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Current and Future Challenges for Water Demand Versus Supply in Tel–Afar District

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Abstract

The current study was conducted using modern technologies in the engineering fields, represented by the GIS program, which specializes in spatial analysis of data, creating digital models, and generating additional data for them, in addition to using the Scenarios model method, which is a tool for warning of what the future will lead to according to the proposed and expected scenarios. The results of the study showed that the main source of water supply in the study area for the municipal sector is the public water network, which is supplied with water from the Tigris River, at a rate of (93%) of the total supply of municipal sector water, and (7%) of groundwater supply. The results showed that the demand for water for the municipal sector in the center of Tal-Afar district accounts for more than (83.5%) of the total demand, followed by the agricultural and livestock sector at a rate of (17.5%), while in the Al-Ayadhiya district, the agricultural and livestock demand recorded a rate of (69.80%) and the municipal demand recorded (30.2%) of the total demand, and in the Zummar district, the agricultural and livestock sector recorded a rate of (66.1%) of the total demand, and (33.9%) for the municipal sector, and in the Rabia district, the largest share was for the agricultural and livestock sector, which recorded (96.5%) of the total demand and (3.5%) for the municipal sector. The results showed that the water gap for the municipal sector is non-existent in the center of Tal-Afar district and records A surplus of (12.5 MCM) then appears in each of Zummar, Al-Ayadhiyah and Rabia and records a deficit in the supply of (0.67, 3.35, 3.59 MCM) respectively and this shortage is addressed by increasing the time period for withdrawing water, or pumping through unlicensed wells. The results of the possible scenarios showed that the best scenario for the municipal sector are scenarios (4,3) which reduce the water gap by increasing the supply and maintaining the demand for water by (33%) while the worst scenario was scenario (2) which leads to an increase in the demand for water by 42.5%.

Keywords: Water Supply; Demand; Water Gap; Scenario; Water Resources; Deficit; Surplus.

1 | Introduction

The demand for water is linked to population growth as well as economic growth, in addition to the efficiency of water use in various sectors, especially in the agricultural sector. Iraq is considered one of the countries that lacks many statistics on water consumption in all aspects, which makes studies related to the issue of



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water more important. Difficulty, therefore, estimates of both demand and water supply depend on scenarios that assume specific efficiency and specific population growth. The contradiction between supply and demand for water resources has become clear, which has led to creating a state of deficit in meeting the water needs of the various sectors, and thus leading to the emergence of a real and clear crisis that may increase in the near future. The world in general faces severe and harsh challenges in preserving water in terms of quantity and quality due to the increasing demand for water as a result of the increase in population and urban expansions in other sectors such as agriculture and industry. The process of wasting water and pollution constitutes additional pressure on the quantity and quality of water available at a time when more than a third of the world's population suffers from a shortage in the quantity of water, which requires reconsidering both the supply and demand for water due to the lack of compatibility between them. Studies and research on this subject have expanded to the point that there is almost no city or country that has not studied the analysis of supply and demand in order to develop plans for water management in that region. The available and renewable water resources and their uses are determined according to the location of their quantitative and qualitative distribution [1]. This requires significant effort and time to monitor and evaluate hydrological variables, with various environmental and climatic conditions.

David and Inocencio [2] used the Log-Log-Model in addition to using the sum of least squares to estimate the water demand for the domestic sector in the city of Manila in the Philippines. Gao et al. [3] presented a study on water resources in the HEXI CORRIDOR, where he divided the water resources into surface water resources represented by three large rivers and about (60) tributaries with a water storage of (6992 MCM), while the groundwater coming from the main sources has a storage of (494 MCM), thus the total available water resources are estimated at (7482 MCM), but the available ones are (6590 MCM).

used Geographical Information System (GIS) to estimate water supply and demand in Wujinag City [4] studied the water supply and demand assessment at (10) standard water supply stations in India, distributed at a station on each river. The study showed that the balance between supply and demand is very important for the preservation of humanity and the ecosystem. Lin et al. [5] presented a study on the importance of water resources in Taiwan by analyzing rainfall, surface runoff, and supply from reservoirs, the number of which ranges to about (109) reservoirs. Agricultural demand dominates water supply, followed by domestic and industrial demand, respectively. The study showed that Taiwan will suffer from a slight water deficit in the coming years, with the deficit starting from the year (2021). In (2011), Saleth [6] studied water scarcity and climate change in India. This study provided a brief overview of the status of water demand and supply. The study estimated the total available water resources at (680 km³), which represents only (61%) of the total available water resources, which amount to (1122 km³). Krishna [7] studied the status of demand and supply of supply water in the city of Bangalore, whose population is around (8.5) million people. The study showed that the per capita share of water according to the design system adopted in the city is (51 m³/y). Qin et al. [8] studied the dynamic system in order to analyze the demand and supply of water in northern China, where it was expressed by the carrying capacity of water resources (WRCC), which is an important measure of water resource development and is the difference between the total supply and the demand for water. Dong and Wu [9], in their study on Shaanxi Province in northern China concluded that the structure of water supply and demand has changed due to the industrial development in China, and that there is a gap between supply and demand. The researchers relied on data and integrated water resources planning in their study. Neelima et al. [10] used performance indicators (i.e. the demand ratio for supply) and the Water Utilization Index (WUI), which can be defined as the irrigated area per unit volume of water, in order to know the amount of water allocated for irrigation in the region. The researcher used remote sensing techniques. Bhat [11] divided India into (19) major water basins in order to analyze the demand and supply of water. He noted that the per capita water rate varies from one basin to another due to the uneven distribution of water resources in terms of time and space, as well as the unreliability of some climatic elements, especially winds, in predicting extreme climate events. Birpınar and Tugay [12] studied the effects of climate change on water resources in Turkey. Climate change and its consequences are a source of concern for food, water, rainfall and temperature. The researcher used relevant climate data resulting from dividing Turkey into (25) hydrological basins.

Ren et al. [13] built a logistic model for analyzing water supply and demand and a predictive model for the next 15 years in northern China by building a model for surface and groundwater resources, desalination, recycling, and environmental pollution that reduces water supply. Jodar-Abellan et al. [14] presented a study on assessing water shortages in southeastern Spain using a conceptual model to assess water needs and scarcity and potential water sources that were identified as inputs, including surface and groundwater, treated water and transfer operations between water basins in addition to domestic and agricultural requirements. Data were collected from 16 districts, and Berndtsson and Tussupova [15] studied the Central Asian region, which includes Uzbekistan, Turkmenistan, Kazakhstan, Tajikistan, and Kyrgyzstan. This region is one of the most likely regions in the world to experience water conflicts in light of the increasing water shortages, which in turn has led to environmental, economic, social and political problems due to limited water resources. Ludtke et al. [16] showed that the daily demand for water in Germany increased as a result of the corona pandemic, as this pandemic affected and changed household activities, thus leading to a change in the pattern of water consumption. They relied in their research on a set of data related to daily water demand by hours and for the period (2020-2006). They concluded that daily water consumption increased by (14.3%), which shows the extent of the impact of the pandemic, which led to an increase of (3968 m³). The pandemic also affected demand patterns, as the time shift of peak water demand from the morning to the evening was observed. This work aims to evaluate the water scarcity in Tel-Afar governorate based on GIS estimation, climate change effects, water quantitative and qualitative data. This paper has the following structure: Section 2 provides the following methods, including the study area and data collection. While section 3, results and discussion that contains data analysis and GIS technique. Finally, in section 4, the concluding remarks and some possible future recommendations are reported.

- Finding the amount of water demand for municipal and agricultural purposes.
- Use several possible scenarios in order to predict water demand and find the amount of the water gap for each scenario.
- Find the amount of water gap between supply and demand, and then classify the city according to international classifications of water scarcity.

2 | Analysis of supply and demand for water in Iraq

Isehak [17] presented a study to find the average daily consumption of the city of Baghdad for the period 1995-1998 and the factors affecting the amount of this consumption as well as predicting the future demand for water. Al-Anbari et al. [18] presented a study to analyze the household demand for the city of Hilla using four Demand models (total demand, winter, summer, and spraying) were used for this purpose, and weekly data was used from randomly monitored homes in the city, equipped with new, unified measures. Multiple gradual regression was used in the analysis to find the relationship between the variables. Al-Ahmady [19] conducted a site study of more than 1682 sites for the purpose of calculating the value of household water consumption in the city of Mosul. The study concluded that the value of household consumption of the city of Mosul in the winter was 125 Lpd and in the summer it was 235 Lpd presented). Issa et al. [20] presented a study on future trends and challenges for water in the Tigris and Euphrates basins, where the monthly rate was used to measure water flow. The study included 15 measuring stations with data on the population growth rate. Al-Furaiji et al. [21] presented a study on assessing the supply and demand for water in southern Iraq. The researchers used data related to population, type of crops, industry, and oil wells in the study area. Abd-El-Mooty et al. [22] studied the challenges facing water resources in Iraq using surface water data, represented by the Tigris and Euphrates rivers, the Shatt al-Arab, groundwater, and arable lands. The total volume of water is 66 billion cubic meters, and the volume of water for home consumption per person is 91.6 m³/y. For the period 1975-2000, this quantity is considered high, and the study recommended the necessity of working to reduce the per capita share of water to 54.75 m³/y. Hussein et al. [23] used a hydrological simulation

technique in order to determine the shortage in Najaf Governorate using data related to rain, surface and groundwater, human consumption, and evaporation and then analyzed this data.

The amount of water needed for human survival depends on environmental conditions and human characteristics. Most studies estimate that the amount of water necessary for human survival ranges between (2.5-2 L/d), while indicated that human It requires (10-20 L/d) in order to prepare meals, and as for bathing, it depends entirely on the technology used in the household activity, and this amount varies between urban and rural areas. Gleick [24] pointed out that developed countries consume between (27-99 L/d). The water used in the industrial sector varies according to the quality of existing industrial plants. Some industries require large quantities of water in addition to their consumption of large quantities of drinking water through the liquefaction network due to the random distribution of industrial plants within the district. The Nineveh Water Department estimates that the consumption of drinking water by industrial plants is (50 L/d) per person, according to statistics issued by the Ministry of Planning. The amount of water used in sewage constitutes 33% of total household use. The water used to fight fires is between 200-300 m³. There are many ways to calculate it, depending on the distance between homes and the number of residents [25].

Water consumption does not remain constant, as there may be annual, seasonal, monthly, weekly, daily, and even hourly changes. Dry years lead to an increase in water consumption, and the demand for water increases in the summer and on holidays and occasions, and during a single day, water consumption is high during the morning hours. Around noon, consumption decreases at night, and the amount of change in demand for water in cities and large districts is close to the average, while we find the opposite in villages, where the change in demand is large

The per capita share of potable water is a global variable that is closely linked to the extent of the region's development and urbanization, and through it the status of the water needs of the region's population is determined, as the United Nations Environment Program determined the amount of water per person per day (400 L/d) as a minimum, while the World Bank specified the per capita share of water resources as (1000 m³/y). The per capita share varies from one country to another In Iraq, for example, the per capita share of water increased from (280 L/d) in 1976 to (321 L/d) in the 1990s. The Ministry of Municipalities and Public Works determined the per capita share of potable water for drinking and industry in urban and rural areas.

(450 L/d) and (250 L/d) respectively. Table 1 shows the average water consumption rate of the population and the highest consumption rate in the study area, based on use.

Table 1. Shows the consumption rate and the highest possible water consumption for each sector.

No	Usage	Max. Consumption (L/d)	Consumption rate(L/d)	%
1	Residential	300	200	44
2	Industrial	160	75-50	24
3	Commercial	100	75-50	15
4	Public services	60	50	9
5	Leakage and loss	50	50	8
Total		670	450-400	%100

2.1 | Study Area

Tel-Afar district is located in the northwestern part of Nineveh Governorate, about 69 km away from the Syrian-Iraqi border, between two longitudes (42°38'37"-42°18'20") east and two latitudes (36°31'20). "-36°14'33") to the north. Tal Afar District extends over an area of (4453 km²). It is bordered to the west by Sinjar District, to the south by Hatra District, to the east by Mosul District, and to the north-east by Tel Kayf District. To the north, it is bordered by Dohuk Governorate, and Figure 1 shows location of the study area.

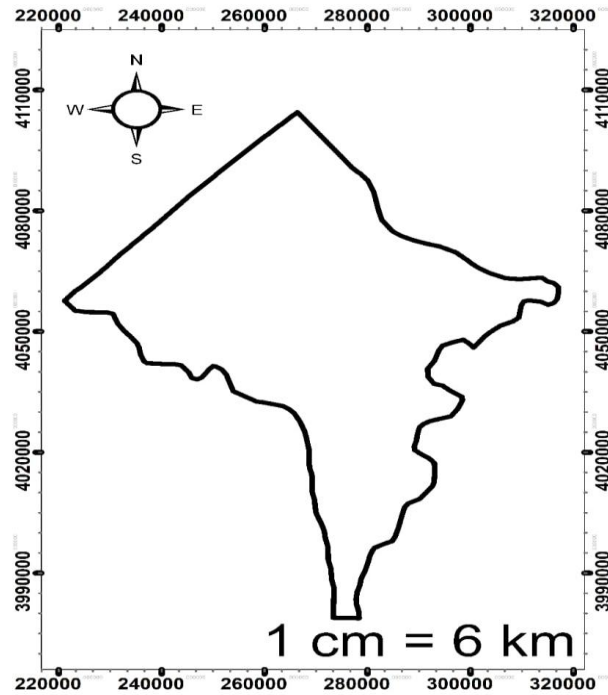


Figure 1. shows the study area in relation to Iraq and Nineveh.

2.2 | Methods for Calculating Water Demand

Population Method:

Population changes (population growth, population density, and population increase) generally affect the quantities of water that are withdrawn and made available to meet the increasing demand. The per capita share of water is estimated using the average water production and population size for a given year through the Eq. (1):

$$Q = \Sigma q \cdot p \cdot f \quad (1)$$

Whereas:

Q: The amount of water required in m³/year

q: Water consumption rate per capita in m³/day

P: future population

f: The efficiency of transported water arrival is usually taken as 100%

Land use Method

This method is used to estimate water demand after knowing the land uses by dividing the area into sub-areas in which the total demand within each sub-area is known. The sub-areas are then divided into different use categories based on the land use plan. For example, the city is divided into areas. Low, medium and high population density, industrial and commercial areas, roads, squares, green belt areas...etc. Therefore, the demand for water is calculated through the Eq. (2):

$$Q = \Sigma S \cdot A \quad (2)$$

Whereas:

Q: Total future water demand

S: Water consumption standard for each region

A: Areas of land for different uses

Water Consumption Records Method

Water demand is estimated based on the historical water demand in that area through water consumption records, especially when there are meters in the studied area.

The Goodrich Method

This method is used to calculate the average daily consumption rate, meaning it estimates the maximum demand for water and is calculated through the Eq. (3) [25].

$$Q = 180.t^{-0.1} \quad (3)$$

Whereas:

Q= Average time rate of water demand (volume/day)

t= The length of time in which the request is processed (2 hours - 365 days)

The population method was relied upon to estimate the annual demand for water by applying (Eq.1) and adopting the per capita share in district and sub-district areas is (450 L/d), and the per capita share in rural areas is (250 L/d) and for various uses (domestic - Industrial - Commercial), and Table 2 shows the daily demand for water in urban and rural areas, according to population projections (population estimate) expected for the year (2018). Per capita water consumption per day is 571, 145, 202.5 and 268.9 liters/day in Tel-afar, Ayadiya, Zummar and Rabia, respectively.

Table 2. Shows the daily water demand in urban and rural areas.

No	Administrative unit	Number of population		Water Demand in regions		Total demand m ³ /d
		Urban	Rural	Urban m ³ /d	Rural m ³ /d	
1	Tel- afar	172453	42573	77604	10644	88248
2	Aydiya	13252	48905	5963	12227	18190
3	Zummar	17554	115849	7900	28962	36862
4	Rabia	18671	81747	8402	20436	28838

Municipal Water Supply Rate

The percentage of municipal water supply for each region is calculated by the ratio between the annual water productions to the annual water demand for that regions as shown in Table 3. using the following equation:

$$WSC = \frac{AP}{AD} \quad (4)$$

Whereas:

Water Supply Coverage =WSC

Annual Production=AP in MCM

Annual Demand=AD in MCM

Table 3. Shows the percentages of annual municipal water supply in the study area.

No	Administrative unit	Annual Production MCM	Annual Demand MCM	Water supply coverage %
1	Tel-Afar	44.8074	32.21052	139.1
2	Aydiya	3.285	6.63935	49.47
3	Zummar	9.855	13.454995	73.2
4	Rabia	9.855	10.526235	93.6

Forecasting Future Water Demand for the Municipal Sector

Predicting future water demand is very important because it combines three interconnected processes, the first of which is supply management, the second is demand management to determine the impact of the presence of water meters and detect leakage locations and prices, and the third is water demand and supply management. Due to the lack of historical data representing the state of water demand or supply, we relied on four scenarios to analyze supply and demand, taking into account the following restrictions: that there is no possibility to build more liquefaction plants in the study area, there is no reliance on the use of non-traditional water resources (water desalination - water recycling) and the main source of surface water supply is the Tigris River.

Scenario 1: Current Population Growth (2.4%)

This scenario assumes that there is no increase in the population growth rate for all the coming years. This percentage will remain constant, assuming that the water supply policies and infrastructure also remain constant.

Scenario 2: Increased of Population Growth (3.0%)

This scenario assumes that the population growth rate increases (3%) for all years (2018-2030) and assumes that water supply policies and infrastructure also remain constant.

Scenario 3: Expanding Water Projects and Increasing Production Capacity

This scenario depends entirely on the state's plan to establish and initiate the Rabia-Sinjar-Al-Baaj water project with a capacity of up to (16,000 m³/d), and to increase the production capacity of the currently operating projects to approximately (40%) in order to cover the needs of the study area by operating backup pumps. And increasing the number of operating hours for some carrier lines, such as the Ayadiya carrier line and the capacity (300 m³/hr).

Scenario 4: Leakage Loss Reduction

This scenario is based on reducing losses from the water network, which is tantamount to establishing new water stations, while the state of water supply and infrastructure and the rate of population growth remain the same, and bringing the percentage of water waste to acceptable global (7-10) % rates.

Scenario Results:

Figure 2 show the results of scenarios (1, 2, 3, and 4) for the center of Tel-Afar, Al-Ayadiya, Zummar, and Rabi'a, respectively. Which was applied in order to forecast water demand for the municipal sector in the study area for different periods of time and for each administrative unit.

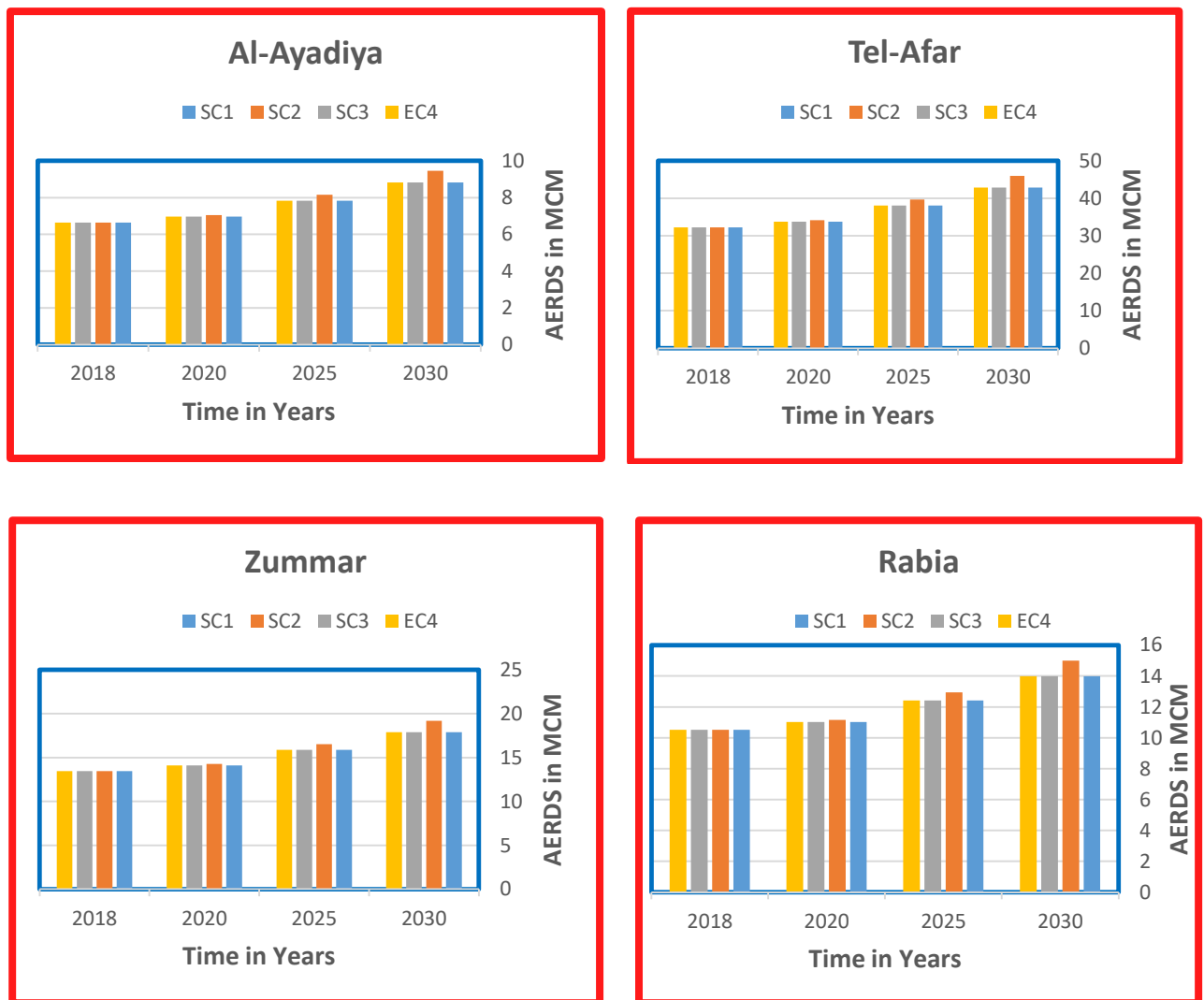


Figure 2. Shows the Available and expected residential demand Scenario [AERDS] for the municipal sector in the study area for the four different scenarios.

Amount of Water Deficit (Water Gap):

As for the amount of the expected water gap for the four scenarios, it was clarified through Figure 3. and the amount of water deficit for the household sector expected until the year (2030) for the center of Tel-Afar, Al-Ayadiyah, Zummar, and Rabi'a and for the various scenarios is shown by comparing the volume of prepared water resources.

Current and Expected Needs:

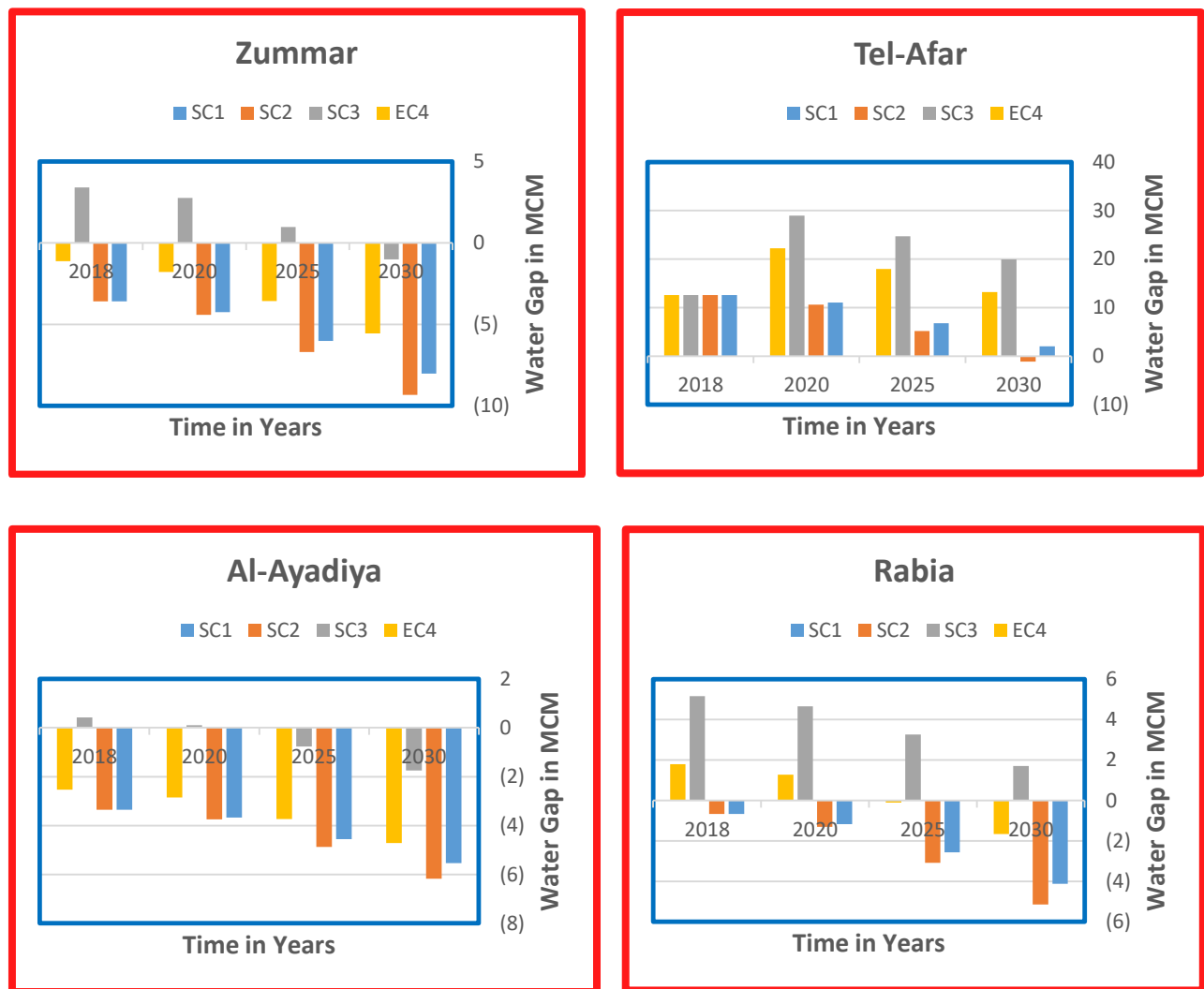


Figure 3. Shows the amount of water gap in the study area according to the four scenarios.

Analysis and Discuss the Results

Analysis of processing results and water demand for the municipal sector

The results of the analysis showed that there are two factors that explain the current increase in demand for water, which is rapid population growth and the high average per capita consumption of water in the municipal sector. What is most striking is that the average daily consumption per capita ranges between 250-450L//d in the study area, which is a high percentage.

The volume of population consumption in the Tel-Afar district center has increased to reach (571 L\d) this quantity is greater than the planning standard specified for an individual, which is (450 L\d). This increase results from the large number of projects and liquefaction stations and their concentration near the city center of the city, as the average center for the projects is located near the center of Tal-Afar, which explains the increase in water supply.

As for Rabia and Zummar subdistricts, their per capita share of water amounts to 268 L\d and 202.5 L\d respectively, while Al-Ayadiyah sub-district recorded the lowest per capita share of 145 L\d. Thus, the general average rate of per capita share throughout the study area is around 296.5 L\d and we note the common and striking feature is the very high level of average per capita consumption in the center of Tal Afar and the

decline in the per capita share of water in the Al-Ayadiyah district. The reason for this is the low coverage of the water supply network as well as the spatial distance of the district from liquefaction projects and units.

Factors that Affect Water Demand Include

- **Population:** Population growth is the main factor in water use and demand, and the growing population increases the demand for water for municipal use, as is the case in the study area.
- **Water pricing:** The demand for water with an increase in its price leads to a decrease in demand for it, and the current pricing for water consumption is very low and does not cover the actual cost of water treatment. Its value is about (10) Iraqi dinars per cubic meter for every (30) cubic meters of water. Water per month. The water pricing structure is based on a progressive tranche system that consists of four tranches, each of which has (30) cubic metres. As for government departments and industrial factories, the price is up to (100) Iraqi dinars per cubic meter, and there is another price that depends on the area of the house. If the area is less than (100) square meters, there are also four segments, and if the area of the house is more than (100) square meters, there are five segments. This price is very low when compared to the average operation and maintenance, which is estimated at (155) dinars per cubic meter for the year (2013). Despite the low price, a large portion of the population does not pay their water consumption bills.
- **Social and demographic characteristics of the family:** Social and demographic characteristics affect the demand for water, which include family size, level of education, and age of the population, as the demand for water is likely to increase with the increase in family size.
- **Water losses and losses:** Water losses are represented by water loss and leakages from various municipal water treatment facilities and illegal violations of the network. The percentage of losses in liquefaction stations in Iraq reaches (40-50%), and in Nineveh Governorate it is estimated at (40%), and in the study area it is estimated. The percentage of losses is (35%-20%) depending on the type and age of the project.

In order to know the future demand for water, four possible scenarios were relied upon, and the selection of these scenarios was based on the current situation of the concerned departments and studies related to the subject. Figure 2 shows the results of these scenarios.

We conclude from Figure 2 that the worst scenario that could face the study area is scenario (2), which leads to an increase in the percentage of water demand for the domestic sector to (42.5%), which is a very high percentage while the state of water supply remains, and this scenario It will lead to reducing the per capita share in Tal Afar center from (571 L/d) to (400 L/d), in Al-Ayadiyah district from (145 L/d) to (101 L/d), and in Zammar district from (202.5 L/d) to (142 L/d) and in Rabia district, it decreases from (268.88 L/d) to (188.5 L/d), while in the rest of the scenarios the rate of increase in demand will be around (33%), which is a percentage close to the global rate, which in turn leads to a reduction in the share of per capita of water, while the state of supply remains. In Tal Afar, the per capita share drops to (430 L/d), and in the Al-Ayadiyah district, the per capita share is (109 L/d), and in Zummar, the per capita share is 152 L/d, and in the Rabi'a subdistrict, the per capita share is 202L/d.

As for water supply, the state of supply remains the same as in scenario (1-2-4), namely reliance on liquefaction stations, water projects, and stations installed on wells. There is a change in the increase in the supply rate in scenario (3) for the entire study area, through planned projects. It has or is under implementation, such as the Rabia Water Project and increasing the current capacity of the transmission lines.

This, in turn, will increase the per capita share of water for Tel-Afar center from (571 L/d) to (601 L/d), and in Al-Ayadiyah the per capita share will increase from (145 L/d) to (234 L/d), and in Zummar from (202.5 L/d) to (260.5 L/d) and in Rabia from (268.88 L/d) to (322 L/d). As for the amount of the water gap and

its changes in the study area, it was estimated by comparing the volume of available water resources with the current and expected needs until the year (2030) and for various scenarios.

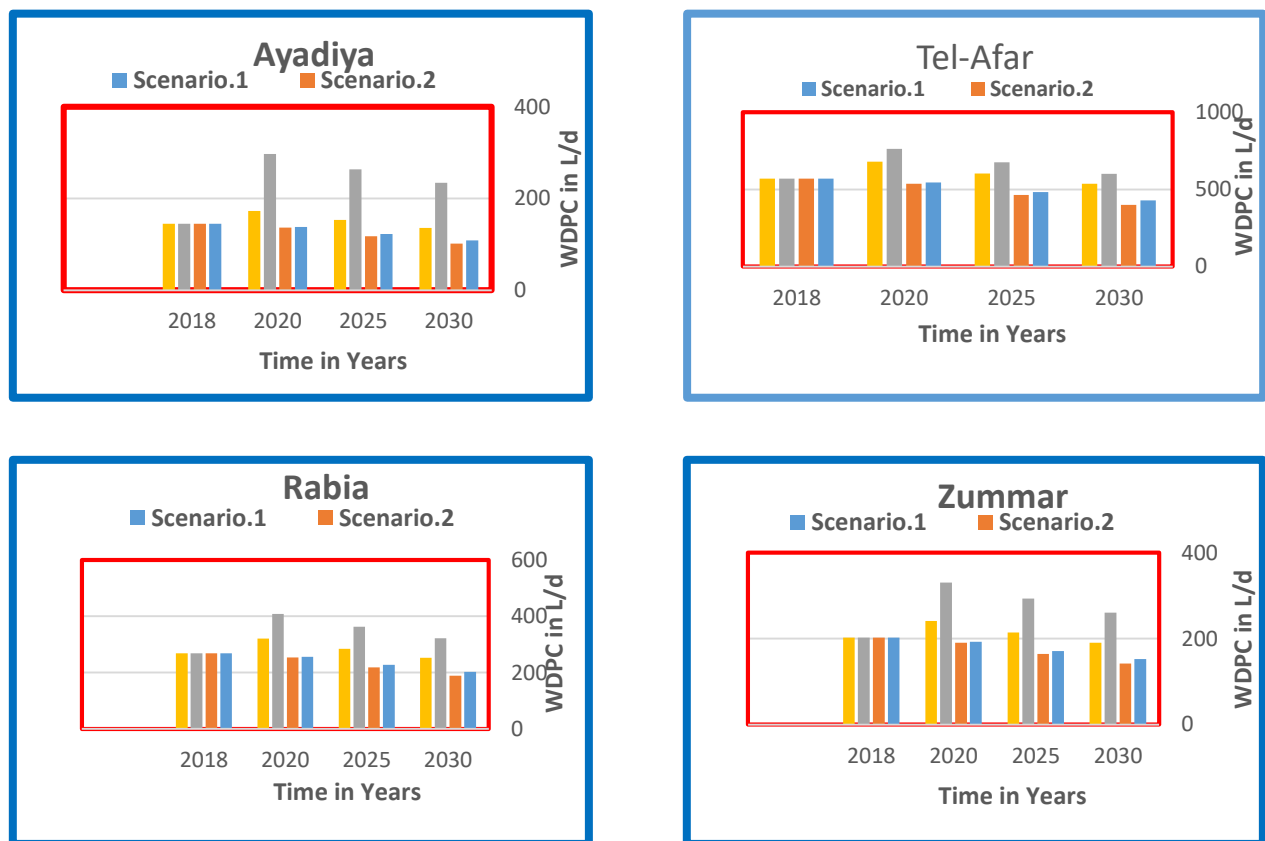


Figure 4. Shows the amount of water demand for various sectors in the study area.

It is clear from Figure 4 that scenario (1) increases the water gap for the household sector over time throughout the study area, and the gap between supply and water demand for the municipal sector in the center of Tel-Afar is non-existent. It increases in the Al-Ayadiya district due to the increase in population over time and the status of water supply remaining the same. The same applies to Zammar and Rabia. While we find that scenario (2) is the worst scenario, which depends on increased population growth while the state of equipment remains, while the best scenario is scenario (3), in which the water gap is non-existent in Tel-Afar, decreases in Al-Ayadiyah district, and is almost non-existent in Zummar until (2025), then It will reappear, but at a small rate, in 2030. In Rabia district, the water gap will disappear if the Rabia project is established, which it is hoped will enter service in 2024. Thus, scenario (3) gave the best results and reduced the water gap for the domestic sector. As for scenario (4), it is a scenario concerned with managing water demand by reducing losses and leakages in the network by reducing the gap between supply and demand, as there is a surplus of water supply in Tel-Afar and in the Al-Ayadiyah district, which reduces the difference between supply and demand, and the same is the case in Zummar and Rabi'a. Therefore, the worst scenario for the study area is (scenario 1-2) because they both depend on fixed water supply, while the best scenario is (3-4) as water supply increases, either through new water projects, or by increasing the number of operating hours of pumps. , or reduce leakage from the network. Figure 4 shows the daily per capita share of water in the study area under the four different scenarios.

We note from Figure 4 and based on the available information and future expectations that the center of Tel-far will witness, in scenario (1), a decrease in the per capita share from (571 L\ d) to (429.5 L\ d) in the year (2030), which means a decrease The per capita share is 33% higher than it was due to population growth and the status of water supply remaining the same. In scenario (2), which represents the worst scenario, the per

capita share of water will decrease from (571 L\ d) to (400 L\ d), meaning that the amount of decrease will be around (42%). Despite this decrease, the per capita share will be within the planning standard. In the center of Tal Afar.

Scenario (3) will witness an increase in the per capita share of water from (571 L\ d) to (601 L\ d), and this is also the case in scenario (4), in which the per capita share rises from (571 L\ d) to (536.8 L\ d)

While we find that the matter is getting worse in the Al-Ayadiya district, which records the lowest per capita share of water. In scenario (1), the per capita share will decrease from (144.7 L\ d) to (109 L\ d), and this decrease is a result of the population increase, and in scenario (2) the per capita share will decrease. per capita from (144.7 L\ d) to (101.5 L\ d), which represents the worst scenario where the per capita share of water is less than the applicable planning standard.

Scenario (3) will witness an increase in the per capita share of water to (243 L\ d) as a result of supply management and an increase in the number of operating hours and the number of working pumps. In Scenario (4), which focuses on the aspect of demand management by reducing losses and leakages in the network, which led to To increase the per capita share of water from (144.7 L\ d) to (172 L\ d) in the year (2020) and then witness a decline due to the increase in population.

In Zummar district, according to scenario (1), the per capita share of water was estimated at (202 L\ d) and then decreased to (152 L\ d). The same situation was repeated in scenario (2), where it recorded a decrease from (202 L\ d) in (2018) to (142 L\ d) by (202 L\ d). 2030) This indicates that the per capita share of water remains below the planning standard for both cases.

As for scenario (3), it witnessed an increase in the per capita share from (202 L\ d) to (260.5 L\ d) by the year (2030), and the same is true in scenario (4), which also witnessed a noticeable increase in the per capita share from (202 L\ d). d) to (241 L\ d) by (2020) and then to decrease approximately (190 L\ d) in 2030.

As for Rabia district, it also suffers from a decrease in the per capita share of water, as it recorded in scenario (1) a decrease in the per capita share from (268.8 L\ d) to (202 L\ d). While in scenario (2), the per capita share decreased to (188.5 L\ d), and in scenarios (3 and 4), which witnessed a clear improvement in the per capita share of water to record approximately (322 L\ d) and (252 L\ d) in the year (2030) respectively.

Among the factors that led to an increase in the gap between supply and demand for water in the study area are:

- The small number of operating stations and projects necessary to meet the needs of the population.
- The use of drinking water for irrigation and irrigation of agricultural lands in the area extending between Al-Kasak and the entrance to Tel-Afar negatively affected the per capita share of water for the rest of the study area.
- Providing water distribution networks for some projects, such as the old Tel-Afar project, and the unjustified encroachment by residents on the distribution networks without legal deterrent had a negative impact on water distribution network throughout the study area is estimated at approximately (185 km).
- The continuous fluctuation in the supply of electrical energy has had a negative impact on the supply of water, in addition to a decrease in the water level in the source of the supply.

Supply and Water Demand

Table 4. Shows the amount and type of demand for water for various sectors.

Administrative unit	Agriculture Demand MCM	Residential Demand MCM	Livestock Demand MCM
Tel-Afar	5.86	32.21	0.49
Aydiya	14.78	6.64	0.56
Zummar	25.2	13.45	1
Rabia	288.32	10.53	1.94
Total	334.16	62.83	3.99

It is clear from Table 4 that the demand for water for municipal consumption in the center of Tel-Afar recorded the highest demand, at a rate of (83.5%) of the total demand, followed by agricultural demand, at a rate of (15.2%), and the demand for water for watering livestock came in third place, at a rate of (1.3%) of the total demand. In Al-Ayadiyah, agricultural demand ranked first, with a percentage of (67.24%) of the total demand, followed by municipal demand, with a percentage of (30.2%), and water demand for watering livestock ranked third, with a percentage of (2.56%). Also in Zammar, agricultural demand was the most important factor in the total demand, at a rate of (63.55%), followed by municipal demand, at a rate of (33.9%), and the demand for water for watering livestock, at a rate of (2.55%). As for Rabia, agricultural demand recorded a percentage of (95.85%) of the total demand, and both municipal demand and demand for watering livestock recorded a percentage of (3.5%) and (0.65%) of the total demand, respectively, and Figure 4 shows the spatial distribution of water demand for different sectors in the study area. Table.5 shows the total quantity and source of water supply for various uses within the study area.

Table 5. Shows water supply by source for each sector.

Administrative unit	Residential supply MCM		Agriculture Supply MCM	
	Surface water	Groundwater	Surface water	Groundwater
Tel-Afar	44.8	-----	-----	6.74
Aydiya	3.28	-----	-----	7.8
Zummar	9.85	-----	37	0.6
Rabia	-----	9.85	222	3.64
Total	57.93	9.85	259	18.78

3 | Conclusion

The study concluded that Tel-Afar District is facing increasing water-related challenges due to the spatial disparity between water demand and available supply sources, in addition to the impacts of continuous population growth and the high rates of per capita water consumption in certain administrative units. Spatial analysis using Geographic Information Systems (GIS) revealed that water demand is predominantly concentrated in the municipal sector within the district center, whereas the agricultural sector constitutes the dominant share of water demand in the surrounding sub-districts.

The findings further indicated a significant imbalance in the water supply–demand relationship across the district. While the center of Tel-Afar exhibits a relative surplus in water supply, the sub-districts of Al-Ayadiyah, Zummar, and Rabia experience increasing water deficits, adversely affecting water security and sustainable development in the region. Moreover, future scenario modeling demonstrated that maintaining

or increasing the current population growth rates would widen the water gap and reduce per capita water availability to levels that may fall below the adopted planning standards.

The study demonstrated that supply-side management, through the development of water infrastructure projects and the expansion of production capacities, together with demand-side management aimed at reducing water losses and leakage within distribution networks, represents the most efficient and sustainable approach for mitigating the anticipated future water deficit. Furthermore, the results confirmed that strategic planning based on future scenarios provides an effective scientific framework for supporting decision-makers in formulating water policies and achieving integrated water resources management.

Accordingly, the study recommends the adoption of advanced water demand management programs, the modernization of water distribution infrastructure, and the expansion of strategic water projects. It also emphasizes the importance of employing modern geospatial technologies and artificial intelligence applications for monitoring water resources and forecasting future changes. Such measures are essential for enhancing water security and ensuring environmental and developmental sustainability in Tel-Afar District over the coming decades.

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Data Availability

The datasets generated during and/or analyzed during the current study are not publicly available due to the privacy-preserving nature of the data but are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare that there is no conflict of interest in the research.

Ethical Approval

This article does not contain any studies with human participants or animals performed by any of the authors.

References

- [1] Hoekstra, Arjen Y., Mesfin M. Mekonnen, Ashok K. Chapagain, Ruth E. Mathews, and Brian D. Richter, 2012, "Global Monthly Water scarcity: Blue water footprint versus blue water Availability", PLOS ONE, 7(2): 1-9.
- [2] David, Cristina, C. and Arlene B. Inocencio, 1998, "Understanding Household Demand for Water: The Metro Manila Case", International Development Research Center, Ottawa, Canada, 1-24.
- [3] Qian -zhao, GAO, DU Hu-Lin, and Zu Rui-Ping, 2002, "The Balance Between Supply and Demand of Water Resource and The Water -Saving Potential for Agriculture in the Hexi Corridor" Journal of Chinese Geographical Science, 12(1): 23-29.
- [4] Singh, Ajay, and Anand Patwardhan, 2010, "Assessing Water Demand -Supply Imbalance in Continental India" International Conference on Environmental Engineering and Applications, 181-183.
- [5] Lin, Chien -Tsun, Hsin -Hsiung Chen, Tomnori Kume, and C hyi Rong Chiou, 2010, "Comparison of Potential water supply and demand in Taiwan" Water International, 35 (2): 165-176.
- [6] Saleth, Rathinasamy Maria, 2011, "Water Scarcity and climate change in India: the need for water demand and supply management" Hydrological Sciences Journal, 56(4): 671-689.
- [7] Krishna.R. 2012. Sustainable urban habitats and urban water supply: accounting for unaccounting for water in Bangalore city, India. Current Urban Studies Journal, 1(4):156-165.
- [8] Qin, Huanhuan, Amy Cha-tien Sun, Jie Liu, and Chunmiao Zheng, 2012, "System dynamics analysis of water supply and demand in the North China Plain", Journal of water Policy, 14: 214-231.
- [9] Dong, Ying, and Xi-jun Wu, 2013, "Water Supply and Consumption Structure Change and Water Demand Forecast in Northern Shaanxi" Journal of Applied Mechanics and Materials, 353: 2943-2947.

- [10] Neelima, T.L., K.V.Ramana, M.D.Raddy, M.U.Deve, V.Ramulu and A.V.Ramanganeyulu. 2014, "Supply Demand Ratio and water utilization Index in Jurala project command area, Andhra Pradesh, India, International Journal of Bio-resources and stress management ,5(1):68-73.
- [11] Bhat, Tariq Ahmad, 2014, "An Analysis of Demand and Supply of Water in India" Journal of Environmental and Earth Science, 4 (11): 67-72.
- [12] Birpinar, Mehmet Emin, and Çigdem TugaÇ, 2018, "Impact of climate change on Water Resources of Turkey" Conference Water resources and Wetlands (Romania), 154-152.
- [13] Ren, C., Dong, Y., Xue, P., & Xu, W. (2019, July). Analysis of water supply and demand based on logistic model. In IOP Conference Series: Earth and Environmental Science (Vol. 300, No. 2, p. 022013). IOP Publishing.
- [14] Jodar-Abellan, A., Fernández-Aracil, P., & Melgarejo-Moreno, J. (2019). Assessing water shortage through a balance model among transfers, groundwater, desalination, wastewater reuse, and water demands (SE Spain). *Water*, 11(5), 1009.
- [15] Berndtsson, Ronny, and Kamshat Tussupova, 2020, "The Future of water Management in Central Asia" Journal of Water, 12(2241): 1-5.
- [16] Ludtke, Deike U., Robert Luetkemeier, Mishael Schneemann, and Stefan Liehr, 2021, "Increase in Daily Household Water Demand during the first Wave of the covid -19 Pandemic in Germany" Journal of Water, 13(260): 1-13.
- [17] Isehak, R.J., 2001, "An Analysis of Residential Demand for Water: A Case Study of the City of Baghdad for the Period 1995 to 1998", M. Sc. Thesis, University of Technology
- [18] Riyadh, H. AL-Anbari, Jabbar H., ALBaidhani, and Isra Sadi Samaka, 2004, "Residential Water Demand Analysis in Hilla", The Iraqi Journal For Mechanical And Material Engineering, Special Issue (B), 334-346.
- [19] Al-Ahmady, Kossay K., 2011, "Calculating and Modeling of an Indoor Water Consumption Factor in Mosul City, Iraq' Journal of Environmental Studies, 6: 39-52.
- [20] Issa, I. E., N. A. Al-Ansari, G. Sherwany, and S. Knutsson. 2013, "Trend and Future challenges of water resource in the Tigris –Euphrates Rivers basin in Iraq" Hydrology and Earth System Sciences, 10: 14617-14644.
- [21] Al-Furaiji, M. H. O., Karim, U. F., Augustijn, D. C., Waisi, B. I. H., & Hulscher, S. J. (2016). Evaluation of water demand and supply in the south of Iraq. *Journal of water reuse and desalination*, 6(1), 214-226.
- [22] Abd-EL-Mooty, Mohamed, Rawya Kansoh, and Ahmed Abdulhadi, 2016, "Challenges of Water Recources in Iraq" Hydrology Current Research, 7(4): 1-8.
- [23] Hussein, Ayad, K., Hayder H. K., and Ali, M. H., 2020, "A Simulation Hydrological estimation of Shortage Problem in AL-Najaf Region" Journal of Critical Review, 7(9): 3111-3121.
- [24] Gleick, Peter H., 1996, "Basic Water Requirements for Human Activities: Meeting Basic Needs" Journal of Water International, 21: 83-92.
- [25] Al–Sudani, Hussein Ilaibi Zamil, 2020, "Derivation Mathematical equation to estimate water surplus and groundwater recharge in Iraq" Journal of Applied Water Science, 10(97): 1-11.

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