Salud, Ciencia y Tecnología - Serie de Conferencias. 2025; 4:1524
doi: 10.56294/sctconf20251524

ORIGINAL

Performance Evaluation of Water Management Planning in Karbala City, Iraq

Evaluación del rendimiento de la planificación de la gestión del agua en la ciudad de Karbala, Irak

Nabaa Mahdi Mohammed Ali Al-Saffar[1], Alaa Hussein Al-Fatlawi[1]

[1]Environmental Engineering Department, College of Engineering, University of Babylon, Babylon 51001, Iraq.

Cite as: Al-Saffar NMMA, Al-Fatlawi AH. Performance Evaluation of Water Management Planning in Karbala City, Iraq. Salud, Ciencia y Tecnología - Serie de Conferencias. 2025; 4:1524. https://doi.org/10.56294/sctconf20251524

Submittedd: 19-08-2024 **Revised:** 22-12-2024 **Accepted:** 25-02-2025 **Published:** 26-02-2025

Editor: Prof. Dr. William Castillo-González

Corresponding author: Nabaa Mahdi Mohammed Ali Al-Saffar

ABSTRACT

Introduction: Karbala, a significant religious tourist destination, faces increasing water demand due to rapid population growth. The city primarily relies on the Al-Husseiniya River, a tributary of the Euphrates River, and groundwater sources comprising 1,837 active wells with an average discharge rate of 0,014 m^3/s. The irrigated land area is estimated to be 49,312 km^2.
Objectives: the study aims to evaluate the effectiveness of current water management strategies in Karbala, identifying infrastructure limitations and proposing sustainable solutions to improve water supply. It also seeks to analyze the impact of population growth on water resources and promote public participation in water conservation. Finally, the goal is to develop a comprehensive framework for water planning and management to ensure short- and long-term sustainability.
Method: this study evaluated the current water management strategies by analyzing internal and external water sources, considering population growth and infrastructure limitations. A mixed-method approach was employed, integrating quantitative data from water utility reports and qualitative insights from stakeholder interviews. The project was designed for a duration of six years, divided into two phases: the first from 2025 to 2030 and the second from 2030 to 2035.
Results: despite partial reliance on the town's water supply system, Karbala faced a significant shortfall in meeting demand due to rapid population growth and infrastructure issues. Private connections and alternative sources provided some relief, but interruptions in supply persisted.
Conclusions: addressing these challenges was essential for ensuring a sustainable water supply for Karbala's growing population. Studying urban water supply in Karbala identified service delivery issues and provided insights for policymakers, NGOs, and academics to develop solutions and guide future research.

Keywords: Water Management Plan; Water Supply; Water Demand; Ground Water.

RESUMEN

Introducción: Karbala, un importante destino turístico religioso, se enfrenta a una creciente demanda de agua debido al rápido crecimiento de la población. La ciudad depende principalmente del río Al-Husseiniya, un afluente del río Éufrates, y de fuentes de agua subterránea que comprenden 1837 pozos activos con un caudal medio de 0,014 m^3/s. La superficie de regadío se estima en 49,312 km^2.
Objetivos: el estudio tiene como objetivo evaluar la eficacia de las estrategias actuales de gestión del agua en Karbala, identificando las limitaciones de las infraestructuras y proponiendo soluciones sostenibles para mejorar el suministro de agua. También busca analizar el impacto del crecimiento de la población en los recursos hídricos y promover la participación pública en la conservación del agua. Por último, el objetivo es

desarrollar un marco integral para la planificación y gestión del agua que garantice la sostenibilidad a corto y largo plazo.
Método: este estudio evaluó las estrategias actuales de gestión del agua mediante el análisis de las fuentes de agua internas y externas, teniendo en cuenta el crecimiento de la población y las limitaciones de las infraestructuras. Se empleó un enfoque de método mixto, integrando datos cuantitativos de los informes de las empresas de suministro de agua y conocimientos cualitativos de las entrevistas con las partes interesadas. El proyecto se diseñó para una duración de seis años, divididos en dos fases: la primera de 2025 a 2030 y la segunda de 2030 a 2035.
Resultados: a pesar de depender parcialmente del sistema de suministro de agua de la ciudad, Karbala se enfrentaba a un importante déficit para satisfacer la demanda debido al rápido crecimiento de la población y a los problemas de infraestructura. Las conexiones privadas y las fuentes alternativas proporcionaron cierto alivio, pero persistían las interrupciones en el suministro.
Conclusiones: abordar estos desafíos era esencial para garantizar un suministro de agua sostenible para la creciente población de Karbala. El estudio del suministro de agua urbano en Karbala identificó problemas en la prestación de servicios y proporcionó información a los responsables políticos, las ONG y los académicos para desarrollar soluciones y orientar futuras investigaciones.

Palabras clave: Plan de Gestión del Agua; Suministro de Agua; Demanda de Agua; Agua Subterránea.

INTRODUCTION

Water stands as a vital necessity for human survival, health, and dignity, playing a foundational role in human progress. However, the global freshwater reservoirs endure escalating pressures, leaving numerous individuals without adequate access to fulfill their basic needs. As population numbers rise, economic activities expand, and living standards improve, the demand for freshwater intensifies, leading to heightened competition and conflicts over this finite resource. Assessing water quality is essential for identifying pollution sources and developing effective strategies for sustainable water management.[1,2]

In today's society, it's crucial to design and implement sustainable water supply systems capable of delivering safe drinking water to meet the needs of both humans and livestock. Water serves as a universal resource essential for the survival of all living creatures, including humans, plants, and animals. Without water, life cannot exist. Having access to safe and affordable drinking water is universally acknowledged as a basic human requirement.[3]

Hence, the design and analysis of water distribution networks are crucial in modern societies, as their effective operation directly impacts the well-being of the population. In rapidly growing cities like Karbala, ensuring access to clean drinking water and developing sustainable, economically feasible pipe network systems or water supply schemes is crucial.[4]

Clean water availability significantly contributes to the socioeconomic development of a country. By enhancing health and raising living standards, clean water provision boosts economic productivity within society. However, many developing countries, such as Iraq, still face challenges with low coverage of potable water supply and sanitation, leading to issues like water shortages and waterborne diseases among citizens. A robust water distribution infrastructure is essential for the development of any town.[5]

This study investigates the theoretical framework for designing an enhanced water distribution network for Karbala City. The goal of this water supply network is to meet the current and future demand for clean water in Karbala, enhancing the town's existing water supply infrastructure. By determining the present and projected population of the area and establishing the daily water requirements, the design process relied on topographic, hydrogeologic, hydrologic and data, with a focus on pipe networking models and performance theories.

The development of mathematical models is an effective tool for water resource management, enabling the prediction of pollution levels and the implementation of proactive measures to protect and sustain water resources.[2]

The main aim of this study is to develop a comprehensive water resource management plan that ensures the fair and sustainable distribution of water in Karbala Governorate. This will be achieved through analyzing current water sources, assessing future demand, and identifying optimal strategies for water conservation and efficiency improvement. The study also focuses on the impact of environmental factors and climate change on water availability, proposing technical and administrative solutions to enhance water resource sustainability.[6]

Literature review and hypotheses development

1. *Water Management*

Water management is a critical aspect of sustainable development, ensuring the availability, quality, and equitable distribution of water resources. Effective water management is essential for agriculture, industry, domestic use, and ecosystem preservation. This literature review explores key aspects of water management, including historical perspectives, modern strategies, challenges, and case studies.

2. Historical Perspectives

Water management has evolved from ancient civilizations' irrigation systems to modern integrated water resource management (IWRM). Early civilizations, such as those in Mesopotamia, Egypt, and the Indus Valley, developed sophisticated irrigation and drainage systems to support agriculture. The Roman Empire's aqueducts and medieval canal networks also demonstrate early advancements in water management.

3. Modern Water Management Strategies

3.1 Integrated Water Resource Management (IWRM)

IWRM is a comprehensive approach that promotes coordinated development and management of water, land, and related resources. It aims to maximize economic and social welfare without compromising the sustainability of ecosystems. Key principles include stakeholder participation, demand management, and adaptive governance.

3.2 Water Conservation and Efficiency

Technological advancements, such as drip irrigation, wastewater recycling, and desalination, contribute to water conservation. Efficient water use in agriculture, which accounts for the largest share of global freshwater consumption, is a priority.

3.3 Urban Water Management

Rapid urbanization has increased pressure on water resources. Strategies like rainwater harvesting, smart water grids, and sustainable drainage systems (SuDS) help manage urban water demands.

4. Challenges in Water Management

4.1 Climate Change and Variability

Climate change affects precipitation patterns, leading to droughts and floods. Adapting to these changes requires resilient infrastructure and adaptive policies.

4.2 Water Scarcity and Pollution

Increasing demand for water, coupled with pollution from industrial and agricultural activities, threatens water security. Strategies such as pollution control, watershed management, and efficient water use help address these challenges.

4.3 Governance and Policy Issues

Water management requires effective governance, enforcement of regulations, and stakeholder participation. Conflicts over transboundary water resources highlight the need for international cooperation and legal frameworks.

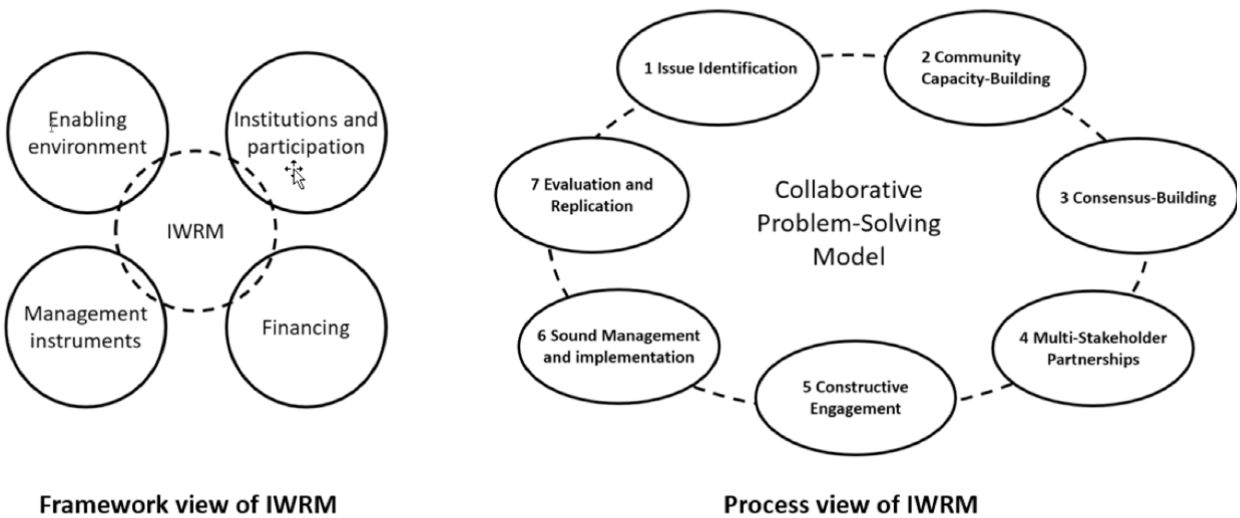

Figure 1. Framework and process views of IWRM

https://doi.org/10.56294/sctconf20251524

METHOD

Study Area and Data collection

Location and Topography

Karbala Governorate, situated approximately 100 km from Baghdad in the middle of Iraq, is a significant religious center in the country and globally (figure 2) include residential neighborhoods in the city of Karbala. Covering an estimated area of 5550 hectares, it comprises four urban and five rural areas. The city, with elevations ranging from 2320 to 2460 meters above sea level, spans an area of nearly 30 square kilometers, located between Northern latitude (32° 40 00-32° 20 00) and Eastern Longitude (44° 25 00- 43° 45 00).[7]

Karbala and its surroundings straddle the boundary between the stable platform (Al-Salman sub-zone) and the unstable platform (Mesopotamian subzone). The geological formations in Karbala City consist of tertiary and quaternary sediments. The region experiences a climate typical of a western desert, with scorching, arid summers and chilly, rainy winters. Approximately 90 % of the annual rainfall is recorded between November and April.[8]

Climate inequality is a crucial environmental issue that requires thorough study and assessment. Climate change can lead to heightened drought severity, elevated risk of flooding, increased soil salinity, liquid waste accumulation, and declining groundwater levels. The area of Karbala city is about 5043 kand constitutes 1,2 % of the total Iraq area. The land is soft, pure (pure from pebbles and pushes), and covered with dense orchards that are irrigated from Euphrates.[9]

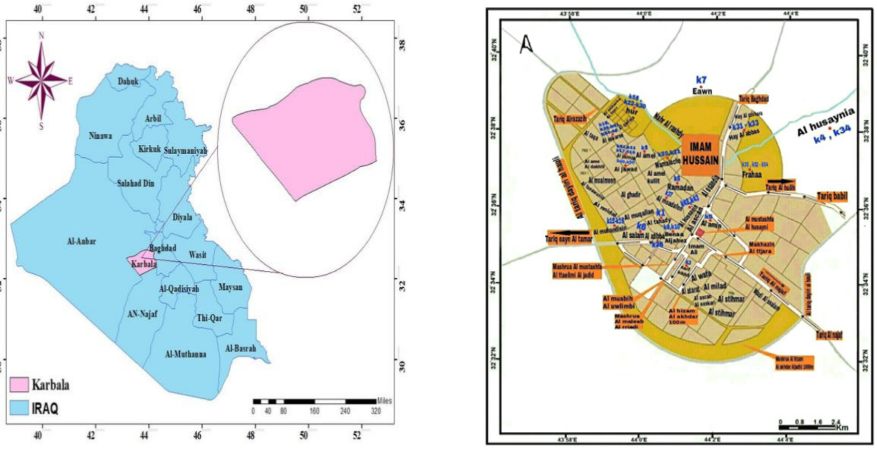

Figure 2. Karbala Governorate, and residential neighborhoods in the city of Karbala.[10]

Climate

Karbala Governorate experiences a high average annual rainfall of 1367 mm, with the heaviest rainfall occurring between September and March, and July being the driest month. As shown in Figure 3, the average monthly temperature ranges from 8°C to 50°C, with the lowest temperatures of 8°C to 10°C and the highest of 45°C to 50°C, as show in figure 3. The coldest temperatures are recorded in December, January, and February, while the highest temperatures are seen during the spring season (June, July, and August). The temperature variation is minimal, which is typical for this climatic region. According to climatological classification, Karbala Governorate falls under the "hot, dry summers and cold, rainy winters" climate category.[11]

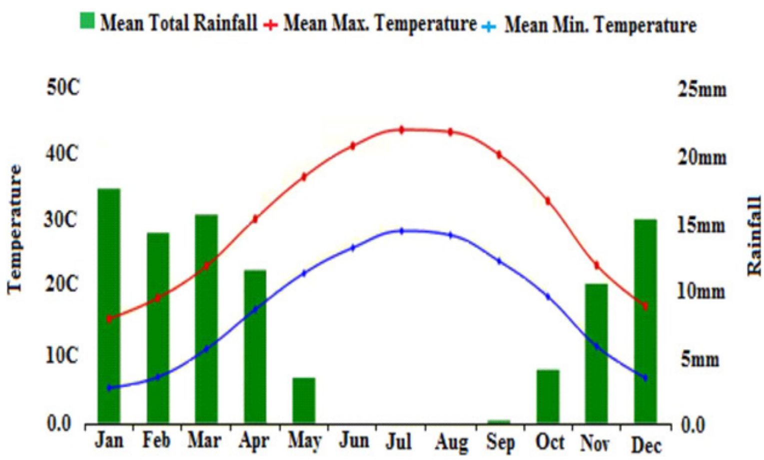

Figure 3. The climatological data for Karbala city from 1980 to 2020.[12]

https://doi.org/10.56294/sctconf20251524

Population

According to the 2024 census, the total population of this town was reported to be 1 419 817 with 719041 males and 700 775 females. Based on this, the estimated population for 2029 is 1 603 063. Karbala is the largest of three religious towns in Iraq and is a significant destination for religious tourism. Additionally, it functions as a major hub for marketing, attracting thousands of rural visitors. The town's primary economic activities, as indicated by the local administration, include trading, hotel services, and small-scale industries.

Future Development of the Town

In 2008, a comprehensive town development plan was crafted. Information from the town's administration office suggests a significant boost in the town's economy. Anticipated growth includes a substantial expansion in vegetable farming and small-scale industries, with the building and hotel sectors following suit. The trading and some industries are also expected to experience notable growth.

Existing Water Supply and Sanitary Service

Water Supply Service

Al – Hussainya river is one of the important water sources in Karbala Province is branched from Euphrates River at the right side in front of Al – Hindya barrage, its length reached about 30,6 km. This river irrigates about 186 000 acres of the agriculture areas and is the only water source.(13) Raw water was treated through main water treatment plants with different capacities, as shown in the table 1. The primary issue in the current system is the lack of water. Data from the water supply directorate reveals that most homes in Karbala city receive only partial water supply from the municipal system. Unfortunately, the available water is not enough to fulfill all needs, leading to a shortfall that must be supplemented by alternative sources like wells and water vendors.

Sanitary Service

The overall sanitation situation in the town is poor, with sanitation-related diseases being prevalent. There is a lack of proper liquid waste disposal systems in the town. Some districts rely on septic tanks in their dwelling units, with sludge disposal being managed by vacuum trucks. Additionally, waste from bathing and other household activities is sometimes improperly discarded onto the streets.

Table 1. Main Water Treatment Plants in Karbala City.(14)

NO.	Project name	Total discharge m^3/h	Actual discharge m^3/h	Service areas	Project water source
1	Karbala Unified Water Project	8000	10000	Commemorations of the martyrdom, birth, frames, political prisoners, military housing, and the neighborhoods surrounding them, part of Al-Harr District, and Ain Al-Tamru District, part of Al-Husseiniyah District.	Euphrates River
2	Al Hussein City Project	6400	8000	Part of the city center and its surrounding neighborhoods, part of Al-Husseiniyah District, and part of the neighborhoods of Al-Harr District	Al-Husseiniyah River
3	Al-Hussein neighborhood water project and Al-Mashrou complexes	3200	4000	Part of the city center and its surrounding neighborhoods	Al-Husseiniyah River
4	Old Safi project	1080	1350	Part of the old city centre	Al-Husseiniyah River
5	Al-Hussein City water collectors	320	400	Part of the city center and its surrounding neighborhoods and part of Al-Husseiniya district	Al-Husseiniyah River
6	Raw water project water complex	160	200	Part of the old city centre	Al-Husseiniyah River

Population Forecasting & Design Period

Population Forecasting

Once the planning phase is set, it's essential to figure out the town's population for different time frames. With the area's population projected to grow, it's crucial to gather accurate current and historical population data from the census office to determine the town's projected population. The town's future growth heavily depends on factors like expanding trade, industrial advancements, discoveries of resources such as oil, and the establishment of railway stations. These factors can lead to significant increases, slow growth, stagnation, or even a decrease in population.(15) Population forecasting and determining the design period are essential

https://doi.org/10.56294/sctconf20251524

steps in designing a water supply system. The economic design period of water supply components depends on factors such as their lifespan, initial cost, interest rates on loans, expandability, and potential obsolescence due to technological advances. Estimating the flow at the end of the design period is crucial for designing the system's parts.[16]The current urban development plan for Karbala, established in 2018 by the Karbala Urban Planning Institute, outlines specific zones for residential, commercial, industrial, and institutional purposes. As the private sector continues to grow, there will be an increased need for essential services, with water being the most crucial. The proposed plan, based on on-site surveys, topographic maps, and input from local communities, government, and non-governmental organizations, forms the foundation for assessing water demand and planning future water supply systems. It is crucial to determine the planning horizon and estimate the area's population for any water supply scheme. Typically, water supply projects are designed to meet the population's demand for a specific period after construction completion.[17]

Design Period

The design period refers to the duration for which the water works have been designed. Before designing and constructing a water supply scheme, it's essential to ensure that the water works have sufficient capacity to meet the town's future water demand for the specified design period. Typically, the design period ranges from 20 to 30 years, striking a balance between not being too long or too short.[17] Various elements of the treatment and distribution systems may be designed based on different flow criteria, as outlined in the figure 4.
The design period of a water supply scheme can be constrained by various factors:

1. *Available Funds:* The availability of funds for completing the project can limit the design period.
2. *Lifespan of Materials:* The lifespan of pipes and other structural materials used in the water supply scheme can also determine the design period.
3. *Interest Rates:* The rate of interest on loans taken to complete the project affects the feasibility of a longer design period.
4. *Town Expansion:* The anticipated rate of expansion of the town influences the design period, as the water supply system needs to accommodate future growth.

Given that Karbala is a religious tourism city expected to experience future growth, a shorter design period of 6 years has been adopted. This decision is based on considerations such as the lifespan of materials and the anticipated expansion of the town.[18]

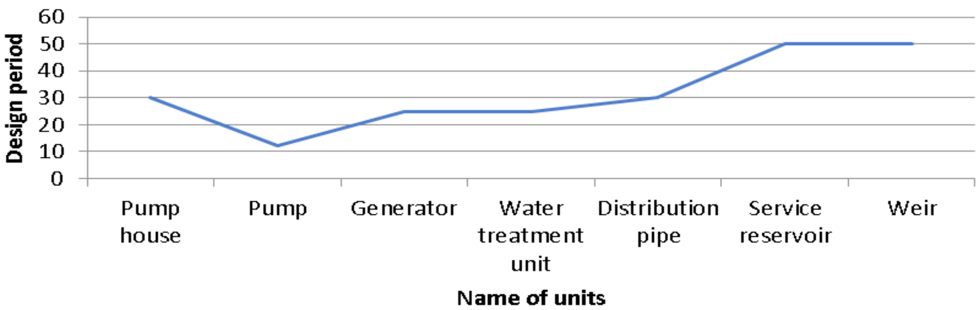

Figure 4. Design periods for various units of water supply.

Water Demand Assessment

Designing water systems involves estimating anticipated water demands, which are essential for sizing transmission, pumping equipment, storage facilities, and distribution pipelines. Estimating water demands for a specific town relies on several factors, including the population size, their lifestyle and activities, the cost of water supply, the wastewater services availability, and the demand purpose. These demands vary depending on the needs of the residential population, institutions, industries, social establishments, etc. Additionally, allowances must be made for factors such as leakage, wastage, and operational needs like mains flushing.[19] Factors influencing water demand in a town include climatic conditions, town size, cultural practices, industrial activities, water cost, water quality, distribution system pressure, supply system, and charging method:

1. *Climatic Conditions:* Water consumption increases during summer due to higher temperatures, increased outdoor activities, and more frequent water usage for hygiene purposes.
2. *Size of the Town:* Larger cities typically have higher water demands per capita compared to smaller towns due to greater infrastructure needs and population density.
3. *Culture of People:* Different socio-economic groups have varying water usage patterns. Higher-income

households tend to consume more water for amenities, while lower-income groups may use water more conservatively.

4. Industries: Industrial areas tend to have higher water demands due to manufacturing processes and cooling systems.

5. Cost of Water: Higher water costs may lead to reduced water demand as consumers become more conscious of their usage.

6. Quality of Water: Consumers prefer systems providing clean and safe water, which influences water demand.

7. Pressure in the Distribution System: Adequate pressure ensures continuous water supply, especially in multi-story buildings, influencing demand.

8. System of Supply: Continuous supply systems may lead to higher water consumption compared to intermittent supply systems due to consumer behavior.

9. Method of Charging: Metered water supplies encourage water conservation as consumers become more aware of their usage and associated costs.

Water demand calculations for a town consider these factors along with available data. In cases where data gaps exist, estimates are made based on similar town profiles and general experiences.(20) The demand of water is divided under the following categories or types of water demand.

- Domestic water demand
- Non domestic demand
- Unaccounted for water

The per capita water demand across different demand categories fluctuates based on factors such as town size, level of development, water supply schemes, socio-economic conditions, water cost, sanitation systems, and climatic conditions. Determining the per capita water demand required for sufficient supply levels entails assessing the fundamental water needs for various activities within each demand category.(15)

Domestic Water Demand Projection

In order to predict the future water needs in Karbala, the following procedures were implemented:

1. Studying how the population is distributed according to the water services they use and forecasting this for the future
2. Determining the amount of water each person will need based on the specific type of water service they utilize
    - Estimating the water usage for each type of water service
    - Accounting for changes in climate
    - Considering socio-economic aspects during the estimation process

Table 2 gives the population data for Karbala city. (14)

Adjustment Factors

1. Adjustment for climate: climate conditions are indeed a primary factor influencing water demand within a population. Hence, water demand calculations should be adjusted to account for variations in climatic conditions. Karbala typically receives around 11,79 millimeters (0,46 inches) of rainfall annually, with 25,9 rainy days (7,1 % of the time), placing it in Group A based on the design criteria. Hence, an adjustment factor of 1,1 was applied as shown in table 4.

2. Socio-economic adjustment factors: the socio-economic adjustment factor is determined by the level of development in the specific town being studied, as socio-economic conditions have a significant impact on water consumption rates. Assessing the current and future development potential of towns involves subjective judgment due to the challenges in quantifying various development aspects (table 5).

Karbala has been designated as a town with high standards of usage and significant development potential, placing it in the Group A category with an adjustment factor of 1.1. By factoring in population changes, service mode adjustments, and per-capita demand, the projected domestic water demands have been calculated and are detailed in the table 6.

3. Non domestic water demand: non-residential water usage was also methodically evaluated and can be broadly categorized into the following main groups:

- *Commercial water demand:* commercial water usage pertains to the water provided to commercial establishments like hotels, butcher shops, retail stores, metal workshops, video rental outlets, vegetable vendors, milling facilities, soft drink distributors, laundry services, tea houses, restaurants, and more.

https://doi.org/10.56294/sctconf20251524

The amount needed can vary significantly based on the city's characteristics and the quantity and types of commercial establishments within it.

Table 2. Population and demand forecasting for Karbala city.

Neighborhood	Population (2024)	Projected Population (2029)	Existing demand (2024)	Predicted demand (2029)
AL Ghadeer quarter /1	16 018	47 829,49	5 606 300	11 957 372,50
AL Ghadeer quarter /2	23 254	69 436,07	8 138 900	17 359 017,50
AL Nasr quarter	8 017	23 938,62	2 805 950	5 984 655,00
Employees quarter	8 095	24 171,54	2 833 250	6 042 885,00
Municipality quarter	2 063	6 160,08	722 050	1 540 020,00
Police quarter	305	910,73	106 750	227 682,50
Karbala University quarter	57	170,20	19 950	42 550,00
Bab AL Shuhada quarter	2 004	5 983,91	701 400	1 495 977,50
Bab AL Najaf	836	2 496,28	292 600	624 070,00
Bab AL Khan	4 350	12 989,03	1 522 500	3 247 257,50
Bab AL Taqa	5 454	16 285,56	1 908 900	4 071 390,00
Bab AL Salam	3 779	11 284,03	1 322 650	2 821 007,50
AL Abbas quarter	5 735	17 124,62	2 007 250	4 281 155,00
AL Hussein quarter /1	3 932	11 740,89	1 376 200	2 935 222,50
AL Hussein quarter /2	3 440	10 271,78	1 204 000	2 567 945,00
AL Amell quarter /1	6 322	18 877,39	2 212 700	4 719 347,50
AL Amell quarter /2	7 517	22 445,64	2 630 950	5 611 410,00
AL Amell quarter /3	4 673	13 953,50	1 635 550	3 488 375,00
AL Naqib quarter	11 282	33 687,87	3 948 700	8 421 967,50
AL Resala quarter	1 553	4 637,23	543 550	1 159 307,50
AL Fars quarter	226	794,27	79 100	198 567,50
AL Zahraa quarter	1 836	5 482,27	642 600	1 370 567,50
Doctors quarter	3 126	9 334,19	1 094 100	2 333 547,50
Industrial quarter	2 358	7 040,95	825 300	1 760 237,50
AL Wafa quarter	3 667	10 949,60	1 283 450	2 737 400,00
AL Shuhada quarter	6 243	18 641,49	2 185 050	4 660 372,50
Teachers quarter	8 351	24 935,95	2 922 850	6 233 987,50
Justice and Health quarter	2 275	6 793,11	796 250	1 698 277,50
Ramadan quarter	3 574	10 671,91	1 250 900	2 667 977,50
AL Bahadalia quarter	6 486	19 367,09	2 270 100	4 841 772,50
AL Shayer quarter /1	1 554	4 640,22	543 900	1 160 055,00
AL Shayer quarter /2	5 220	15 586,84	1 827 000	3 896 710,00

Table 3. Population growth rate

Year	Growth Rate (%)
2012-2018	1,85 %
2018-2024	2,52 %
2024-2029	1,42 %
2029-2035	1,36 %

Table 4. Adjustment factors for climate.[21]

Group	Mean annual PPT(mm)	Factor
A	900 or less	1,1
B	900-1200	1,0
C	1200 or more	0,9

Table 5. Adjustment factor for socio-economic conditions.[22]

Group	Description	Factor
A	Towns with high living standards and significant development potential	1,1
B	Towns with great development potential but lower current living standards	1,05
C	Average towns	1,0
D	Developed rural towns	0,9

Table 6. Projected domestic water demand.

Year	2018	2024	2029	2030	2035
Total Population	1 227 356	1 419 817	1 603 063	1 642 458	1 854 438
Total domestic demand (Lpcd)	350	350	350	350	350
Socio-economic	1,1	1,1	1,1	1,1	1,1
Climatic Factor	1,1	1,1	1,1	1,1	1,1
Total domestic demand (m^3/d)	519 785,27	601 292,50	678 897,18	695 580,96	785 354,49

- *Industrial water demand:* the assessment of industrial water supply needs is typically done separately. In the case of Karbala town, certain industrial sectors are considered part of residential demand. Therefore, the future industrial water requirements are not taken into account at this point (table 7).

Table 7. Anticipated water demand for industrial purposes.

Year	2018	2024	2029	2030	2035
TDD(m^3/d)	519 785,27	601 292,50	678 897,18	695 580,96	785 354,49
% of TDD	15 %	15 %	15 %	15 %	15 %
Industrial water demand(m^3/d)	77 967,79	90 193,88	101 834,58	104 337,14	117 803,17

- *Institutional Water Demand:* the water needed for schools, hospitals, health centers, government offices, religious institutions, and other public facilities is categorized as institutional water demand.
- *Fire Fighting Demand:* firefighting water demand refers to the volume of water needed to combat a fire outbreak. This requirement is influenced by the population size, albeit within a minimum threshold. As population increases, so does the number of buildings, consequently heightening the fire risk. The minimum threshold for firefighting demand denotes the quantity and rate of water supply necessary to extinguish the most extensive potential fire within the community. Importantly, the amount of water required for firefighting will not exceed the volume of water distributed during the peak day of water demand.[23] The volume of water necessary to extinguish a fire is contingent upon factors such as population, building contents, building density, and their fire resistance. In our scenario, firefighting water requirements are addressed by allocating an additional 10 % of the storage reservoir volume specifically for firefighting purposes, without utilizing water from other sources. Consequently, the water needed for firefighting will be supplied by temporarily halting the supply to consumers for the required duration and redirecting it solely for firefighting purposes.[24]

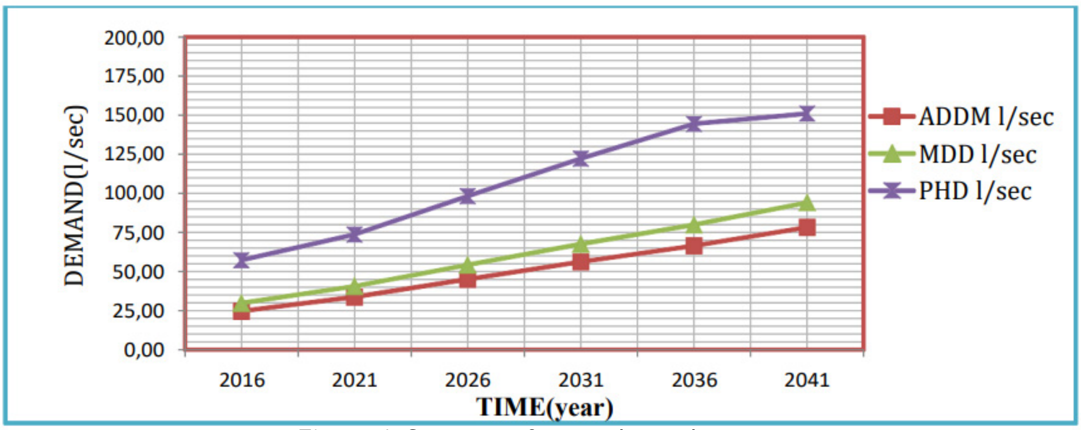

Figure 4. Summary of water demand assessment.

https://doi.org/10.56294/sctconf20251524

DISCUSION

The water resources management in Karbala is facing numerous challenges that require urgent attention and strategic planning. With the increasing population and ongoing urban expansion, the demand for water is rising rapidly, placing significant pressure on the existing water supply systems. The city's current water supply infrastructure is struggling to keep pace with this demand. Approximately 90 % of the population in Karbala relies on alternative water sources, such as private wells and water vendors, due to the inadequate supply from the municipal system. This reliance on non-traditional sources indicates the severity of the water shortage issue in the city.

The primary challenges affecting water management in Karbala are the limited availability of water resources, the rapid population growth, and the aging infrastructure. Karbala's water supply mainly depends on the Euphrates and Al-Hussainya Rivers, but these sources are becoming increasingly stressed due to pollution and overuse from neighboring areas. As the population grows, so does the demand for water, further exacerbating the problem. The existing water treatment plants and distribution networks are not sufficient to meet the city's current and future needs, leading to interruptions in water supply and difficulties in providing consistent service to residents.

To address these issues, a comprehensive water management plan must be put in place. This plan should include upgrading and expanding the existing infrastructure to improve water treatment capacities and increase the efficiency of the water distribution network. Enhancing the water treatment plants or constructing new ones capable of handling the growing demand is essential. Additionally, the distribution networks need to be updated to ensure that all areas, especially the rapidly expanding urban zones, have access to a reliable water supply.

Another important aspect of water management in Karbala is the use of sustainable solutions such as wetland systems to improve water quality. Wetlands can naturally filter and purify water, reducing pollution and improving the overall water quality in both rural and urban areas. These systems could be an effective and environmentally friendly way to address water quality issues in the region.

Furthermore, groundwater management plays a critical role in the long-term water sustainability of Karbala. Since many residents depend on wells for their daily water needs, it is crucial to establish a comprehensive strategy to manage groundwater resources. This involves protecting groundwater from contamination and ensuring that it is not over-exploited, as this could lead to depletion and further exacerbate the water scarcity problem.

Urban planning must also be closely integrated with water resource management to ensure that water systems are prepared for future growth. As Karbala continues to develop, urban planning should account for water availability and ensure that new developments are built with access to adequate water supply systems.

Looking to the future, Karbala's water demand will only increase as the population grows and urban development continues. Therefore, it is essential to invest in the modernization of the water supply system, adopt advanced water treatment technologies, and explore solutions such as water reuse. Collaboration between local authorities and international organizations can also help to ensure the success of water management strategies and promote the sustainable use of water resources in the city.

Managing water resources in Karbala requires a holistic and well-planned approach that addresses the city's growing water needs, improves water infrastructure, and incorporates sustainable practices. By implementing these strategies, Karbala can meet the future demands for water and ensure a sustainable water supply for its residents in the long term.

CONCLUSIONS

Based on survey data from residents, it has been found that Karbala's water supply system currently cannot meet the growing demand due to population growth, urban expansion, and economic development. Approximately 90 % of households rely on private connections, but this is insufficient, leading to water shortages supplemented by wells and water vendors. The existing infrastructure is aging, causing occasional interruptions in supply. Implementing wetland systems for water quality improvement is a sustainable approach to enhance local water management and reduce pollution.[25]

The assessment of risks related to chemical and microbial contaminants is essential for sustainable water management.[26] Given the rising population and infrastructure challenges, planning and executing a new water supply system is urgent. A modeling approach for improving treated water quality compliance is necessary for optimizing treatment processes and enhancing efficiency.[27] The project is planned for a six-year period, divided into two phases: 2025-2030 and 2030-2035, with geometric population forecasting due to limited data from the central statistical authority.

REFERENCES

1. Jury, M., Malmgren, B. A., and Winter, A. Subregional precipitation climate of the Caribbean and relationships with ENSO and NAO. Journal of Geophysical Research: Atmospheres, 2007; 112 (D16).

2. Al-Fatlawi, A. Water quality assessment of Euphrates River within the middle of Iraq. The International Congress Geotunis 2010. 5th Edition.

3. Connor, Richard, The United Nations world water development report 2015: water for a sustainable world. Publishing UNESCO. 2015; 1.

4. Adedeji, Kazeem B. Towards digitalization of water supply systems for sustainable smart city development—Water 4.0. Applied Sciences. 2022; 12.18: 9174.

5. Tutusaus, Mireia, and Klaas Schwartz. Water services in small towns in developing countries: at the tail end of development. Water Policy. 2018; 20.S1: 1-11.

6. Smith, L., Jacob, L., Butler, L., Schuch, F., Barnett, Y., Grabovac, I.,and Tully, M. A. Prevalence and correlates of physical activity in a sample of UK adults observing social distancing during the COVID-19 pandemic. BMJ open sport & exercise medicine. 2020; 6(1), e000850.

7. Christia, Fotini, Elizabeth Dekeyser, and Dean Knox. To Karbala: Surveying Religious Shi'a from Iran and Iraq. 2016

8. Rzóska, Julian, ed. Euphrates and Tigris, Mesopotamian ecology and destiny. Springer Science & Business Media. 2012; Vol. 38.

9. Zimmermann, Michel, and Steve Pye. Inequality in energy and climate policies: Assessing distributional impact consideration in UK policy appraisal. Energy Policy. 2018; 123: 594-601.

10. Al-Anbari, Mohammad Ali, and Yusra Raad Ensaif. Landfill Site Selection in Karbala Governorate, Iraq." Journal of Engineering and Sustainable Development. 2018; 22.6: 30-42.

11. Ali, Kamal K., and Zainab A. Kadham. Evaluate the Climatic Conditions for the Al-Najaf–Ain-Al-Tamur Area (Middle of Iraq). 2018.

12. Kadum, W. H., & Al-Ali, I. A. Climate parameters analysis as an indication of climate Changes for Diwaniya, Nasiriya, Kut and Karbala meteorological stations-Central and southern Iraq: Karbala climate condition as a case study. Iraqi Journal of Science. 2022; 5295-5308.

13. Hassan, F. M., Salman, J. M., & Abdulameer, S. H. Seasonal Variation of Environmental Properties and Phytoplankton Community in Al-Hussainya River, Holly Karbala, Iraq. Mesop. Environ. J. 2014; 1(1), 56-82.

14. Abdul Rasoul, K. S., & Matar, A. J. Natural Development Pillars in the Holy Province of Karbala. International Journal of Sustainable Development & Planning. 2024; 19(10).

15. Mekuriaw, Temesgen, "Analysis of current and future water demand scenario in Yejube town, Ethiopia."International Journal of Advanced Science and Engineering. 2019; 6.02: 1291-1304.

16. Griffin, M. A., & Curcuruto, M. Safety climate in organizations. Annual review of organizational psychology and organizational behavior. 2016; 3(1), 191-212.

17. Alegre, I., Mas-Machuca, M., & Berbegal-Mirabent, J. Antecedents of employee job satisfaction: Do they matter. Journal of Business Research. 2016; 69(4), 1390-1395.

18. Ameyaw, E. E., Pärn, E., Chan, A. P., Owusu-Manu, D. G., Edwards, D. J., & Darko, A. Corrupt practices in the construction industry: Survey of Ghanaian experience. Journal of Management in Engineering. 2017; 33(6), 05017006.

1.

19. Mala-Jetmarova, H., Sultanova, N., & Savic, D. Lost in optimisation of water distribution systems? A literature review of system design. Water. 2018; 10(3), 307.

20. Deng, J., Zhou, F., Hou, W., Silver, Z., Wong, C. Y., Chang, O., & Zuo, Q. K. The prevalence of depression, anxiety, and sleep disturbances in COVID-19 patients: a meta-analysis. Annals of the new York Academy of

https://doi.org/10.56294/sctconf20251524

Sciences. 2021; 1486(1), 90-111.

21. Jasim, W. T., & Altaee, A. H. The Effect of Green Training and Development on Sustainable Performance: An Analytical Research in the Ministry of Environment. Journal of Economics and Administrative Sciences. 2023; 29(138), 1-21.

22. Bronić, M., Ott, K., Petrušić, M., Prijaković, S., & Stanić, B. Budget transparency in Croatian Counties, Cities and Municipalities: November 2022-April 2023. IPF notes. 2023; (123), 1-16.

23. Holuša, J., Fiala, T., & Foit, J. Ambrosia beetles prefer closed canopies: A case study in oak forests in Central Europe. Forests. 2021; 12(9), 1223.

24. Mac Bean, C. S. B., & Ilemobade, A. A Re-evaluation of the South African Guidelines for the Provision of Water for Fire Fighting (Doctoral dissertation, University of the Witwatersrand, Faculty of Engineering and the Built Environment). 2018.

25. Al-Fatlawi, Alaa, Wetland System for Water Quality Improvement in Rural Areas, Second International Conference on Building, Construction and Environmental Engineering - BCEE2, Beirut, Lebanon, October. 2015.

26. Al-Fatlawi, Alaa. Risk assessment concerned to chemical and microbial contaminants of water supply system: case study, 2nd International Conference on "Ecological Theology and Environmental Ethics (ECOTHEE-11), Crete, Greece. 2011.

27. Al-Fatlawi, Alaa, A Modeling Approach Towards Improving Compliance of Treated Water Quality to Reduce Manpower and Chemicals, The Second International Conference on Water Resources and Environmental Management 9–11/4/2013, Geneva, Switzerland.)International Journal of Environmental Monitoring and Analysis, 2013, Vol. 1, 5.

FINANCING
None.

CONFLICT OF INTEREST
None.

AUTHORSHIP CONTRIBUTION
Conceptualization: Nabaa Mahdi Mohammed Ali Al-Saffar, Alaa Hussein Al-Fatlawi.
Research: Nabaa Mahdi Mohammed Ali Al-Saffar, Alaa Hussein Al-Fatlawi.
Methodology: Nabaa Mahdi Mohammed Ali Al-Saffar, Alaa Hussein Al-Fatlawi.
Drafting - original draft: Nabaa Mahdi Mohammed Ali Al-Saffar, Alaa Hussein Al-Fatlawi.
Writing - proofreading and editing: Nabaa Mahdi Mohammed Ali Al-Saffar, Alaa Hussein Al-Fatlawi.