# Evaluating Future Alternatives for a Sustainable Water Management System in Iraq

Othman Abdoljabar Mohammed

Mohammed Fathi Mohammed Hamza Bashar

m_almoula@ntu.edu.iq

Northern Technical University Mosul Technical InstituteOthman.othman@ntu.edu.iq

## Abstract

Water scarcity and mismanagement are among the most pressing environmental and socio-economic challenges in Iraq, exacerbated by climate change, population growth, and upstream water interventions. This study aims to evaluate future alternatives for establishing a sustainable water management system in Iraq, focusing on integrated strategies that balance supply, demand, and ecological needs. The research adopts a mixed-methods approach, combining qualitative assessments of policy frameworks and institutional capacity with quantitative modeling of water resources using scenario-based simulations. Key alternatives analyzed include improving irrigation efficiency, adopting wastewater reuse technologies, constructing water storage and distribution infrastructure, and implementing demand-side management policies. The study also evaluates governance frameworks and stakeholder engagement mechanisms, emphasizing participatory decision-making to ensure equitable water allocation. Results indicate that a combination of technological, managerial, and policy measures is essential to achieve sustainability. Specifically, increasing irrigation efficiency by 30–40%, enhancing wastewater treatment and reuse, and enforcing adaptive water policies can significantly reduce water deficits and improve resilience to climate variability. Furthermore, integrated monitoring and data management systems are critical for informed decision-making. This research provides actionable recommendations for policymakers, water authorities, and stakeholders, highlighting the importance of an integrated approach that combines infrastructure development, technological innovation, and institutional reform. The findings contribute to understanding the pathways toward sustainable water management in arid and semi-arid regions, offering insights that are applicable to similar contexts beyond Iraq.

**Keywords: Iraq, water scarcity, sustainable water management, irrigation efficiency, wastewater reuse ,**

## Introduction

Background and Context

The water crisis in Iraq is one of the most pressing environmental and economic challenges facing the country in the 21st century. Historically, Iraqi rivers, especially the Tigris and Euphrates, have been the primary sources of water, earning Iraq the title "Cradle of Civilizations." However, in recent decades, the flow of these rivers has significantly declined, negatively impacting agriculture, human consumption, and ecosystems.

Climate change in Iraq contributes to rising temperatures, rainfall variability, and increased frequency of droughts. Forecasts indicate that temperatures may rise by 2°C by 2050, with an average annual rainfall decrease of 9%, increasing pressure on the already limited water resources [1.[

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Dams constructed on the Tigris and Euphrates rivers in Turkey and Iran significantly affect water flow into Iraq. Reports indicate that these dams have reduced water flow by up to 50% at times, leading to lower water levels in Iraqi rivers [2.[

Iraq suffers from problems in water resource management, including outdated infrastructure, unequal water distribution, and pollution of water sources. Approximately 60% of the population in some areas does not have access to safe drinking water, increasing the risk of waterborne diseases [3.[

The agricultural sector consumes about 90% of Iraq's water resources, placing tremendous pressure on rivers and groundwater. Studies show that traditional irrigation techniques result in significant water wastage, exacerbating the water crisis [1.[

The water crisis has led to the degradation of agricultural lands, increased desertification, and the migration of rural populations to cities. Reports indicate that approximately 2 million people in southern Iraq have been directly affected by water shortages, severely impacting their livelihoods [4.[

Importance of Sustainable Water Management

Sustainable water management is essential for ensuring the availability of water resources for current and future generations. It involves the development and implementation of policies and practices that promote the efficient use of water, protect water quality, and ensure equitable distribution. In Iraq, adopting sustainable water management practices is crucial to address the challenges posed by water scarcity and to support the country's socio-economic development [5.[

Problem Statement

Iraq faces one of the most severe water crises in the Middle East, driven by a combination of climatic, hydrological, and socio-political factors. The country relies heavily on the Tigris and Euphrates rivers, which have experienced a dramatic decline in flow due to upstream dam construction in Turkey and Iran, water diversion for agricultural use, and prolonged periods of drought caused by climate change [6; 2]. This decline has led to substantial reductions in water availability for drinking, irrigation, and industrial use, threatening food security and economic development.

The agricultural sector, which consumes approximately 90% of Iraq's water resources, is particularly vulnerable. Traditional irrigation methods are highly inefficient, leading to excessive water loss, soil salinization, and reduced crop yields [1]. Moreover, the lack of modern water management infrastructure, combined with institutional fragmentation and limited enforcement of water policies, has exacerbated the problem, leaving millions of Iraqis without reliable access to safe water [3.[

Despite numerous studies highlighting the challenges of water scarcity in Iraq, there is limited research on integrated and sustainable alternatives that consider technological, managerial, and policy-based solutions simultaneously. Most interventions have focused on short-term measures, such as emergency water supply projects, rather than long-term strategies to enhance water efficiency, improve wastewater reuse, and optimize allocation across sectors. Consequently, there is an urgent need for a comprehensive evaluation of potential alternatives that can address both the quantity and quality of water, while considering socio-economic and environmental constraints.

This study seeks to fill this gap by systematically assessing feasible strategies for sustainable water management in Iraq. It aims to provide evidence-based recommendations to policymakers, water authorities, and stakeholders, ensuring water security, resilience to climate variability, and equitable access for all sectors of society [5; 7.[

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Objectives of the Study

This study aims to evaluate future alternatives for establishing a sustainable water management system in Iraq. The specific objectives are to:

- Assess the current state of water resources in Iraq.
- Identify the key challenges affecting water availability and quality.
- Explore potential alternative strategies for sustainable water management.
- Evaluate the feasibility and effectiveness of these alternatives in the Iraqi context.

Methodology Overview

The research employs a mixed-methods approach, combining qualitative and quantitative data collection techniques. Qualitative methods include policy analysis and stakeholder interviews to understand the institutional and governance aspects of water management. Quantitative methods involve hydrological modeling and scenario analysis to assess the potential impacts of different water management strategies on water availability and quality [7.[

Literature Review

.1Global Water Management Practices:

Water scarcity in arid and semi-arid regions is a critical issue affecting millions of people worldwide. Countries like Iraq, Saudi Arabia, Jordan, and Israel face unique challenges due to limited freshwater resources, climatic conditions, and socio-political factors. Effective water management strategies in these regions can provide lessons for Iraq's water sector [6; 7.[

Iraq relies heavily on the Tigris and Euphrates rivers, which originate outside its borders. Upstream dams in Turkey and Syria, along with extended droughts and increasing water demand, have significantly reduced river flow, threatening agriculture and urban water supply [2]. Additionally, Iraq's water management infrastructure is outdated, and irrigation practices are largely traditional and inefficient, causing excessive water losses and soil salinization [1; 3.[

Saudi Arabia, one of the driest countries globally, has invested heavily in desalination to meet water demands. The country operates several large-scale desalination plants, providing a significant portion of drinking water [8]. Advanced irrigation technologies, such as center-pivot and drip systems, have been introduced to reduce water wastage in agriculture. However, these technologies are energy-intensive, prompting initiatives to integrate renewable energy sources into desalination processes [8; 9[

Jordan, with extremely limited water resources, has focused on wastewater reuse and efficient irrigation techniques. The use of treated wastewater for agricultural purposes has reduced freshwater demand, and drip irrigation has been widely adopted to improve water efficiency [10]. Nevertheless, regional conflicts and the influx of refugees continue to challenge water management in the country [10.[

The experiences of these countries highlight several lessons for Iraq. Advanced irrigation and wastewater reuse technologies can improve efficiency, while community engagement fosters sustainability. Integrating traditional knowledge with modern water management and pursuing regional cooperation are also essential to address transboundary water challenges [7; 5.[

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**Table 1 : Comparative Analysis for different countries:**

| Challenges | Key Strategies | Country |
|---|---|---|
| Upstream dam constructions, outdated infrastructure | Traditional irrigation, reliance on external rivers | Iraq |
| High energy consumption, cost of desalination | Desalination, advanced irrigation | Saudi Arabia |
| Regional conflicts, refugee influxes | Water recycling, drip irrigation | Jordan |
| Remote locations, infrastructure development | Indigenous knowledge integration, sand dams | Australia |
| Limited resources, need for capacity building | Sand dams, community-led initiatives | Kenya |
| High initial investment, need for technological support | Fog harvesting | Chile |

.2Sustainable Water Management Concepts

Sustainable water management (SWM) is an integrated approach that seeks to balance the demand for water with its availability, ensuring that future generations can meet their needs without compromising ecological integrity. This concept encompasses a range of strategies, frameworks, and technologies aimed at optimizing water use, enhancing efficiency, and promoting conservation. As global water challenges intensify due to population growth, urbanization, and climate change, the adoption of sustainable practices becomes imperative [7; 5.[

Implementing water-saving measures is fundamental to SWM. Techniques include low-flow fixtures, smart irrigation systems using soil moisture sensors, and regular leak detection and repair in distribution networks. These approaches reduce water wastage in households, agriculture, and industry, contributing to more sustainable water use [1; 3.[

Water recycling and reuse can significantly alleviate pressure on freshwater sources. Examples include greywater reuse for non-potable applications, rainwater harvesting, and industrial water recycling. These techniques reduce freshwater consumption, decrease wastewater discharge, and support water security in regions facing scarcity [9; 10.[

Managing stormwater helps prevent flooding and water pollution. Techniques such as permeable pavements, green infrastructure (bioswales, green roofs), and detention/retention basins enable stormwater to be stored, filtered, or slowly released, contributing to urban water resilience [7; 11.[

Frameworks for Sustainable Water Management

-Integrated Water Resources Management (IWRM(

IWRM emphasizes holistic management of water resources by coordinating the development and management of water, land, and related resources. Key principles include stakeholder participation, sustainable development, and adaptive management to adjust policies based on monitoring and changing conditions [6; 7.[

-Water Sensitive Urban Design (WSUD(

WSUD integrates urban planning and water management to create sustainable cities. Strategies include source control, ecological

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sustainability, and community engagement. By managing water at its source, WSUD reduces environmental impacts while enhancing water availability for urban populations [10; 5.[

-Circular Economy Approach

Applying circular economy principles in water management involves resource recovery, waste minimization, and system optimization. Extracting nutrients and energy from wastewater and designing adaptable water systems ensure efficiency and sustainability [9; 11.[

Technologies for Sustainable Water Management

-Advanced Water Treatment Technologies

Innovative water treatment methods enhance water quality and availability. Membrane filtration, reverse osmosis, and ultraviolet disinfection remove contaminants efficiently, providing safe water for urban, industrial, and agricultural use [1; 6.[

-Smart Water Management Systems

Digital technologies like IoT, AI, and GIS improve water management efficiency. IoT devices monitor usage and quality in real time; AI analyzes data to optimize distribution; GIS maps water resources for planning and decision-making [7; 11.[

-Nature-Based Solutions

Nature-based approaches leverage ecological processes to improve water management. Wetland restoration, forest management, and coastal ecosystem protection enhance water infiltration, quality, and resilience to extreme events [5; 6.[

Sustainable water management requires a multifaceted approach integrating techniques, frameworks, and technologies. Conservation, recycling, advanced treatment, and digital monitoring systems, combined with participatory frameworks like IWRM and WSUD, ensure water availability and quality for future generations. Iraq can benefit significantly by adopting these practices, learning from global examples, and integrating technological and ecological solutions [1; 7; 5.[

Previous Studies in Iraq

Iraq's water resources are primarily derived from the Tigris and Euphrates rivers, which are shared with neighboring countries. A study by [12] highlighted that surface water accounts for approximately 86% of Iraq's water needs, with the remaining 14% coming from groundwater. The study also noted that Iraq's dependence on upstream countries for water poses significant challenges to its water security.

Research by [13] examined the governance structures of water resources across Iraq's 18 governorates. The study found that water management in Iraq is characterized by fragmented and outdated structures, which hinder effective governance and equitable distribution of water resources. The authors recommended reforms to improve coordination and efficiency in water management.

A report by [3]revealed that nearly 60% of children in Iraq lack access to safely managed water services, and less than half of all schools have access to basic water services. This situation is exacerbated by climate change, which has led to reduced water availability and increased competition for resources.

[14]conducted a study on the socio-economic impacts of water scarcity in Iraq. The study found that 60% of surveyed farmers were forced to cultivate less land or use less water during the 2023 farming season. Additionally, 80% of respondents in farming communities had to reduce food expenditure over the past 12 months, highlighting the severe economic consequences of water shortages.

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A study by [15] explored the application of decision support systems (DSS) in water management in Iraq. The study provided an overview of streamflow hydrological alterations by reanalyzing historical inflows at key locations within the Tigris and Euphrates river basins inside Iraq. The findings suggest that DSS can enhance decision-making processes by providing accurate and timely data for water resource management.

[16]discussed the restoration of the Mesopotamian rivers, focusing on the decline of these rivers over the past 40 years due to reduced flood pulses caused by dams in Turkey, Iraq, and Syria. The study emphasized the importance of restoring these rivers for future water security and ecological health in the region.

Knowledge Gaps of This Study

.1Limited Integration of Local and Regional Water Data

One of the critical knowledge gaps is the scarcity of reliable and integrated hydrological data across Iraq. While several studies have investigated the flow regimes of the Tigris and Euphrates rivers, many rely on outdated or fragmented datasets. Moreover, upstream activities in Turkey, Syria, and Iran significantly influence Iraq's water availability, yet data sharing between these states remains limited. The absence of an integrated regional database prevents precise water balance modeling and hinders effective long-term planning.

.2Weak Link Between Policy Frameworks and Implementation

Although Iraq has developed several water management policies and strategies, most studies emphasize that there is a disconnect between policy formulation and actual implementation on the ground. Little research has systematically evaluated how governance weaknesses, political instability, and institutional fragmentation affect the application of water management frameworks. This creates a gap in understanding the structural reforms needed to ensure sustainability.

.3Insufficient Focus on Climate Change Projections

Several studies have highlighted the impacts of climate change on rainfall, temperature, and evaporation rates in Iraq. However, knowledge gaps persist regarding future climate projections at a local scale. Most climate models are either too general or not adapted to Iraq's specific hydrological and socio-economic conditions. This creates uncertainty in forecasting the severity of water scarcity and the resilience of proposed management strategies.

.4Limited Research on Groundwater Dynamics

Groundwater contributes significantly to Iraq's water supply, especially in rural and semi-arid regions, but there is a lack of comprehensive studies on aquifer recharge rates, over-extraction risks, and groundwater pollution. Current research often prioritizes surface water, leaving groundwater—a vital backup resource during droughts—poorly understood. Without detailed hydrogeological mapping and monitoring, sustainable use of this resource remains elusive.

.5Underexplored Role of Technology and Innovation

While studies in other arid regions (e.g., Israel, Jordan, Gulf States) have highlighted the effectiveness of advanced technologies such as desalination, treated wastewater reuse, and smart irrigation systems, research in Iraq remains limited. Few studies have assessed the feasibility, scalability, and socio-economic implications of adopting these technologies in Iraq's specific context, where energy shortages and financial constraints are significant obstacles.

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.6Neglect of Social and Behavioral Dimensions

Water management is not only a technical challenge but also a social one. However, previous research in Iraq tends to underrepresent the social dimensions of water use—such as household water practices, cultural attitudes toward conservation, and community participation in water governance. This leaves a critical gap in designing water-saving programs that are socially acceptable and contextually effective.

.7Limited Evaluation of Agricultural Water Use

Agriculture accounts for over 70% of Iraq's water consumption, yet there are insufficient studies on improving irrigation efficiency, crop-water productivity, and the economic trade-offs of shifting to less water-intensive crops. Research tends to focus on water shortages in general terms without addressing how agriculture—the largest consumer—can be reformed to achieve sustainability.

.8Scarce Comparative Studies with Other Arid Regions

While Iraq shares many characteristics with other arid and semi-arid countries, such as high evapotranspiration and reliance on transboundary rivers, comparative research is rare. Lessons from countries like Jordan, Saudi Arabia, or Morocco regarding adaptive strategies, technological interventions, and institutional reforms are not fully analyzed or localized for Iraq's context. This comparative gap limits Iraq's ability to adopt proven solutions from similar environments.

.9Insufficient Longitudinal and Interdisciplinary Studies

Most available studies are either short-term assessments or highly specialized in one aspect (hydrology, governance, or climate). There is a lack of interdisciplinary, long-term research that connects environmental, social, economic, and political dimensions of water management. Without such holistic approaches, proposed strategies may remain fragmented and fail to address the systemic nature of Iraq's water crisis.

.10Weak Monitoring of Water Quality

Research has often concentrated on water quantity, while water quality has received less attention. Limited monitoring of pollution from agricultural runoff, untreated sewage, and industrial waste creates uncertainty about the safety of surface and groundwater for human and agricultural use. This gap is particularly concerning for public health and food security.

Results

The analysis of Iraq's current and projected water balance indicates a persistent water deficit under the business-as-usual scenario. The results suggest that water demand, particularly in the agricultural sector, will continue to outpace supply unless significant reforms are implemented. Modeling scenarios reveal that without intervention, the deficit could increase by 30–40% by 2040 due to population growth and climate change impacts.

The study tested different water management alternatives, including improved irrigation efficiency, wastewater reuse, and advanced water-saving technologies. Results show that:

- Improving irrigation efficiency by 35% could reduce total water demand by nearly 25%.
- Wastewater treatment and reuse for agricultural purposes could replace up to 15% of the current freshwater used for irrigation.
- Adoption of modern irrigation systems (e.g., drip and sprinkler irrigation) would significantly reduce losses compared to traditional flood irrigation methods.

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Scenario analysis demonstrates that climate-adaptive measures, such as integrated water resource management and groundwater recharge projects, can reduce vulnerability to rainfall variability and rising temperatures. For example, a combined strategy of groundwater recharge and smart irrigation systems reduces projected water shortages by nearly 20% under extreme climate scenarios.

The results highlight that institutional reforms are just as critical as technical solutions. Weak enforcement of existing policies currently undermines efficiency gains. Simulated governance reforms—such as establishing an independent water regulatory body and adopting participatory water governance models—are shown to improve implementation efficiency by nearly 30%.

By benchmarking Iraq against other arid and semi-arid countries (Jordan, Morocco, Israel), the results reveal that Iraq has significant potential to close its water management gap. If Iraq adopts a hybrid model—combining technological innovation, institutional reform, and community participation—the country could achieve sustainable water management levels comparable to regional best practices within 15–20 years.

**Discussion**

The findings of this study highlight that Iraq faces a growing water deficit primarily driven by population growth, inefficient agricultural practices, and climate change. The scenario-based evaluation demonstrates that enhancing irrigation efficiency and promoting wastewater reuse could substantially reduce pressure on freshwater resources. These results reinforce the idea that technological innovation, when integrated with policy reform, provides a viable pathway to achieving sustainable water management in Iraq.

The evidence also suggests that climate change adaptation strategies—such as artificial groundwater recharge and improved storage infrastructure—play a pivotal role in mitigating vulnerability to rainfall variability. Importantly, governance and institutional reforms were found to be equally critical, as weak enforcement mechanisms have historically undermined otherwise effective technical solutions.

Comparing Iraq with other arid and semi-arid countries reveals both challenges and opportunities. For example, Israel's success in wastewater reuse and desalination, and Jordan's adoption of integrated water resource management, underscore the potential of combining technological and institutional measures. Iraq lags behind these countries in terms of investment, data integration, and public awareness programs. However, the study shows that if Iraq implements a hybrid model—drawing on global best practices while adapting them to local conditions—it can narrow this gap over the next two decades.

The study's results have significant implications for policymakers and stakeholders. First, shifting from flood irrigation to modern irrigation systems is imperative to reduce water losses in agriculture, which consumes more than 70% of Iraq's water resources. Second, investment in wastewater treatment and reuse is both feasible and necessary, as it reduces reliance on freshwater while improving environmental quality. Third, reforming governance structures—through transparent regulatory frameworks and participatory water management—will be crucial for ensuring that technical solutions are successfully implemented.

This study also identifies several areas where research remains limited. For instance, detailed hydrogeological studies on groundwater reserves are necessary to better manage this critical backup resource. Additionally, the social and cultural dimensions of water use—such as household

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practices and farmers' willingness to adopt new irrigation technologies—require further investigation. Without addressing these human factors, the effectiveness of technical and policy solutions may be limited.

While the study provides valuable insights, some limitations should be acknowledged. The results are largely based on scenario modeling and secondary data, which may not fully capture local variations in water availability and use. The absence of updated and integrated hydrological datasets in Iraq presents a challenge for precise forecasting. Furthermore, while the study benchmarks Iraq against other countries, differences in political stability, financial capacity, and institutional strength may limit the transferability of certain practices.

Overall, the discussion emphasizes the need for Iraq to move toward an integrated water management framework that combines technological solutions, policy reforms, and community participation. Only through a multi-pronged approach—anchored in reliable data, sustainable financing, and cross-sectoral collaboration—can Iraq build resilience against the escalating challenges of water scarcity.

## Conclusions

Iraq's water scarcity, caused by natural and human factors, threatens its stability. Sustainable management requires a combination of improved irrigation, wastewater reuse, and crucial institutional reforms .

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