year, which is given a value of 3 for normal. Dry years have a value of less than 3, and wet years are greater than 3. The future average streamflow is illustrated in Figure 3, which is compatible with the results of Mounir et al. (2011) study [49].

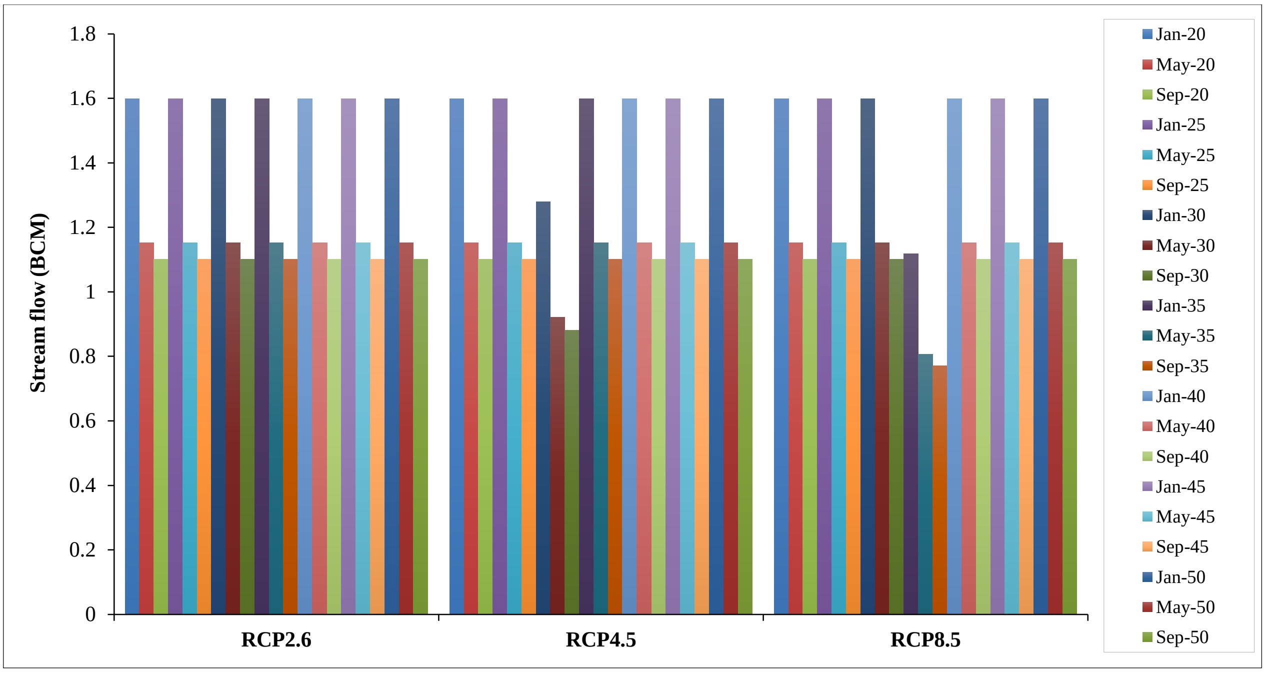


Figure 3. Projections of Stream flow for the period of 2020–2050 in the Euphrates River Basin

The increment in the streamflow can be explained by a tight correlation between rainfall and streamflow; when the total amount of rainfall increases, the streamflow rises accordingly. The minimum streamflow was in September 2035 under RCP 8.5, and as a result, September 2035 under RCP 8.5 will likely exacerbate the water shortage in the dry season. The results indicated the timing of the projected maximum streamflow in January 2045, mainly because maximum rainfall will likely occur this month.

3.2. Model Calibration/Validation

The WEAP model utilized historical water discharge data from 1989 to 1993 for calibration and three years (from 1994 to 1996) for validation (Figure 4.). The coefficient of the crop (kc), the conductivity of the root zone, the direction of preferred flow, and the soil water's capacity were manually calibrated to simulate the river's discharge in the WEAP model. These parameters were chosen based on the location of the research region and WEAP's default parameters [50]. For the calibration and validation process, the root mean square error (RMSE), the determination coefficient (R2), and the Nash-Sutcliffe efficiency index (NSE) were calculated to assess the model's performance [51]. The results of RMSE, R2, and the Nash-Sutcliffe efficiency index were 0.03, 0.6, and 0.5 during calibration and 0.02, 0.6, and 0.6 during validation, respectively. The results indicate the model's capacity to reflect the real-world water-use status. Therefore, it can be judged that the model could be satisfactorily utilized in further evaluation, i.e., scenario analysis.

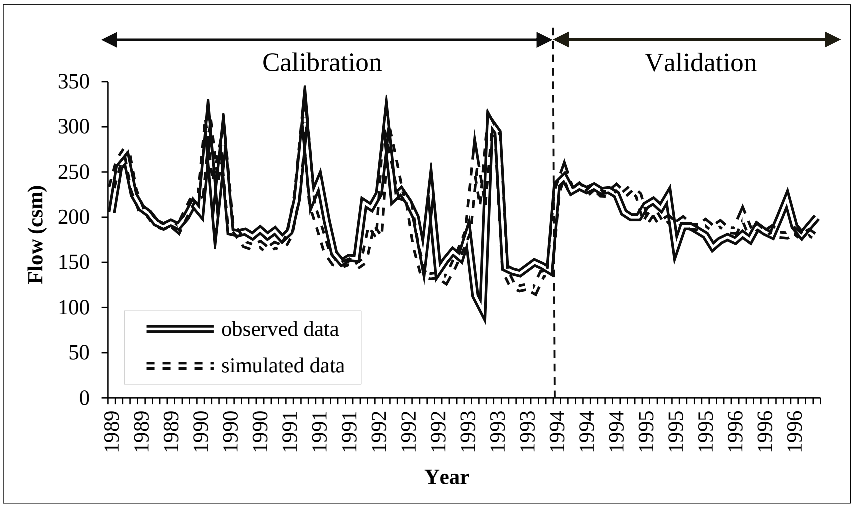
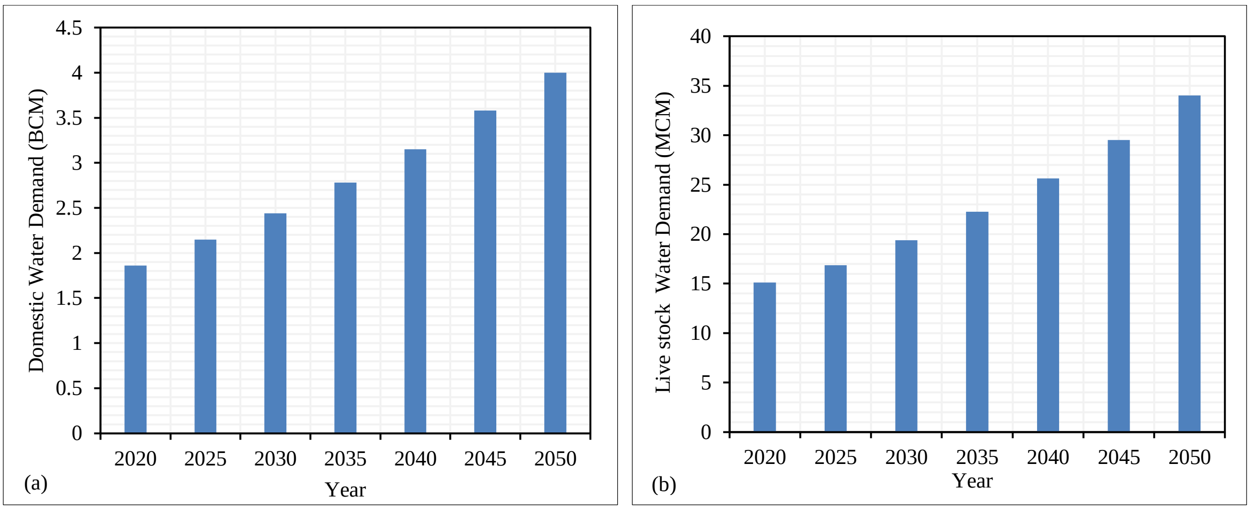


Figure 4. Calibration process results

3.3. Reference Scenario (RS)

The WEAP model was utilized to explore the demand for water for the Euphrates River Basin for 2020-2050, considering the current conditions explained in section 2.6. In other words, this future scenario assumes no changes in the respective constraints of the present state. Figure 5 illustrates the water demands of the reference scenario. The inhabitants growth rate will increase domestic demand from 1.86 $\times 10^9$ m^3 in 2020 to 4.3×10^9 m^3 in 2050, as illustrated in Figure 5-a. In addition, the demand for livestock increased from 14.7×10^6 m^3 to 34×10^6 in 2050, as illustrated in Figure 5-b. At the same time, demand for agriculture and fishponds was assumed to be constant value (13.4×10^9 m^3 and 4.7 10^6 m^3) over time, as illustrated in Figures 5-c and 5-d. In this scenario, the total water demand for all sectors will increase from 13.2×10^9 to 15.4×10^9 m^3 in 2050. The findings show that the water demand of agriculture sector will be the highest value, then the sector of domestic. Finally, live stocks and fish pond sectors respectively. Result show that the water supplied yearly will be sufficient, implying that no unmet demand was projected.



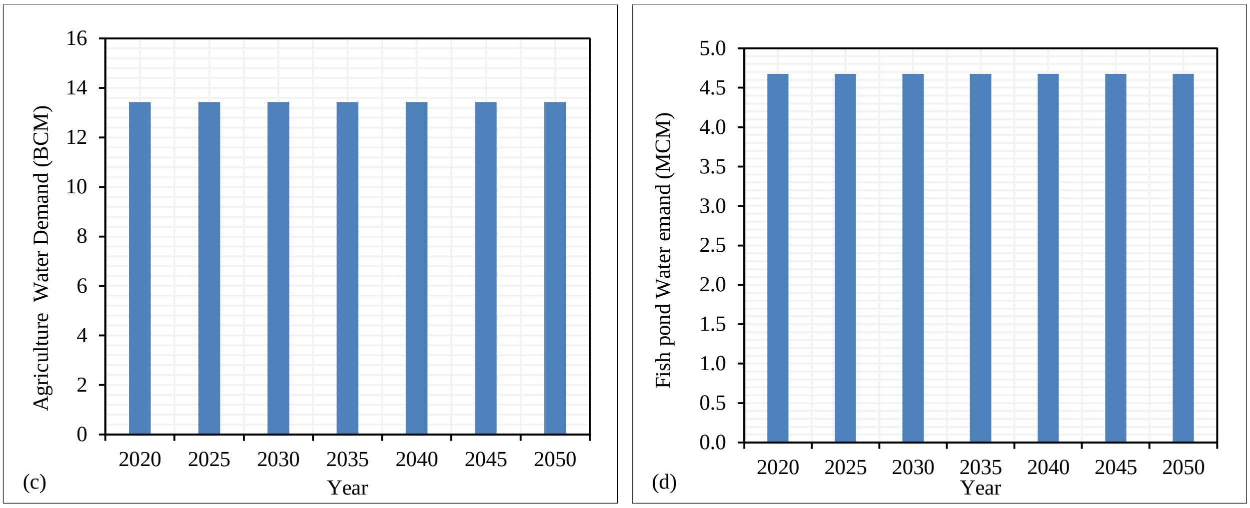


Figure 5. Water demand for the reference scenario for domestic, livestock agriculture, and fishponds sectors for the period (2020–2050)

3.4. Great Inhabitants Growth Scenario

The results of a comparison between the reference and great population growth scenarios are presented in Figure 6. According to the reference scenario, the domestic water demand increased from 1.86×10^9 m^3 in 2020 to 4.3×10^9 m^3 in 2050. In contrast, the water demand under the great population growth scenario will increase to 8.85×10^9 m^3 by 2050. Meanwhile, the other sectors (agriculture, livestock, and fisheries) retain the same values as in the reference scenario because of their non-vulnerability to population growth. Therefore, the total water demand for all sectors increases from 15.4×10^9 in the reference scenario to 19.4×10^9 in this scenario in the year 2050, which indicates that the total water demand under the Great Inhabitants Growth Scenario is higher than the reference scenario, with a percentage increase of 26%.

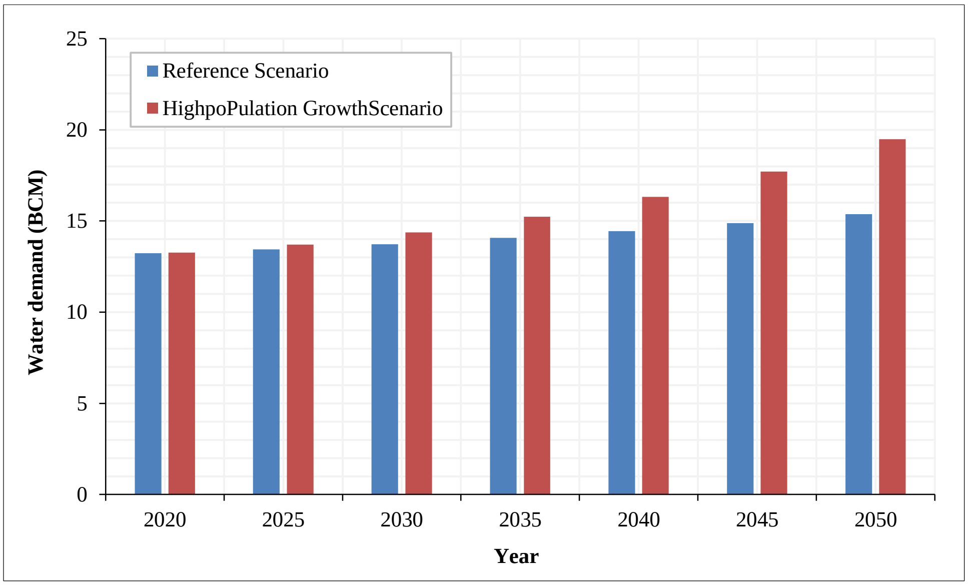


Figure 6. Reference and great inhabitants growth water demand scenarios for the period (2020– 2050)

The quantity of water in the Euphrates River Basin will be enough to meet water demand in all sectors until 2044; after this year, there will be an unmet demand from 2045 to 2050, as illustrated in Figure 7. As it can be showed from this figure, the lowest value of unmet demand was in 2040, while the highest value is recorded in 2050.

3.5. Climate Change Scenarios

The results of simulating climate change scenarios are illustrated in Figure 8. The agricultural demand will increase from 11×10^9 m^3 in 2020 to 18.6×10^9 m^3, 19×10^9 m^3, and 20×10^9 m^3 in 2050 for RCP2.6, RCP4.5, and RCP8.5 scenarios. Agricultural consumption during 2020–2050 illustrates a progressive rise in water demand because of its vulnerability to climate change, while the other sectors have a constant value for 2020–2050. The total water demand will increase to 22.7×10^9 m^3, 23×10^9 m^3, and 24×10^9 in 2050. Climate change scenarios are higher than the reference scenario, with a percentage increase of 49 % for RCP2.6 scenario, 54% for RCP 4.5, and 56% for RCP8.5 scenario.

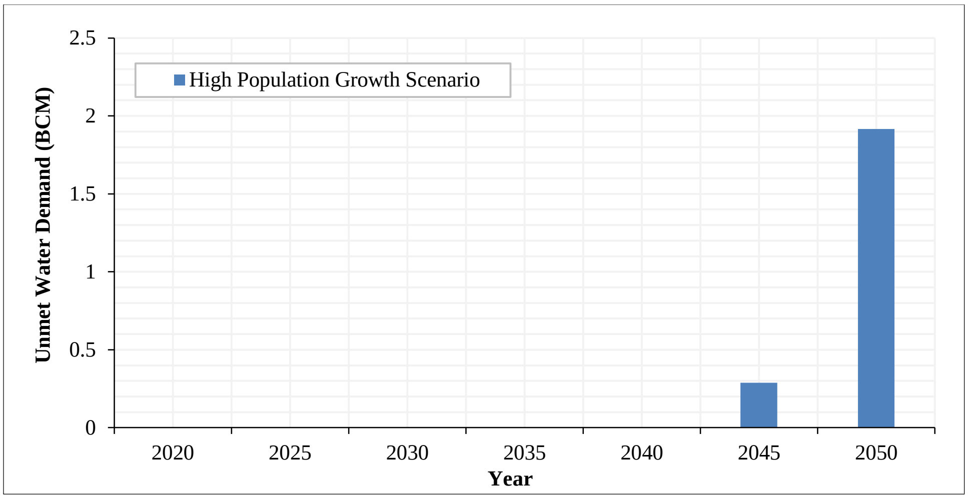


Figure 7. The unmet water demand for great growth scenarios for the period (2020–2050)

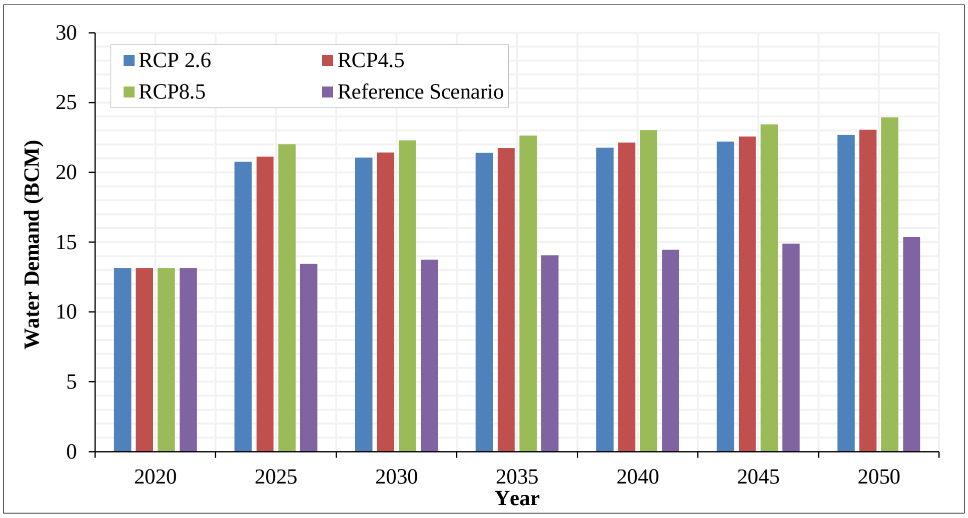


Figure 8. Water demand for climate change scenarios (2020–2050)

Unmet demand for climate change scenarios fluctuated from one year to another due to wet and dry years and water demand. Unmet water demand was 5.6×10^{9} m^3, 6.5×10^{9} m^3, and 8.3×10^{9} m^3 in 2050 for RCP 2.6, RCP4.5, and RCP8.5 scenarios, as illustrated in Figure 9. The year 2035 had the most unmet demand because it was drier than other years under RCP8.5. It shows that the unmet demand for domestic products in all governorates is 0 due to the prioritization of water supply to the domestic sector. In contrast, agriculture will have the highest unmet water demand due to the most significant need for water in addition to not giving priority to the agricultural sector in supplying water, which led to a shortage of water for the agricultural sector and requires future scenarios and solutions to avoid this deficit in the future.

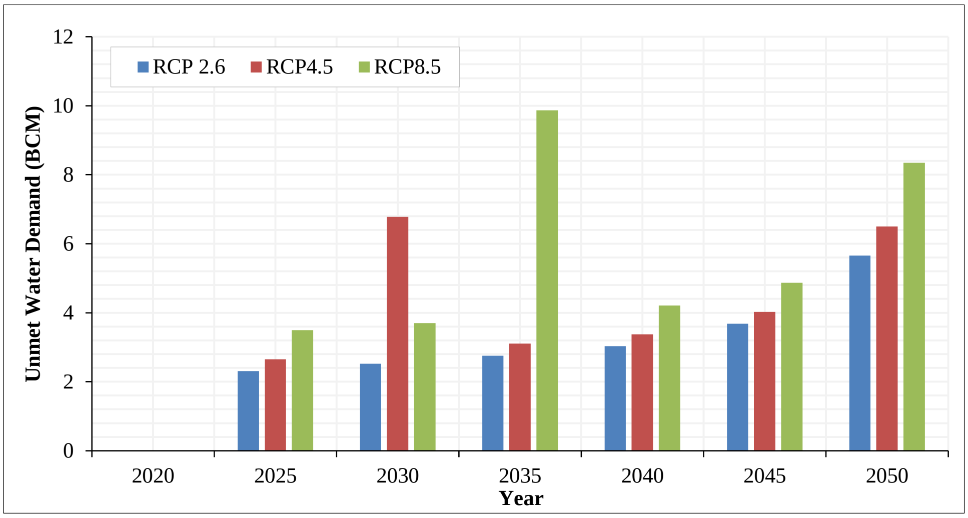


Figure 9. Unmet water demand for climate change scenarios (2020–2050)

3.6. Management Scenario

The results of climate change and management scenarios are presented in Figure 10. The Figure illustrates the annual demand for water for all sectors under climate change and management scenarios during the period 2020– 2050. The results illustrate that water demand is reduced from 22.7×10^{9} m^3, 23×10^{9} m^3, 24×10^{9} m^3 in 2050 under RCP2.6, RCP6.5, RCP8.5 to 9.7×10^{9} m^3 for management scenario.

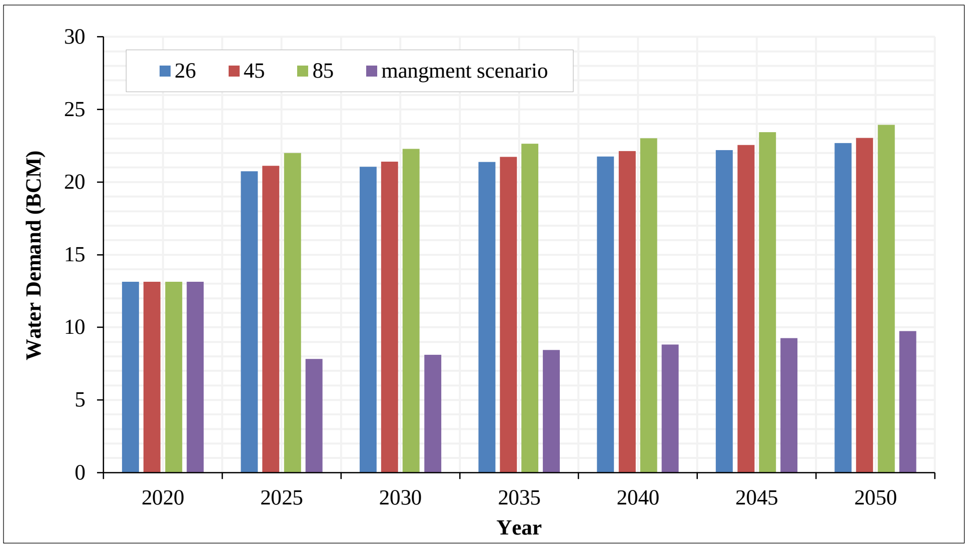


Figure 10. Annual water demand for all sectors in the reference and management scenarios (2020– 2050)

Unmet water demand is still increasing under climate change with no management scenario. Under management scenarios, unmet water demands are observed to decrease to a significantly lowest amount, as illustrated in Figure 11.

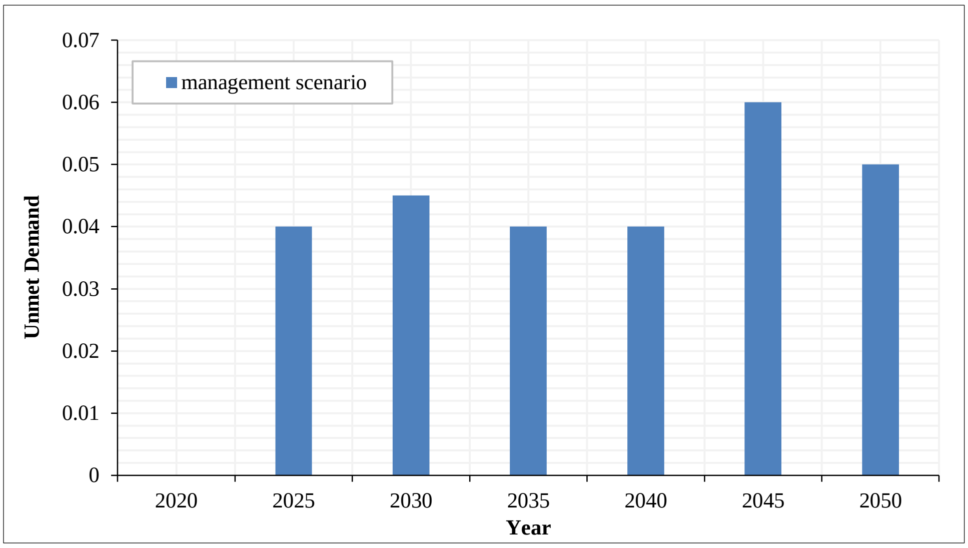


Figure 11. Unmet water demand for management scenario (2020–2050)

4. Discussion

This research presented and analyzed water-management techniques and policies in the Euphrates River Basin based on the great inhabitants' growth, climate change, and management scenarios. To create a sustainable water supply and demand system, first it is necessary to comprehend the present water supply and demand in the research area and to evaluate the influence of population growth and climate change on the water resources of the Euphrates River Basin. Then, depending on the current supply-demand scenario, a management scenario was utilized in the WEAP model to improve water management for improved results (lower unmet water demand).

For this paper, a reference scenario was developed based on the present water supply and demand in the "Euphrates River Basin". Similar research was found by Matchett et al. [52] and Kou et al. [53], who utilized the water evaluation and planning system model to calculate the demand for water in the future, taking into account present and reference scenarios. According to the present research, the demand for water in the reference scenario in 2050 would be 14%

higher than the demand for water in the current year. For this scenario, the water demand would rise to 53%, 56% for domestic and livestock, and a constant percent for the fishpond and agriculture sectors. The same findings have been reported by Touseef et al. [54]: water demand in the Hongshui River Basin will rise by 38%, 60% for domestic industries, and 63% for cattle, forestry, and animal husbandry. A related investigation was published in Kathmandu Valley, Nepal, and concentrated on integrating urban water management in many scenarios. They concluded that a 6% population growth rate would raise daily water use from 135 to 150 L/person. The results of their investigation will aid in resolving basin-wide water management issues [16]. Another investigation in the Al-Anbar district estimated that average unmet demands are likely to reach 153.19, 14.22 MCM by 2040 under reference to water tax scenarios [55].

The WEAP model was utilized in this investigation to examine population growth and climate change scenarios, which place great pressure on water supply accessibility. These demands increase water scarcity in the river; therefore, it is necessary to motivate administrators of water resources to implement water management policies [56].

The reference scenario hurts the supply system via increasing demand for water, which is predicted to double by 2050; this quick increase in demand for water is caused by the increasing population, with a rate of 2.58% yearly.

The population growth scenario was also analyzed in this study. The projected water demand in the Euphrates River Basin under a 5% great population growth rate scenario was 20×10^{9} m^3, which reflected a rise in the water demand of 54% more than the reference scenario. Based on the great population growth scenario, the water demand will rise by 51% for domestic and a constant percent for other sectors. There should be enough water available until 2045 in the great scenario. Similar results were recorded by Mukhtar & Mutar [57] in Baghdad City, Iraq. The investigation aimed to examine integrated urban water management under many different scenarios. They discovered that a 5% population growth rate would raise the demand for water from 10.40 BCM in 2040 under the reference scenario to 11.05 BCM in 2040 under the great-inhabitant's growth scenario.

The present investigation also modeled water demand utilizing general circulation models" GCMs" for the "low climate change scenario (RCP-2.6)", "medium climate change scenario (RCP-4.5)", and "high climate change scenario (RCP-8.5),". The findings illustrate that the demand for water is likely to increase in the RCP2.6, RCP4.5, and RCP8.5 scenarios. Under low and medium climate scenarios, the total water demand was 22.7 and 23 Bm^3, respectively, which illustrated a rise in the demand for water by 49% and 54% more than the reference scenario in 2050. The great climate change scenario would significantly increase water demand by 56% more than the reference scenario; consequently, it is crucial to implement policies to reduce the unmet need to the minimum amount.

In the most ideal or management scenario, the total water demand projected will reduce to 10 Bm3, which represents a decrease in demand for water of 58% more than the reference scenario; as a result, unmet water demand is noticed to decrease to the lowest amount.

5. Conclusions

This research included three models: the LARS model to forecast the climate in the future; CROPWAT for determining irrigation water requirements in the present and future; and finally, the WEAP model was utilized to simulate the supply and demand of water in the Euphrates River Basin.

- The developed WEAP model illustrates that the growth rate of the population and climatic factors will be the two main causes of water shortages in the Euphrates River Basin in the future.
- The water is enough, according to the reference scenario.
- The quantity of water in the Euphrates River Basin will be enough to meet the water demand in all sectors until 2044; after this year, there will be an unmet demand from 2045 to 2050 under a great population growth scenario.
- Agriculture is the main factor that pressures future water resources.
- Due to the high rise in evapotranspiration rate in the study area under climate change scenarios, irrigation water demand tends to increase for all demand sites under these scenarios.
- The unmet demand was increased to 5.6×10^9 m^3, 6.5×10^9 m^3, and 8.3×10^9 m^3 in 2050 under RCP2.6, RCP4.5, and RCP-8.5; therefore, the management scenario should be utilized to maintain the sustainability of water resources.
- The management scenario minimized demand of water to the lowest value.

5.1. Recommendations

The optimal water-energy and food nexus allocation under climate change will be achieved by taking the necessary measures and essential strategies to avoid scarcity or overflow.

- It will be necessary for additional research to assess the water demand in other Iraq basins.

- Water management is a complex process that includes many sectors, as it is not exclusively the task of the Ministry of Water Resources but is also subject to the work of the Ministry of Agriculture. The Ministry of Municipalities includes even the simplest citizens in society. Hence, everyone participates in managing water resources in one way or another, and there is a need to educate everyone about the problem of water scarcity and mandatory rationing.
- Emphasizing the importance of concerted efforts, cooperation, and severe coordination between the relevant state institutions in protecting surface water resources and preventing overstepping them.
- Using alternative methods of farm irrigation, such as sprinkler and drip irrigation
- Spreading awareness about rationalizing local water consumption and reducing water waste.
- Reconsidering the method of dealing with rainwater and considering it a water resource, not waste water.
- Any water resource management plan in the Euphrates River Basin must consider the existence of many technologies to conserve water (preventing pollution and reducing evaporation) or obtain water through water harvesting (artificial cloud seeding, fog harvesting, rainwater harvesting), or obtain safe water from unconventional sources (desalination of the groundwater, drainage water, and wastewater treatment). Non-conventional sources represent an important source that should not be dispensed with by working seriously to maintain sewage treatment plants currently operating, increase their number in proportion to the current and future quantities of water produced, and establish desalination plants for saline water, whether sewage water or groundwater.
- The (what-if) scenarios technique may be utilized to examine the current and predicted water demand/supply situation for better-managing water resources and providing food security in various basins worldwide. As well as, It will be necessary for more research to assess the water demand in Iraq's other basins and beyond 2050.

6. Declarations

6.1. Author Contributions

Conceptualization, N.S., M.M. and K.S.; methodology, M.M. and K.S.; software, N.S.; data processing, N.S. and K.S.; validation, N.S.; investigation, N.S. and K.S.; resources, K.S. and N.S.; writing—original draft preparation, N.S., M.M., and K.S.; writing, editing, and reviewing, N.S., M.M., and K.S.; visualizing, N.S., M.M., and K.S.; supervision, M.M. and K.S.; Project management, N.S., M.M., and K.S. all authors have read and approved to the published version of the work.

6.2. Data Availability Statement

The data presented in this study are available in the article.

6.3. Funding

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6.4. Conflicts of Interest

The authors declare no conflict of interest.

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