



RESEARCH ARTICLE

SUSTAINING IRAQ'S HIDDEN RESOURCE: A REVIEW OF THE STRATEGIES FOR EFFECTIVE GROUNDWATER MANAGEMENT

Layth Abdulameer^a, Ala Hassan Nama^b, Muthanna M. A. AL-Shammari^a, Najah M. L. Al Maimuri^c, Farhan Lafta Rashid^a, Ahmed N. Al-Dujaili^{d*}

^aPetroleum Engineering Department/ College of Engineering/ University of Kerbala, Kerbala 56001, Iraq.
^bDepartment of Water Resources Engineering/ College of Engineering/ University of Baghdad, Baghdad, Iraq.
^cBuilding and Construction Technologies Engineering Department, College of Engineering and Engineering Technologies, Al-Mustaqbal University, Babylon, Hillah, 51001, Iraq.
^dPetroleum Engineering Department/ Amirkabir University of Technology, No. 350, Hafez Ave, Valiasr Square, Tehran, Iran 1591634311.
^{*}Corresponding Author Email: ahmed.noori203@aut.ac.ir

This is an open access journal distributed under the Creative Commons Attribution License CC BY 4.0, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited

ARTICLE DETAILS

Article History:

Received 23 December 2024
Revised 03 January 2025
Accepted 18 January 2025
Available online 08 March 2025

ABSTRACT

Groundwater has become a vital resource for domestic, agricultural, and industrial use, especially as surface water supplies decline due to reduced rainfall, decreasing river flows, and increasing evaporation. This study reviews the critical state of groundwater resources in Iraq, focusing on challenges such as over-extraction, contamination, and the worsening effects of climate change on water availability. The review highlights the urgent need for a comprehensive monitoring and assessment framework to track groundwater levels and quality, utilizing real-time data on aquifer health, water table depth, and contamination. It also emphasizes the importance of implementing sustainable groundwater management practices tailored to the unique geological and Iraqi aquifer hydrological conditions. A key recommendation is adopting a participatory approach to groundwater management, engaging local communities, water users, and stakeholders in decision-making. This approach aims to promote ownership, accountability, and sustainable practices while promoting equitable resource management. The study also stresses addressing infrastructure and institutional challenges, including inadequate storage, poor regulation, and lack of coordination among authorities. Furthermore, the research calls for incorporating climate change considerations, such as altered precipitation patterns and rising temperatures, into long-term groundwater management strategies to adapt to changing environmental conditions. In conclusion, a collaborative approach combining scientific research, effective governance, community engagement, and climate adaptation is essential to ensure the long-term sustainability of Iraq's groundwater resources, supporting food security, economic development, and resilience against increasing water scarcity.

KEYWORDS

Water table depth, Over-extraction, Contamination, Worsening effects of climate change

1. INTRODUCTION

Droughts are a natural element of the hydrological cycle, but their occurrence and intensity have grown recently. These dry spells can have profound socioeconomic, environmental, and political consequences, particularly in arid and semi-arid areas that are most at risk from the negative effects of excessive groundwater depletion (Petersen-Perlman et al., 2022; Long et al., 2020). Groundwater systems are often categorized as either renewable or non-renewable, based on factors like natural recharge rates or estimates of aquifer storage and groundwater residence time (Cuthbert et al., 2023). However, the capture concept -how pumping affects recharge and discharge - complicates these straightforward classifications (Bairami et al., 2024). As a result, a groundwater system cannot be inherently renewable or non-renewable; its classification depends on the specific manner in which the groundwater is being utilized (Shuvo et al., 2024). Groundwater potential, from the standpoint of storage and extraction, refers to the highest volume of water that can be drawn from an aquifer without undermining the long-term recharge capacity of the watershed (Huang et al., 2024). Mapping groundwater potential is a highly effective technique for evaluating this capacity, taking into account

a range of factors that influence groundwater conditions. These factors include topography, geology, hydrology, hydrogeology, climate, and land cover (Zerouali et al., 2024). Groundwater models (GWMs) offer valuable insights into the volume and sources of water entering an aquifer, the preferential flow pathways, the potential consequences of groundwater extraction, and a comprehensive range of hydro-chemical characteristics if solute transport is incorporated into the model (Altimiras Granel, 2024) . These models are essential tools for water resource evaluations, calculating sustainable yields, conducting environmental impact assessments, and managing water resources in an integrated manner (Doost et al., 2024). Among the various computational tools available for simulating groundwater systems, MODFLOW stands out as one of the most widely adopted and internationally recognized models (Nguyen et al., 2024).

Groundwater represents a critical lifeline for Iraq, a nation grappling with water scarcity exacerbated by climate change and upstream dam construction (Al-Ansari et al., 2023). The Tigris and Euphrates rivers and their affluents used to be the major sources of water in Iraq, but their discharge has been declining since the 1970s because of all these reasons

Quick Response Code		Access this article online	
		Website: www.watconman.org	DOI: 10.26480/wcm.01.2025.120.131

(Al-Ansari, 2021; Al-Ansari, 2013). This decline has shifted significant pressure onto groundwater resources, making them the primary water source for domestic, agricultural, and industrial needs (Hassan et al., 2023; Hashim et al., 2024). Based on history, groundwater use can be attributed to going back a long time, especially in arid and semi-arid regions, where people relied on underground water due to a lack of surface water (Al-Rubaie and Al-Kubaisi, 2024). However, this has not been well managed for some time, thus giving rise to some of the problems that need to be combatted (Mawlood, 2019; Al-Jawad et al., 2019). In light of this, there cannot be a better option for food production than groundwater, as it plays an important role in the food security of Iraq, as highlighted by the agricultural industry (Qureshi and Al-Falahi, 2015). Other authors have established that groundwater quality is heterogeneous by region, highlighting the need for region-specific management strategies (Ismael et al., 2020).

Achieving sustainable management of the groundwater resource in Iraq entails a more rigorous and increased use of quantitative and qualitative assessment of the water. Open access and excessive exploitation due to growing human and livestock populations and additional requirements for agriculture have led to the conspicuous lowering of the water table in some areas. This unsustainable use is further compounded by the deterioration of water quality from underground sources due to pollution from various sources (Al-Abadi, 2015). Many of these sources of water have high levels of salinity, posing a threat to agricultural productivity in many regions (Dallas and Hasson, 2006). Industrial activities and poor management of waste pollution contaminate water sources (Aziz and Hussain, 2023). The effect of climate has, therefore, contributed to issues of precipitation and losses due to evaporation (Nanekely et al., 2019; Khaled, S., Gmail, I., and Abd-Elaty, 2023). The key insight deduced from the analysis is that outlining protection areas around strategic springs is a way to avoid contamination threats. For example, the Saruchawa, Qulai Rania, and Qulai Kanimaran springs in Iraqi Kurdistan have been categorized into vulnerability zones to prioritize protection efforts (Ata et al., 2024). Solving such complex issues requires a proactive approach that factors scientific enlightenment, technological advancement, and sound administration (Ali et al., 2017; Shakoor et al., 2017).

This study delves into the alarming state of groundwater resources in Iraq, shedding light on the significant challenges that have emerged due to excessive extraction, contamination, and the growing threat of climate change. It explores how the overuse of groundwater for agricultural, industrial, and domestic purposes has led to severe depletion of water levels. In addition, the article examines the widespread pollution from agricultural runoff, industrial waste, and inadequate waste management, which further compromises water quality. The impacts of climate change, such as rising temperatures, reduced rainfall, and increased evaporation, are also discussed, as well as their contribution to diminishing water availability, exacerbating the country's water scarcity crisis.

The research uses what is available in the literature to stress the importance of functioning management practices. Figure 1 shows the factors influencing groundwater management in Iraq.

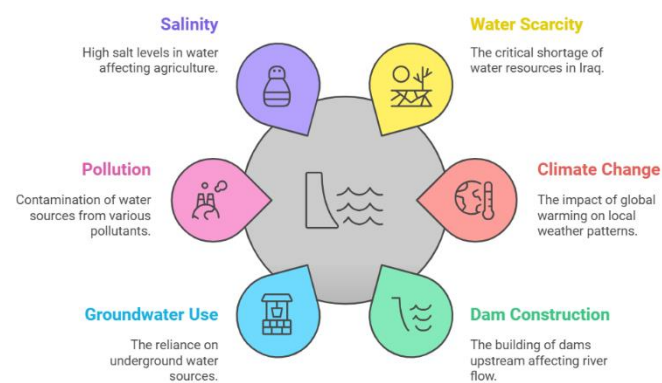


Figure 1: Factors influencing Groundwater management in Iraq

2. THE CURRENT STATE OF GROUNDWATER IN IRAQ

2.1. Overview of Groundwater Resources

In Iraq, the depth of the groundwater table varied within the qualifiers ranging from less than 1 m to more than 700 m below the ground surface, Figure 2 (Al-Jiburi, H. K., and Al-Basrawi, N. H., 2015). Some of the groundwater naturally flows out through springs.

In Iraq, the age of aquifer systems is between Quaternary and Paleozoic. These systems are mainly formed of sedimentary rocks to a depth of 1000 m. Iraq's hydrological formation are classified into two regions; Nubio-Arabian and Taurus Zagros (Khafaji et al., 2022). According to the physiological, structural, geological, and hydrogeological characteristics, these two hydrological regions are divided into seven hydrogeological zones: The Mesopotamian Foredeep (Mesopotamian), Low Folded Zone, High Folds Zone, Suture and Thrust Zone, Al-Jazira Zone, Western Desert Zone, and Southern Desert Zone (Figure 3). The groundwater aquifers in Iraq, their location, types, and geological formation are summarized in Table 1.

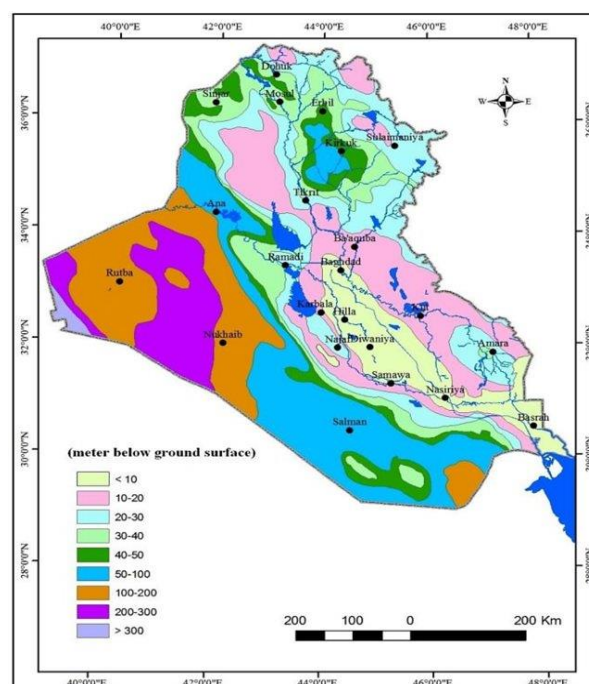


Figure 2: Depth of groundwater in Iraq (Al-Jiburi and Al-Basrawi, 2015).



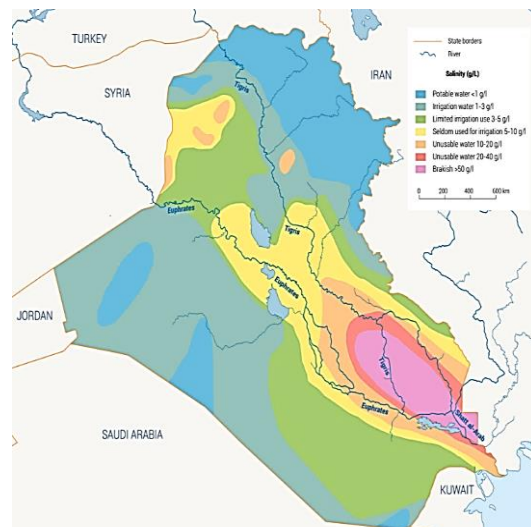
Figure 3: Hydrogeological Zones of Iraq (Jassim and Goff, 2006).

Table 1: Groundwater aquifers in Iraq and their characteristics, Based on (Al-Zubedi, 2022 Al-Zubedi A. S., 2022; Khafaji et al., 2022; Jassim and Goff, 2006; Saleh et al., 2020; Alattar, 2024).

Aguifer	Type of Aquifer	Location	Water Bearing Strata
Qamchuqa	Confined	High Folded Zone	Karstic Fracture Carbonate Rocks
Tayarat	Confined	Western and Southern Desert	Karstic Fracture Carbonate Rocks
Kometan	Confined	High Folded Zone	Karstic Fracture Carbonate Rocks
Hartha	Confined	Western Part of the Western Desert	Karstic Fracture Carbonate Rocks
Suffi	Confined	Northwestern Parts of the Western Desert	Sandstone and Carbonate Rocks
Umm Er Radhuma	Mostly Confined	Western and Southern Desert	Karstic Fracture Carbonate Rocks
Akashat Equivalent of Umm Er Radhuma	Mostly Confined	Western Part of the Western Desert	Karstic Fracture Carbonate Rocks
Mulussa	Mostly Confined	Western Part of the Western Desert	Karstic Fracture Carbonate Rocks
Ga`ara	Mostly Confined	Western Part of the Western Desert	Sandstones
Bai Hassan (Upper Bakhtiari)	Partly Confined	Low Folded Zone and Mesopotamia Zone	Sandstone
Mukdadia (Lower Bakhtiari)	Partly Confined	Low Folded Zone and Mesopotamia Zone	Pebbly Sandstone, Sandstone and Siltstone
Char Equivalent of Euphrates	Partly Confined	Southeastern Part of the Southern Desert	Sandstone, Pebbly Sandstone and Limestone
Pila Spi	Partly Confined	High Folded Zone, Low Folded Zone	Karstic Fracture Carbonate Rocks
Sinjar	Partly Confined	High Folded Zone and Low Folded Zone	Karstic Fracture Carbonate Rocks
Khurmala Equivalent of Sinjar	Partly Confined	High Folded Zone and Low Folded Zone	Karstic Fracture Carbonate Rocks
Sarmord	Partly Confined	High Folded Zone	Karstic Fracture Carbonate Rocks
Dokan	Partly Confined	High Folded Zone	Karstic Fracture Carbonate Rocks
Aqra- Bekhme	Partly Confined	High Folded Zone and Low Folded Zone	Karstic Fracture Carbonate Rocks
Alluvium	Mostly Unconfined Semi-Confined or Confined	Most parts of Iraq	Gravel, Sand and Silt
Dibdbba	Mostly Unconfined	Southeastern Part of the Southern Desert and Karbala – Najaf Plateau	Pebbly Sandstone and Sandstone
Injana (Upper Fars)	Mostly Unconfined	Low Folded Zone, Al- Jazira Zone and Northeastern Part of the Western Desert	Sandstone and Siltstone
Fatha (Lower Fars)	Mostly Unconfined	Low Folded Zone, Al- Jazira Zone and Northeastern Part of the Western Desert	Karstic Fracture Carbonate Rocks
Euphrates	Mostly Unconfined	Al-Jazira Zone and Middle Part of the Western Desert	Karstic Fracture Carbonate Rocks
Dammam	Mostly Unconfined	Western and Southern Desert	Karstic Fracture Carbonate Rocks
Rutbah	Unconfined	Western Part of the Western Desert	Sands and Sandstone
Muhaiwir	Unconfined	Western Part of the Western Desert	Karstic Fracture Carbonate Rocks

The sources of groundwater recharge are mainly composed of infiltrated water from precipitation river water and irrigation water. The main recharge zone is located in northern Iraq, with a recharge rate of around 250 mm/yr. However, this recharge rate decreases in the south of Iraq to be negligible (≤ 20 mm/yr) (Bundesanstalt et al., 2013. Based on this recharge, the expected total annual sustainable groundwater yield by 2035 is around 5×10^9 m³/yr, which represents about 9% of the freshwater sources, with an increase of 1.5×10^9 m³/yr for all the aquifers systems (Alwash et al., 2018).

On the other hand, the quality of groundwater in Iraq varies greatly across the aquifers (Figure 4). While most of the areas with good groundwater quality are concentrated in the north and north-east of Iraq, the quality of groundwater in central Iraq, especially the middle Euphrates, and southern Iraq along the Tigris and Euphrates rivers, is limited to poor quality and unsuitable for use even for agricultural purposes.

**Figure 4:** Distribution of groundwater quality in Iraq Based on (Al-Jiburi, and Al-Basrawi, 2015; Alattar, 2024).

More studies are needed to systematically document and describe these aquifers' area and permeability characteristics (Vakili et al., 2024). It is important to establish long-term sustainable extraction strategies to enhance minimal exploitation. Carbonate formations in the Upper Cretaceous and partly karstified formations in Judea and Samaria are also important water sources. Correspondingly, a large part of the water consumption is extracted from these aquifer systems annually (Al-Dujaili, 2024).

2.1. Overview of Groundwater Resources

Iraq has several significant aquifers that supply a large portion of the country's water needs (Khayyun and Mahdi, 2020). These aquifers vary in physical composition, depth, and coverage; some are more vulnerable to depletion or contamination than others (Abdul-Hameed and Hatem, 2021). These major aquifers' recharge rates, storage capacity, and water quality are particular features, so evaluation before planning management strategies is required. Further research is needed to systematically document and describe the characteristics of aquifer areas and their permeability (Faysal, 2013). It is important to establish long-term sustainable extraction strategies to enhance minimal exploitation. Carbonate formations in the Upper Cretaceous and partly karstified formations in Judea and Samaria are also important water sources. Correspondingly, a large part of the water consumption is extracted from these aquifer systems annually (Eckstein and Eckstein, 2003).

2.2. Challenges Facing Groundwater Management

Several significant challenges hinder effective groundwater management in Iraq:

2.2.1. Over-extraction and Depletion

One of the ways is the direct use of water for food production, especially by irrigation, which has caused many areas to over-extract the aquifer, thus depleting it (Qureshi and Al-Falahi., 2015; Bierkens and Wada, 2019). The increase of irrigated areas in semi-arid regions and low water-use efficiency in irrigation systems have worsened this issue (Qureshi and Al-Falahi., 2015;Bhatia and Singh, 2023). According to some research, the ratio of the volumes used for groundwater extraction is far beyond the volume of the natural recharges in some regions, exacerbating the depletion problem (Nanekely et al., 2019). The impacts of this over-extraction are reduced in the amount of water table, subsidence of soil, and poor crop yields. Therefore, assessing the prevalence and geography of over-extraction and its impact will require more hydrogeological studies and mapping (Shakoor et al., 2017). Solving this challenge calls for efficient conservation irrigation methods, better water management, and control of excessive and unsustainable water pumping from underground sources. Besides, reaching a broad consensus on the guidelines for the nation's groundwater rehabilitation strategies is a necessity.

2.2.2. Pollution and Contamination

There is also a threat of groundwater pollution, which would further harm

water quality in Iraq (Ismael et al., 2020). Potential sources of pollution include direct industrial effluent, agricultural leachates containing fertilizers and pesticides, sewage, and saltwater intrusion at the water/sea border (Al-Charideh and Arman, 2012). The level of contamination also varies in terms of geographical location since the content depends on the usage of land, structures in addition to geological structures, and distance from the sources of pollution. Evaluation of groundwater quality is important for defining areas of contaminated groundwater and subsequent measures towards their remediation (Alwan et al., 2019). Groundwater quality can be differentiated through methods such as artificial neural networks, which can be useful in providing more suitable approaches for management. Monitoring networks are critical to maintaining data standards for detecting spatial and temporal trends in soil salinity and water quality. Additionally, site contamination, especially in areas used as scrap yards, poses a major challenge to remediation.

2.2.3. Impact of Climate Change

The water scarcity problem in Iraq has been worsened by climate change and fluctuating rainfall patterns (Whitman, 2019). Altered precipitation, higher rates of evaporation, and rising temperatures are reducing the rates of recharging groundwater and making water scarce. Where water precipitation decreases, or in the event of prolonged drought, the amount of water the ground can absorb will also be less than that water loses through evaporation when its temperature surges (Milewski et al., 2019). Forecasting the effect of climate change on groundwater flow is important for future water supply and managing its variability. Climate change has to be incorporated into the management plans for groundwater. Understanding the influence of climate variability on groundwater systems is crucial for developing effective strategies to manage these resources.

2.2.4. Infrastructure and Institutional Issues

Lack of infrastructure and institutional management also pose additional challenges to managing groundwater resources in Iraq (Khaled et al., 2023). Small monitoring networks, inadequate data gathering, and absence of implementation and compliance with currently available guidelines hinder management. Irrigation using outdated methods and inadequate drainage facilities led to increased water tables and soil salinity in irrigated land. Secondly, there is also the issue of needing a well-defined regulation and monitoring system to deal with all these. Ensuring sustainable resource mobilization enhances institutional capacity, response data effectivity, and investment in structure and technology are significant priority areas for improving the effectiveness of groundwater management. Because of these reasons, an amalgamation of communities in the planning and implementation of water management projects is crucial and fundamental to successfully implementing operation and maintenance (Nanekely et al., 2019). Table 2 shows summarizes the significant challenges hindering effective groundwater management in Iraq. Figure 5 shows the challenges facing groundwater management in Iraq.

Table 2: The significant challenges hindering effective groundwater management in Iraq.		
Authors	Year	Significant Challenges Hinder Effective Groundwater Management in Iraq
Qureshi et al. 2015	(2015)	Over-extraction and depletion due to increased irrigation and low water-use efficiency.
Nanekely et al. 2019	(2019)	Excessive groundwater extraction exceeding natural recharge rates.
Shakoor et al. 2017.	(2017)	Need for hydrological studies to assess over-extraction prevalence and geography.
Al-Charideh et al. 2012.	(2012)	Pollution and contamination from industrial effluents, agricultural leachates, and sewage. Threat saltwater intrusion at coastal areas affecting groundwater quality.
A. Alwan et al. 2019	(2019)	Importance of evaluating groundwater quality to identify contaminated areas for remediation.

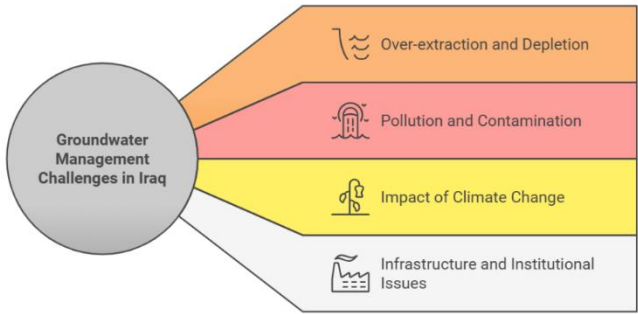


Figure 5: Challenges facing Groundwater management in Iraq

3. Key Strategies for Effective Groundwater Management

Groundwater management is important for water security and development, especially in countries with water shortages like Iraq. This means monitoring the rational, sustainable use of resources and preventing pollution.

3.1. Monitoring and Assessment

To monitor fluctuations in the groundwater, i.e., the variability in the water table and the health and prospects of the aquifer system, the data on the groundwater should be collected periodically. It contains the data, which, in turn, aids in water distribution, setting upper limits on abstraction, and forming the basis for determining measures for regulating pollution (Alwan et al., 2019). The technology that shall be applied in data collection should be strong and measurable to allow comparison in the long and short run and across geographical regions. This involves issues like sample selection procedures, good characteristics of the well-constructed sample, and the generalizability of the obtained samples. For example, research done in North Carolina explained that variation in sample techniques (use of first-draw water versus the impacted lead measurements in well water) affected lead concentrations (Wilson et al., 2024). Consequently, a set of norms would be required to reduce subjectivity and guarantee the validity of the information.

The use of modern technology is of fundamental importance in the monitoring and assessment of groundwater. Geographic Information Systems (GIS) can handle spatial information in hydrogeology, land use, and pollution data. Satellite technologies are useful in determining the changes in the land surface in various factors that determine groundwater recharge, including the transition from forests to developed areas (Ávila-Carrasco et al., 2023). The same applies to remote sensing techniques to measure water height in surface water bodies that are hydrologically linked to aquifers (Roche et al., 2022). In addition, employing advanced data-based models like ANNs and ACO presents a better opportunity to find groundwater quality parameters (Bhavya et al., 2017). These models can minimize direct and costly laboratory analyses and serve as effective tools for studying the dynamics of the state of groundwater. These technologies provide a differential and effective way to monitor groundwater. For instance, a study in the basin of Mexico evaluated the temporal groundwater recharge changers using GIS and satellite data (Ávila-Carrasco et al., 2023). All these will provide a real-life example of how technology can be used to enhance groundwater management.

3.2. Sustainable Withdrawal Practices

Sustainable groundwater withdrawal practices are essential to prevent aquifer depletion and maintain long-term water security. Thus, enforcing responsible extraction rates development, including strict compliance with them, is vital for avoiding unwanted impacts on aquifers. Such rates should be pegged on the replenishment rates of the aquifer, the storage capacity of the aquifer, and the potential demand for the water (Badenhop and Timms, 2010). Such conditions require detailed knowledge and understanding of the aquifer's hydrogeological properties, which can best be acquired through monitoring and model study. As a result of sustainable

yield assessment, proper care must be taken that the extraction rates are agreeable to the aquifer, further establishing strict regulations and monitoring mechanisms. Breaching these guidelines has serious impacts, including land subsidence, increasing saltwater intrusion in coastal areas, and a decreased supply of water in the future (Nalley et al., 2015). Also, the existing formal and informal restraints like understanding water prices, aimed at using water more efficiently, and legislation like water pricing policies that indicate the real cost of water are very effective (Arifuzzaman and Islam, 2024). This can be extended with educational materials and public campaigns to increase actors' concern for the sustainable usage of groundwater.

Enhancing aquifer recharge is a critical aspect of sustainable groundwater management. Options for doing so are to use rainwater harvesting and managed aquifer recharge MAR programs and promote measures that enhance the infiltration ratio (Lee et al., 2019). Rooftop rainwater harvesting can provide a reliable water source for non-potable uses, reducing the demand for groundwater resources (Veen and van, 2016). MAR schemes in this study rely on artificial recharging of the aquifers through treated wastewater or surface water (Imig et al., 2022; Kwoyiga, L., and Stefan, C., 2023). The kind of MAR methods to be applied depends on the nature of the targeted aqueous formation and the availability of the appropriate source water. In addition, infiltration rates can be increased through agricultural inputs management, for example, through minimum tillage practices or by advocating the use of cover crops. Besides augmenting aquifer recharge, these methods enhance health and reduce greenhouse gas emissions (Ayeni and Olagoke-Komolafe., 2024). To optimize the achievement of aquifer recharge strategies, much attention should be paid to the planning process and involvement of different stakeholders, as well as the creation of relevant legal mechanisms.

3.3. Pollution Prevention and Management

Groundwater pollution poses a serious threat to human health and the environment. Effective management necessitates a comprehensive approach to pollution prevention and remediation. Agricultural runoff remains the biggest threat to groundwater contamination by pollutants; such as nitrates and pesticides (Ottoson et al., 2013). Policymaking to prevent agriculture runoff involves measures by one strategy that works together with another. These are encouraging conservation agriculture, reducing the use of fertilizers, and providing better ways of managing nutrients (Ottoson et al., 2013; Moklyachuk et al., 2016). Living strips or covers alongside water reservoirs can filter runoff before it affects underground water. Cover crops can also minimize soil erosion and nutrient loss. In addition, it is possible to reduce pesticide contamination of the groundwater through the amendment of legislation that existed in the user status and the promotion of education or training assessments for farmers (Guerrero et al., 2024). The operations of these policies must be complemented by strict enforcement machinery or measures as well as collaboration between the government, farmers, and other players (Wang and Islam, 2022).

While wastewater goes largely untreated and uncontrolled, the outcome is poor for the environment and poses a potential risk to water supply since it pollutes the water table. Proper tools of wastewater treatment are essential for safeguarding groundwater standards. Treatment purposes should suit the nature of the wastewater together with the physical, chemical, and biological conditions supporting the community (Ghaly et al., 2021). This may include using physical, chemical, or biological techniques by which pollutants are eliminated from the water before it is released. There is a need to ensure that all wastewater treatment adheres to the minimum set quality standards (Zaki et al., 2021). In addition, using recycled water, especially for irrigation, minimized water demand from groundwater sources and enhanced water sparing. Such action entails a lot of planning and coordination to avoid compromising public health and the environment while using the treated wastewater. Table 3 shows the summary table for strategies for effective groundwater management. Figure 6 scheme effective groundwater management.

Table 3: Strategies for effective groundwater management.		
Authors	Year	Strategy for Effective Groundwater Management
Tesfaldet et al. 2023	(2023)	Implementing regular data collection to track groundwater levels and quality.
Wilson et al. 2024	(2024)	Implementing practices that ensure the long-term viability of groundwater resources.
Vila-Carrasco et al., 2023.	(2023)	Technological Innovations: Utilizing new technologies for efficient water use and monitoring.
Badenhop et al., 2010	(2010)	Creating clear policies and regulations for groundwater extraction and usage.

Table 3(Cont.): Strategies for effective groundwater management.		
Arifuzzaman et al., 2024	(2024)	Implementing financial incentives for water conservation and sustainable practices.
Lee et al., 2019	(2019)	Investing in infrastructure to enhance water management systems.
Lee et al., 2019	(2019)	Promoting public awareness and education on sustainable groundwater use.
Ottoson et al., 2013	(2013)	Pollution Prevention: Establishing measures to prevent contamination from various sources.

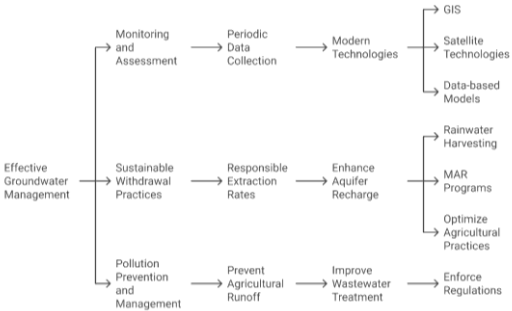


Figure 6: Scheme effective Groundwater management.

4. Policy and Institutional Framework

A robust policy and institutional framework is essential for effective groundwater management.

4.1. Existing laws and regulatory management.

A general analysis of the current national and local legislation on groundwater management in Iraq is crucial to assess their adequacy and identify gaps. This review should consider two legal structures on groundwater extraction, allocation, and protection (Sulaiman et al., 2022).

The review should also examine the enforcement mechanisms connected with these policies and identify areas where improvements are needed. It should also evaluate the institutions' ability to implement and enforce these policies, a process usually associated with various difficulties in developed nations (Meshesha and Abdi, 2019). The existing legal and institutional setting should be assessed in light of the normative rules of the international community for sustainable and sound groundwater consumption. This review would help formulate new and better policies and regulations for the country that are more comprehensive and effective than those existing now and are on par with those of other countries.

Table 4: Policy and Institution Framework.		
Authors	Year	Key Aspects of Policy and Institution Framework
Sulaiman et al., 2022	(2022)	Review of existing laws governing groundwater extraction, allocation, and protection.
Meshesha et al., 2019	(2019)	Assessment of the effectiveness of enforcement mechanisms related to groundwater policies.
Davis et al., 2007	(2007)	Evaluation of institutions ability to implement and enforce groundwater management policies.
Wilkinson et al., 2015	(2015)	Importance of involving various stakeholder in the policy-making process for groundwater management.
Aquino et al., 2023	(2023)	Adoption of integrated approaches that consider social, economic, and environmental factors in policy frameworks.
Katusiime et al., 2020.	(2020)	Transparency and Accountability: Emphasis on transparency in decision-making and accountability of institutions managing groundwater resources.

5. Community Engagement and Education in Groundwater Management

5.1. The Role of Local Communities in Groundwater Management

The sustainable management of groundwater resources hinges critically on the active involvement of local communities (Maheshwari et al., 2014; Maldonado et al., 2018; Taylor et al., 2009). They ascribe considerable credibility to customary water use practices, local hydrological processes, and realities of the socio-economics of natural resources; this knowledge holds invaluable resource governance (Krishnan et al., 2020).

4.2. Integrated Water Resource Management (IWRM)

Integrated Water Resource Management (IWRM) is a holistic approach to water management that examines the interconnectedness of different water resources and uses. According to the principles of IWRM, the process pays much attention to stakeholder participation in the decision-making process (Davis, M., 2007; Wilkinson et al., 2015). These are government ministries, departments, and agencies; the local population; and private organizations. Based on water availability, necessity, efficiency, and environmental, social, and economic aspects, IWRM has become an influential strategy for water management (Aquino et al., 2023). In Iraq's case, IWRM is applicable because of the competing water supply and demand resulting from the diverse hydrogeological nature and the pressures from water use sectors (agricultural and industrial), and domestic. Applying IWRM in this regard can assist in achieving rational use of water, especially in groundwater resource utilization, without compromising future requirements and any impairment to the earth's ecosystem (Katusiime and Schtt, 2020). This involves changing the fragmented, sectoral approach to a more coherent and planned strategy.

To achieve the goal of IWRM in Iraq, there is a need to enhance cooperation between the government and the NGOs. Official bodies can enforce policies and standards due to their power and financial means, while NGOs may become key to community mobilization, capacity awareness, and monitoring. Stakeholder engagement can bring together information and knowledge for implementing IWRM activities that are efficient and sustainable. It should also define the reporting lines and the interfaces for synchronizing coordination at different organizations. It stated that the participation of NGOs in the management of accessible water resources increases the chances of management success due to high levels of accountability and, therefore, public confidence (Katusiime and Schtt, 2021). Collaborative efforts are essential for integrating IWRM principles, and all stakeholders must be committed to transforming the vision into reality. Table 4 shows the policy and institution framework. Figure 7 shows the policy and institutional framework for groundwater.

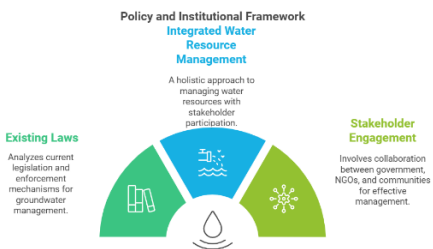


Figure 7: Policy and institutional framework for Groundwater

Lack of consideration of this local knowledge results in poor practice and various clashes of interest. It is recommended that a multidisciplinary methodology that combines the best scientific knowledge with indigenous ideas is required to preserve the groundwater. Furthermore, the combination of traditional ecological knowledge (TEK) with scientific methods is essential for a holistic understanding of the socio-hydrological system and for designing appropriate interventions (Lpez, 2014; Caro-Borrero et al., 2017). Analyses of successful case studies demonstrate a great need for discussions and cooperation between local communities, NGOs, and government agencies to discuss practices for sustainable usage of ground waters. Experience in community-based groundwater management has also shown that sound local institutions and usage organizations support sustainability.

Stakeholder engagements in the management of groundwater are extremely crucial, as stated by (Blomquist et al., 2005; Endo, 2020; Megdal et al., 2017). A comprehensive approach to groundwater management requires the involvement of various stakeholders, including the community, farmers, government bodies, researchers, non-governmental organizations, and the private sector. Every stakeholder has a specific view, experience, and concern. Every stakeholder has its own wanted outcome. This situation could result in problems such as conflict, mismanagement, poverty, and, therefore, unsustainable utilization of groundwater (Walter, 2013). Stakeholder management entails initiating channels so stakeholders can freely communicate, be involved in decision-making processes, and hold responsibility for handling groundwater. This mandates the dissemination of information, identification of modes of communication, and ways of handling disputes between different stakeholders. The process should also necessitate capacity-building interventions to influence local communities to improve their engagement in groundwater usage (Gomes et al., 2018). A cross-sectional comparison of different institutional systems of river basin management demonstrates how the engagement of stakeholders for basin management can be better coordinated to promote better-integrated resource management. However, some questions appear regarding both the fair inclusion of stakeholders and the exclusion of elite capture, especially in the particular conditions of the power imbalance.

5. 2. Awareness and Education Campaigns

Education of the people on the need to protect and use water, especially groundwater, is essential for long-term results (Unterbruner et al., 2015; Muhammad and Amal, 2020). Public awareness programs are useful in ensuring people use appropriate water in society (Esfandiari et al., 2022). Such campaigns should be culturally more subtly and include such groups as farmers, schoolchildren, and other populations (Little et al., 2016). Appropriate education programs employ different approaches, such as multimedia learning programs, PRA activities, door-to-door campaigns, workshops, and community events. These programs should include general ideas concerning groundwater hydrology, information about efficient water usage, and ways to involve people in observing and protecting water resources. The gamification techniques can further enhance engagement and knowledge retention, particularly among younger audiences (Di Paolo and Pizzoli, 2024). Religious-centric approaches can also be used to disseminate water management campaigns in some parts of the world. The impact of such campaigns depends on several factors, which include the quality of the educational materials to be used, the coverage to be achieved by these campaigns, and the extent of community participation. However, correcting the misperceptions and raising public awareness concerning groundwater is important for the informed decision-making of society and rational use of water resources (Dermatas, 2017). Moreover, including water education in school systems can enhance responsible water use standards from childhood (Ankaya and Ien, 2015; Masirin et al., 2020Y). Figure 8 shows Community Engagement in Groundwater Management.



Figure 8: Community Engagement in Groundwater Management.

6. CASE STUDIES AND BEST PRACTICES

6.1. Successful Groundwater Management Examples

Numerous successful groundwater management initiatives showcase the effectiveness of community engagement and education (Maheshwari et al., 2014; Maldonado et al., 2018; Taylor et al., 2009). The MARVI project in Gujarat and Rajasthan highlighted how research from the natural sciences can be combined with local involvement as an effective transdisciplinary strategy (Maheshwari et al., 2014). This successfully led to incidences of a participative method being developed, local volunteers (Bhujal Jankaars) being trained, and a variety of community participation practices being present (Maheshwari et al., 2014). Likewise, the community-supported groundwater observation system in Rocky View County, Alberta, Canada, shows that it is possible to start and maintain a vast community science program for sustainable groundwater management (Little et al., 2016). The assessments were conducted by university researchers with county staff's active participation and involving community volunteers; the project produced new long-term data sets (Little et al., 2016). In the socio-groundwater system, Yucatan Peninsula, Mexico, the research work categorized the toolbox as material flow analysis, mental model contribution, and community conservation (Maldonado et al., 2018). This approach was transdisciplinary, which encouraged stakeholders from different sectors to participate in enhancing the management of groundwater resources (Ghaly et al., 2021). On the other hand, a survey of experiences in Ontario, Canada, underscored certain difficulties in harmonizing several investigation programs focused at a community level (Taylor et al., 2009). This is why there is a need for more convergence, or what we call the ascendancy of the state, in water research within communities.

Studies of successful groundwater management initiatives, specifically within Iraq, show that the principles and best practices discussed apply to similar arid and semi-arid regions facing water scarcity (Al-Jawad et al., 2019; Chowdhury, 2021). For instance, water scarcity, development pressure, and climatic change effects affect the Diyala River Basin in Iraq (Al-Jawad et al., 2019). Optimization modeling provides potential and more efficient management situations about sustainable solutions and future forecasts to aid decisions (Al-Jawad et al., 2019). Nevertheless, the present study revealed that research on constructing a water stress reduction approach based on a sustainability framework is still rare (Al-Jawad et al., 2019).

In Bangladesh, over-abstraction of groundwater for irrigation is an issue. One can add the over-abstraction of groundwater for irrigation purposes to this list. Therefore, a high rainfall-dependent irrigated dry-season rice crop and a near-zero marginal cost of irrigation are partly to blame for this sustained practice (Chowdhury, 2021). Education policy reforms and developing people-centered frameworks that include all the principals help solve this crisis (Chowdhury, 2021). Along similar lines, the case of the Jaguaribe River Basin in Brazil shows that strong political support over the years provides the basis for effective water resources management reform and decentralization (Formiga-Johnsson and Kemper, 2005). It confirms that despite unfavorable initial conditions, decentralization can also be accomplished with appropriate institutional adaptations and higher levels of stakeholder involvement (Formiga-Johnsson and Kemper, 2005). It also highlighted the relevance of the science of participatory approaches to enhance community involvement and contribute toward sound policy accords (Maheshwari et al., 2014; Maldonado, López, and Cristina, 2018; Formiga-Johnsson and Kemper, 2005).

6.2. Lessons Learned from Other Countries

Comparative analyses of groundwater management strategies across different countries reveal valuable lessons (Blomquist et al., 2005; Braune, and Xu, 2019; Santos et al., 2023; Albati, F. M., 2023). As the Australian case about the management of the Great Artesian Basin has demonstrated, it becomes apparent that accurate and timely information disclosure, the flexibility of management systems, and stakeholders' engagement (Little et al., 2016). On the other hand, experience from the successful use of aquifer injection using coal seam gas-produced water in the Surat CMA, Queensland, Australia, and the Powder River Basin, Wyoming, has given a glimpse of the regulatory instruments that can foster the protection of valuable groundwater resources (Robertson, 2019).

In Southern Africa, the difficulties inherent to the implementation of the links between groundwater management and sectors dependent on water from aquifers, like agriculture and rural development, demonstrate that the construction of national, regional, and local systems must be the result

of a long process of evolution within a global strategic IWRM framework (Robertson, 2019). The analysis of the socio-groundwater system in Yucatan, Mexico, illustrates that collaboration with the local actors is also needed other than the technical approach. The study also reveals the shortcomings of the hydrological-only models and single discipline method. In Portugal, the survey on population knowledge about sustainable water consumption has shown a high practice but a low knowledge of water recycling (Figueiredo et al., 2024). This underlines the fact that to educate the public about the proper use of water and encourage sustainable practices, it is now necessary to work with a special focus on particular communities and individuals (Figueiredo et al., 2024). Some investigations in India stress consumer behavior as the most significant determinant of sustainable water consumption (Dermatas, 2017). Some

recommendations for the actionable plan proposed in the study are Storage and conservation, recycling, and stakeholders. Moreover, last but not least, there is public participation (Ginwal and Kumar, 2023).

Privatization of the management of groundwater provision has been adopted in Saudi Arabia as a climate-resilient approach to coping with water scarcity. Prospective experiences of successful and unsuccessful environments in other nations can be valuable in introducing water privatization (Albati, 2023). These examples show that appropriate management of the groundwater resources means that the socio-economic, cultural, and environmental conditions are to be considered; the scientific data used jointly with the local knowledge; the stakeholder involvement; and the effective policy-tools application. Table 4 shows the case studies and best practices in groundwater management.

Table 5: Summary case studies and best practices in groundwater management.

Author/s	Case Study	Location	Key Features	Outcomes
Al-Jawad et al. (2019)	Diyala River Basin Study	Iraq	water scarcity, development pressure, and climate change effects.	Identification of optimization modeling for sustainable management solutions.
Maheshwari et al. (2014)	MARVI Project	India	Combination of natural sciences with local involvement; training local volunteers (Bhujal Jankaars)	Effective transdisciplinary strategy leading to community participation practices.
Maldonado et al. (2018)	Groundwater System	Mexico	material flow, mental model, and community conservation	stakeholder participation in groundwater management.
Little et al. (2016)	Community-Supported Observation	Canada	Involvement of university researchers, county staff, and community volunteers	Creation of long-term data sets for sustainable groundwater management
Chowdhury (2021)	Over-Abstraction Issue	Bangladesh	High rainfall-dependent irrigation practices leading to groundwater over-abstraction.	Need for education policy reforms and people-centered frameworks to address the crisis.
Formiga et al. (2005)	Jaguaribe River Basin Case	Brazil	Strong political support for water resource management reform and decentralization.	Successful decentralization and enhanced community involvement in water management.
Braune et al. (2019)	Groundwater System Analysis	Southern Africa	integration of groundwater management with agriculture and rural development.	The need for a long-term evolution of management systems within IWRM.
Robertson (2019)	Great Artesian Basin Management	Australia	Accurate information disclosure, flexible management systems, stakeholder engagement.	Improved groundwater management practices.
Figueiredo et al. (2024)	Knowledge Survey	Portugal	High of sustainable practices but low knowledge of water recycling.	improve public understanding of water recycling.

7. CONCLUSION

In conclusion, addressing the complex challenges of groundwater use in Iraq requires a comprehensive and multifaceted approach. Key considerations for effective groundwater management include:

- A deep understanding of groundwater usage in Iraq is critical to addressing the intertwined challenges posed by climate change, declining surface water availability, and increasing water demand. This knowledge is essential for informed decision-making and sustainable resource management.
- Effective strategy developments must incorporate not only scientific research but also the anthropological, cultural, economic, and environmental aspects that shape groundwater use in the country. A holistic view of these factors will foster more practical and context-specific solutions.
- Stakeholder Engagement: Engaging all relevant stakeholders—including government agencies, local communities, industries, and water users—is essential for developing groundwater management strategies that are both inclusive and broadly supported. This collaborative approach fosters a sense of ownership and accountability, encouraging sustainable water resource use.

- Establishing robust monitoring systems and using modern technologies to collect and analyze real-time data on groundwater levels, quality, and usage will greatly enhance decision-making processes. This data-driven approach ensures that groundwater resources are used efficiently and sustainably.
- Strengthening cooperation with local communities and fostering a sense of shared responsibility will lead to more effective management practices. Community engagement is essential for raising awareness about the importance of water conservation and the long-term sustainability of groundwater.
- Emphasizing future-focused strategies to prioritize groundwater conservation will enable Iraq to meet its agricultural, economic, and domestic water needs while safeguarding this crucial resource for future generations.
- To promote the long-term sustainability of groundwater resources in the region, the Network-Based Learning Approach is essential for ongoing knowledge sharing, capacity building, and adaptation to new challenges in groundwater management.

By focusing on these areas, Iraq can enhance its groundwater management, ensuring availability for future generations while supporting agricultural productivity and economic growth in an increasingly water-scarce environment.

REFERENCES

- Abdul-Hameed, S., and Hatem, A. J., 2021. Effect of Shatt Al-Arab Salinity on the Groundwater of Al-Fao and Al-Siba in Southern Iraq." Vol.54, No. 1E, 2021 (Iraqi Geological Journal), (2021). <https://doi.org/10.46717/igj.54.1e.10ms-2021-05-31>
- Al-Abadi, A. M., 2015. The application of Dempster-Shafer theory of evidence for assessing groundwater vulnerability at Galal Badra basin, Wasit governorate, east of Iraq." Springer Nature Volume 7, Pp. 1725–1740. <https://doi.org/10.1007/s13201-015-0342-7>
- Al-Ansari, N., 2013. Management of Water Resources in Iraq: Perspectives and Prognoses. Scientific Research Publishing, Vol.5 No.8, August 2013. <https://doi.org/10.4236/eng.2013.58080>
- Al-Ansari, N., 2021. Water Resources of Iraq." Journal of Earth Sciences and Geotechnical Engineering, Vol. 11, No. 2, 2021, Pp. 15-34. <https://doi.org/10.47260/jesge/1122>
- Al-Ansari, N., Adamo, N., Hachem, A. H., Sissakian, V., Laue, J., and Abed, S. A., 2023. Causes of Water Resources Scarcity in Iraq and Possible Solutions." Scientific Research, Vol.15 No.9, September 2023. <https://doi.org/10.4236/eng.2023.159036>
- Alattar, M. H., 2024. Mapping groundwater dynamics in Iraq: integrating multi-data sources for comprehensive analysis." Modeling Earth Systems and Environment (2024): Pp. 1-11. <https://doi.org/10.1007/s40808-024-02029-9>
- Albati, F. M., 2023. Privatization Of Groundwater Provision Management As A Climate Adaptive Strategy To Address Water Scarcity In Saudi Arabia And A Comparative Analysis For Implementing Water Privatization In Other Countries. <https://doi.org/10.21608/jlaw.2023.298081>
- Al-Charideh, A., and Arman, H., 2012. Use of isotopic tracers to characterize the interaction of water components and nitrate contamination in the arid Rasafeh area (Syria). Springer Science+Business Media (2012). <https://doi.org/10.1007/s12665-012-2104-2>
- Al-Dujaili, A. N., 2024. New advances in drilling operations in sandstone, shale, and carbonate formations: a case study of five giant fields in the Mesopotamia Basin, Iraq." Mining Science and Technology (Russia) 9, no. 4 (2024): Pp. 308-327. <https://doi.org/10.17073/2500-0632-2023-08-146>
- Ali, A., Obeed, A.-A., Frank, A., and Ward, 2017. Groundwater use and policy options for sustainable management in Southern Iraq." International Journal of Water Resources Development, 33 (2017): Pp. 628-648. <https://doi.org/10.1080/07900627.2016.1213705>
- Al-Jawad, J. Y., Al-Jawad, S. B., and Kalin, R., 2019. Decision-Making Challenges of Sustainable Groundwater Strategy under Multi-Event Pressure in Arid Environments: The Diyala River Basin in Iraq." Water 2019, 11(10), 2160. <https://doi.org/10.3390/w11102160>
- Al-Jiburi, H. K., and Al-Basrawi, N. H., 2015. Hydrogeological map of Iraq, scale 1: 1000 000, 2013. Iraqi Bulletin of Geology and Mining 11, no. 1, Pp. 17-26.
- Al-Rubaie, Z., and Al-Kubaisi, Q., 2024. Estimate the Runoff and Groundwater Recharge in Abu-Gharib Area, Western Baghdad Governorate, Iraq." Iraqi Geological Journal Vol. 57, No. 2D, 2024. <https://doi.org/10.46717/igj.57.2d.10ms-2024-10-20>
- Altimiras Granel, J., 2024. Quantifying Groundwater-Surface Water Interactions with Transfer Function Models. (2024). <http://hdl.handle.net/20.500.12380/308195>
- Alwan, I. A., Karim, H. H., and Aziz, N. A., 2019. Groundwater Aquifer Suitability for Irrigation Purposes Using Multi-Criteria Decision Approach in Salah Al-Din Governorate/Iraq. Multidisciplinary Digital Publishing Institute (2019). <https://doi.org/10.3390/agriengineering1020023>
- Alwash, A., Istepanian, H., Tollast, R., and Al-Shibaany, Z., 2018. Towards sustainable water resources management in Iraq." Iraq Energy Institute: London, UK (2018).
- Al-Zubedi A. S., 2022. Groundwater in Iraq, National Iraqi Library and Archive. ISBN- 978-9922-9746-6-8.
- Ankaya, C. F., and Ien, 2015. Development of Pre-Service Science Teachers' Awareness of Sustainable Water Use." Educational Research and Reviews, Vol.10(4), Pp. 471-484, <https://doi.org/10.5897/ERR2014.2053>
- Aquino, J., Sanchez, P. A., Roa, U. F., Dayo, M. H. F., and Gigantone, C., 2023. Experiences, Challenges, and Initiatives on Water Resource Management of a Small Island Community: The Case of Basco, Batanes, Philippines." SciEnggJ Vol. 16 (Supplement) 2023. <https://doi.org/10.54645/202316supesz-63>
- Arifuzzaman, M., and Islam, S., 2024. Compliance of Legal Restrictions in Potable Water Abstraction in Rajshahi WASA Area: An Overview." British Journal of Arts and Humanities 2024; 6(3), Pp. 138-145. <https://doi.org/10.34104/bjah.02401380145>
- Ata, O., Salih, Diary, Ali, and Al-Manmi, 2024. Strategies for Sustainable Water Management. ARO. The Scientific Journal of Koya University, Vol. 12 No. 2 (2024): Issue Twenty-Three. <https://doi.org/10.14500/aro.11435>
- Ávila-Carrasco, J. R., Hernández-Hernández, M. A., Herrera, G., & Hernández-García, G., 2023. Urbanization effects on the groundwater potential recharge of the aquifers in the Southern part of the Basin of Mexico." Hydrology Research (2023) 54 (5): Pp. 663–685. <https://doi.org/10.2166/nh.2023.103>
- Ayeni, O., and Olagoke-Komolafe, O. E., 2024. Environmental impact of modern agricultural practices: Strategies for reducing carbon footprint and promoting conservation." International Journal of Management & Entrepreneurship Research. Vol. 6 No. 9 (2024). <https://doi.org/10.51594/ijmer.v6i9.1581>
- Aziz, F. F., and Hussain, E. K., 2023. Evaluation The Leachate Characteristics and its Impacts on Groundwater Contamination Around Al-Diwaniyah Open Dumpsite." IOP Publishing (2023). <https://doi.org/10.1088/1755-1315/1232/1/012006>
- Badenhop, A., and Timms, W. A., 2010. Managed Aquifer Recharge in Sydney Coastal Sand Aquifers. Environmental Science. (2010).
- Bairami, M., Khajavi, H., and Rastgoo, A., 2024. Assessing groundwater behavior and future trends in the Ardabil Aquifer: A comparative study of groundwater modeling system and categorical gradient boosting hybrid model. Expert Systems with Applications 255 (2024): 124728. <https://doi.org/10.1016/j.eswa.2024.124728>
- Bhatia, S., and Singh, S., 2023. Can an Incentivized Command-and-Control Approach Improve Groundwater Management? An Analysis of Indian Punjab." Multidisciplinary Digital Publishing Institute (2023). <https://doi.org/10.3390/su152215777>
- Bhavya, R., Sivaraj, K., And Elango, L., 2023. Ant Colony Based Artificial Neural Network for Predicting Spatial and Temporal Variation in

- Groundwater Quality." *Water* 2023, 15(12), 2222. <https://doi.org/10.3390/w15122222>
- Bierkens, M. F. P., and Wada, Y., 2019. Non-renewable groundwater use and groundwater depletion: a review." IOP Publishing (2019). <https://doi.org/10.1088/1748-9326/ab1a5f>
- Blomquist, W., Meinzen-Dick, R., and Kemper, K., 2005. Comparison Of Institutional Arrangements For River Basin Management In Eight Basins. Policy Research Working Paper; No. 3636, (2005). <https://doi.org/10.1596/1813-9450-3636>
- Braune, and Xu, Y., 2019. Groundwater management issues in Southern Africa An IWRM perspective." *Water S.A* (2019). <https://doi.org/10.4314/WSA.V34I6.183672>
- Bundesanstalt für Geowissenschaften und Rohstoffe. 2013. Inventory of shared water resources in Western Asia. UN, 2013.
- Caro-Borrero, A. P., Carmona-Jimenez, J., Varley, A., De Garayarellano, G., Mazari-Hiriart, M., and Adams, D. K., 2017. Local And Scientific Ecological Knowledge Potential As A Source Of Information In A Periurban River, Mexico City, Mexico. None. https://doi.org/10.15666/AEER/1501_541562
- Chowdhury, A., 2021. Irrigation Decisions And Use Of Groundwater In Bangladesh: Perspectives On Some Evolving Crisis. *American International Journal of Multidisciplinary Scientific Research*, Vol 11 No 1, (2021). <https://doi.org/10.46281/aijmsr.v11i1.1400>
- Cuthbert, M. O., Gleeson, T., Bierkens, M. F. P., Ferguson, G., and Taylor, R. G., 2023. Defining renewable groundwater use and its relevance to sustainable groundwater management. *Water Resources Research* 59, no. 9 (2023): e2022WR032831. <https://doi.org/10.1029/2022WR032831>
- Dallas, S. and Hasson, A., 2006. Solar-powered saline groundwater management for sustainable agriculture." *Decentralised water and wastewater systems: International Conference, 2006*, <https://doi.org/10.07/2006-12/07/2006>
- Davis, M., 2007. Integrated Water Resource Management and Water Sharing." *Journal of Water Resources Planning and Management*, Volume 133, Issue 5 (2007). [https://doi.org/10.1061/\(ASCE\)0733-9496\(2007\)133:5\(427\)](https://doi.org/10.1061/(ASCE)0733-9496(2007)133:5(427))
- Dermatas, D., 2017. Waste management and research and the sustainable development goals: Focus on soil and groundwater pollution. *Waste Management Research* (2017). <https://doi.org/10.1177/0734242X17706474>
- Di Paolo, R., and Pizziol, V., 2024. Gamification and Sustainable Water Use: The Case of the BLUTUBE Educational Program. *Simulation & Gaming*, 55(3), Pp. 391-417. <https://doi.org/10.1177/10468781231181652>
- Doost, Z. H., and Yaseen, Z. M., 2024. Allocation of reservoirs sites for runoff management towards sustainable water resources: Case study of Harirud River Basin, Afghanistan." *Journal of Hydrology* 634 (2024): 131042. <https://doi.org/10.1016/j.jhydrol.2024.131042>
- Eckstein, Y., and Eckstein, G. E., 2003. Yoram Eckstein, Gabriel Eckstein. *Groundwater Resources and International Law in the Middle East Peace Process*. Taylor and Francis (2003). <https://doi.org/10.1080/02508060308691680>
- Endo, T., 2020. What do studies on consensus-building imply for groundwater governance?. <https://doi.org/10.5917/jagh.62.207>
- Esfandiari, S., Dourandish, A., Firoozzare, A., and Taghvaeian, S., 2022. Strategic planning for exchanging treated urban wastewater for agricultural water with the approach of supplying sustainable urban water: a case study of Mashhad, Iran." *Water supply: the review journal of the International Water Supply Association* (2022). <https://doi.org/10.2166/ws.2022.359>
- Faysal, R. M., 2013. Spatial Analysis of the Assessment of Groundwater Validity for Drinking, Irrigation and animal Watering in Sinjar District Using GIS." None (2013). <https://doi.org/10.33899/edusj.2013.89898>
- Figueiredo, M., Fernandes, A., Neves, J., and Vicente, H., 2024. Sustainable Water Use and Public Awareness in Portugal." *Sustainability* (2024). <https://doi.org/10.3390/su16135444>
- Formiga-Johnsson, R. M., and Kemper, K., 2005. Institutional and Policy Analysis of River Basin Management: The Jaguaribe River Basin, Ceara, Brazil." Policy Research Working Paper; No. 3649 (2005). <https://doi.org/10.1596/1813-9450-3649>
- Ghaly, N., Mahmoud, M. M., Ibrahim, E., Mostafa, E., Abdelrahman, E., Emam, R., Kassem, M. A., & Hatem, H. M., 2021. Greywater Sources, Characteristics, Utilization and Management Guidelines: a review." *Advance in Environmental Waste Management and Recycling*, 4 (2): Pp. 134-151. <https://doi.org/10.33140/aewmr.04.02.08>
- Ginwal, R., and Kumar, D., 2023. Understanding Consumer Choices: Towards Sustainable Water Use in India." *Himalayan Journal of Social Sciences and Humanities*. Vol. 18, (2023) Pp. 1-8. <https://doi.org/10.51220/hjssh.v18i1.1>
- Gomes, S. L., Hermans, L., Islam, K. F., Huda, S. N., Hossain, A. Z., and Thissen, W., 2018. Capacity Building for Water Management in Peri-Urban Communities, Bangladesh: A Simulation-Gaming Approach. *Water* (2018). <https://doi.org/10.3390/W10111704>
- Guerrero, J., Gomes, A., Lorandi, R., Di Lollo, J. A., Mataveli, G., and Moschini, L. E., 2024. Vulnerability Assessment of Guarani Aquifer Using PESTICIDE-DRASTIC-LU Model: Insights from Brotas Municipality, Brazil." *Water* 2024, 16(12), 1748. <https://doi.org/10.3390/w16121748>
- Hashim, N. S., Mutashar, N. S., Jameel, H. T., and Mahmood, S. M., 2024. A Comparative Study to Analyze the Validity of Well Water for Some Areas of Eastern and Western Diyala Governorate." *Academia Open* Vol 9 No 1 (2024). <https://doi.org/10.21070/acopen.9.2024.9848>
- Hassan, W. H., Ghanim, A. A., Mahdi, K., Adham, A., Mahdi, F. A., Nile, B. K., and Ritsema, C., 2023. Effect of Artificial (Pond) Recharge on the Salinity and Groundwater Level in Al-Dibdibba Aquifer in Iraq Using Treated Wastewater." *Water* 2023, 15(4), 695. <https://doi.org/10.3390/w15040695>
- Huang, P., Hou, M., Sun, T., Xu, H., Ma, C., and Zhou, A., 2024. Sustainable groundwater management in coastal cities: Insights from groundwater potential and vulnerability using ensemble learning and knowledge-driven models. *Journal of Cleaner Production* 442 (2024): 141152. <https://doi.org/10.1016/j.jclepro.2024.141152>
- Imig, A., Szab, Z., Halytsia, O., Vrachioli, M., Kleinert, V., and Rein, A., 2022. A review on risk assessment in managed aquifer recharge." *Integrated Environmental Assessment and Management*, Volume 18, Issue 6. <https://doi.org/10.1002/ieam.4584>
- Ismael, N., Abed, H. A., and Abed, M., 2020. Classification of Groundwater Quality using Artificial Neural Networks in Safwan and Al-Zubayr in Basra." *Advances in Computer, Signals and Systems* (2020) 4: Pp. 25-35. <https://doi.org/10.23977/acss.2020.040105>
- Jassim, S. Z., and Goff, J. C., 2006. *Geology of Iraq*. Dolin, prague and

- moravian museum." Brno (Czech Republic) (2006): Pp. 340.
- Katusiime, J., and Schtt, B., 2020. Integrated Water Resources Management Approaches to Improve Water Resources Governance." *Water* 2020, 12(12), 3424. <https://doi.org/10.3390/w12123424>
- Katusiime, J., and Schtt, B., 2021. Common Pool Resource Management: Assessing Water Resources Planning for Hydrologically Connected Surface and Groundwater Systems." *Hydrology* 2021, 8(1), 51. <https://doi.org/10.3390/HYDROLOGY8010051>
- Khafaji, M. S. A., Alwan, I. A., Khalaf, A. G., Bhat, S. A., and Kuriqi, A., 2022. Potential use of groundwater for irrigation purposes in the Middle Euphrates region, Iraq. *Sustain. Water Resour. Manag.* 8, Pp. 157. <https://doi.org/10.1007/s40899-022-00749-3>
- Khaled, S., Gmail, I., and Abd-Elaty, 2023. Unveiling the Hidden Depths: A Review for Understanding and Managing Groundwater Contamination in Arid Regions." *The handbook of environmental chemistry*, null.: Pp. 3-35. https://doi.org/10.1007/698_2023_1049
- Khayyun, T. S., and Mahdi, H. H., 2020. Predicted Climate Change Impact on Groundwater Flow for the Upper Zone of Iraqi Aquifers." *Science Press* (2020). <https://doi.org/10.35741/issn.0258-2724.55.2.17>
- Krishnan, N., Kumarasamy, K., Sivabalan, S., Oliyarasan, R., Ravikumar, S., Barua, S., Mary, M., Ragavendra, K., and Kannan, K., 2020. Participatory GIS Mode of Sustainable Surface and Groundwater Management Practices Involving NGOs in India. *None* (2020). <https://doi.org/10.9734/IJECC/2020/V10I1230343>
- Kwoyiga, L., and Stefan, C., 2023. Institutional Feasibility of Managed Aquifer Recharge in Northeast Ghana." *Sustainability* 2019, 11(2), 379. <https://doi.org/10.3390/SU11020379>
- Lee, Y.-D., Shin, D.-M., Kim, B.-J., and Kim, G.-B., 2019. Selecting Aquifer Artificial Recharge Methods Based on Characteristics of the Target Aquifer. <https://doi.org/10.9720/KSEG.2019.4.483>
- Little, K. E., Hayashi, M., and Liang, S., 2016. CommunityBased Groundwater Monitoring Network Using a CitizenScience Approach." *Ground Water* Volume54, Issue3 (2016). <https://doi.org/10.1111/gwat.12336>
- Long, D., Yang, W., Scanlon, B. R., Zhao, J., Liu, D., Burek, P., Wada, Y., 2020. South-to-North Water Diversion stabilizing Beijing's groundwater levels." *Nature Communications* 11, no. 1 (2020): 3665. <https://doi.org/10.1038/s41467-020-17428-6>
- Lpez, Y., 2014. Social-ecological systems in Mayan communities. A scientific and traditional knowledge perspective of groundwater management. Conference: International Science and Policy Conference on the Resilience of Social and Ecological Systems At: France Affiliation: Ludwig Maximilian University of Munich. 2014. <https://doi.org/10.13140/RG.2.1.4419.0801>
- Maheshwari, M., Varua, J., Ward, R., Packham, P., Chinnasamy, Y., Dashora, S., Dave, P., Soni, P., Dillon, R., Purohit, H., Hakimuddin, T., Shah, S., Oza, P., Singh, S., Prathapar, A., Patel, A., Jadeja, Y., Thaker, B., Kookana, R., Grewal, H., Yadav, K. K., Mittal, H., Chew, M., and Rao, P., 2014. The Role of Transdisciplinary Approach and Community Participation in Village Scale Groundwater Management: Insights from Gujarat and Rajasthan, India. *Water* 2014, 6(11), Pp. 3386-3408. <https://doi.org/10.3390/W6113386>
- Maldonado, López, and Cristina, Y., 2018. Understanding socio-groundwater systems: framework, toolbox, and stakeholders' efforts for analysis and monitoring groundwater resources." (2018). <https://doi.org/10.5282/edoc.21697>
- Masirin, M. M., Abdul Hamid, N. B., Zainorabidin, A., Mahmood, C. H. B., Abdul Rahman, A., Abdul Rahman, R. B., and Mustapa, M. S. B., 2020Y. Education and Communicating Positive Young Minds in Creating Sustainable Environment and Development. *IJEED (International Journal of Entrepreneurship and Business Development)* (2020). <https://doi.org/10.29138/ijeed.v3i4.1118>
- Mawlood, D., 2019. Sustainability of Aquifer and Ground Water Condition in Erbil Basin/ Iraq." *Zanco Journal of Pure and Applied Sciences* (2019). <http://dx.doi.org/10.21271/ZJPAS.31.6.6>
- Megdal, S. B., Eden, S., and Shamir, E., 2017. Water Governance, Stakeholder Engagement, and Sustainable Water Resources Management. Multidisciplinary Digital Publishing Institute (2017). <https://doi.org/10.3390/w9030190>
- Meshesha, Y. B., and Abdi, M. B., 2019. Challenges and opportunities for implementation of Integrated Water Resource Management in Omo-Gibe Basin, Ethiopia." *Journal of Ecology and the Natural Environment*, Vol.11(7), Pp. 84-97, (2019). <https://doi.org/10.5897/JENE2019.0747>
- Milewski, W., Seyoum, W. M., Elkadiri, R., and Durham, M., 2019. Multi-Scale Hydrologic Sensitivity to Climatic and Anthropogenic Changes in Northern Morocco." *Multidisciplinary Digital Publishing Institute* (2019). <https://doi.org/10.3390/geosciences10010013>
- Moklyachuk, I., Yatsuk, Oleksandr, Mokliachuk, L., and Plaksiuk, 2016. Mathematical modeling as a tool for determination of tendencies in changes of humus concentration in soil of arable lands. *None* . <https://doi.org/10.9755/EJFA.2016-04-348>
- Muhammad, S., and Amal, S., 2020. Religious based water management campaigns for sustainable development: prospects and challenges." *IOP Conf. Ser.: Earth Environ. Sci.* 477 012018, (2020). <https://doi.org/10.1088/1755-1315/477/1/012018>
- Nalley, L., Linquist, B., Kovacs, K., and Anders, M., 2015. The Economic Viability of Alternative Wetting and Drying Irrigation in Arkansas Rice Production." *Agronomy Journal*. Volume107, Issue2, 2015, Pages 579-587. <https://doi.org/10.2134/AGRONJ14.0468>
- Nanekely, M., Al-Faraj, F., and Scholz, M., 2019. Estimating Groundwater Balance in the Presence of Climate Change Impact: A Case Study of Semi-Arid Area." *Volume 5, Issue 4, Pages 437-455*, (2019). <https://doi.org/10.21608/jbaar.2019.114536>
- Nguyen, D. T., Tran, N. A., and Van, H. T., 2024. The assessment of groundwater reserves, quality, and balance in Quang Nam region, Vietnam: using MIKE BASIN and MODFLOW models. *Environmental Research Communications* 6, no. 10 (2024): 105004. <https://doi.org/10.1088/2515-7620/ad7ddc>
- Ottoson, A., Haldn, E., and Salomon, E., 2013. Measures to mitigate nitrogen and phosphorous losses can reduce the risk of disease transmission from manure 15th International Conference, Versailles, France. *Proceedings*, 2013, S2.08 ref. 13
- Petersen-Perlman, J. D., Aguilar-Barajas, I., and Megdal, S. B., 2022. Drought and groundwater management: Interconnections, challenges, and policy responses." *Current Opinion in Environmental Science and Health* 28 (2022): 100364. <https://doi.org/10.1016/j.coesh.2022.100364>
- Qureshi, A. A., and Al-Falahi., 2015. Extent, Characterization and Causes of Soil Salinity in Central and Southern Iraq and Possible Reclamation Strategies." *Int. Journal of Engineering Research and Applications*. Vol. 5, Issue 1(Part 1), January 2015, Pp.84-94.

- Robertson, J., 2019. The governance of aquifer injection using coal seam gas produced water in the Surat Cumulative Management Area, Queensland, Australia and the Powder River Basin, Wyoming, USA." *Environmental Science, Political Science* (2019).
- Roche, L., Pasquet, S., Chalikakis, K., Mazzilli, N., Rosas-Carbajal, M., Decitre, J., Serene, L., Batiot-Guilhe, C., Emblanch, C., Marteau, J., and Gaffet, S., 2022. *Water Resource Management. Geophysical Monograph Series* (2022). <https://doi.org/10.1002/9781119722748.ch10>
- Saleh, S. A., Al-Ansari, N., and Abdullah, T., 2020. Groundwater hydrology in Iraq." *Journal of Earth Sciences and Geotechnical Engineering* 10, no. 1 (2020): Pp. 155-197.
- Santos, E., Carvalho, M., and Martins, S., 2023. Sustainable Water Management: Understanding the Socioeconomic and Cultural Dimensions." *Multidisciplinary Digital Publishing Institute*. <https://doi.org/10.3390/su151713074>
- Shakoor, A., Khan, Z. M., Arshad, M., Farid, H. U., Sultan, M., Azmat, M., Shahid, M. A., & Hussain, Z., 2017. Regional Groundwater Quality Management through Hydrogeological Modeling in LCC, West Faisalabad, Pakistan." *Journal of Chemistry Volume 2017*, Article ID 2041648, Pp. 16. <https://doi.org/10.1155/2017/2041648>
- Shuvo, R. M., Chowdhury, R. R., Chakroborty, S., Das, A., Kafy, A. A., Altuwaijri, H. A., and Rahman, M. T., 2024. Geospatially Informed Water Pricing for Sustainability: A Mixed Methods Approach to the Increasing Block Tariff Model for Groundwater Management in Arid Regions of Northwest Bangladesh." *Water* 16, no. 22 (2024): 3298. <https://doi.org/10.3390/w16223298>
- Sulaiman, S. Z., Hamad, K. O., & Andrea, S. R., 2022. Drivers and barriers towards sustainable water management in Erbil Kurdistan Region of Iraq." *World Journal of Advanced Engineering Technology and Sciences* (2022) 06(01), Pp. 010–017. <https://doi.org/10.30574/wjaets.2022.6.1.0033>
- Taylor, R. D., de Lo, R., Kreutzwiser, H., and Bjornlund, B., 2009. Local groundwater management studies in Ontario, Canada: A case for retaining a role for the state in community-based water research. *None* (2009). <https://doi.org/10.1080/13241583.2009.11465362>
- Unterbruner, U., Hilberg, S., and Schiffli, I., 2015. Understanding groundwater - students' pre-conceptions and conceptual change by means of a theory-guided multimedia learning program. *Hydrology and Earth System Sciences. Volume 20, issue 6*, (2015). <https://doi.org/10.5194/HESS-20-2251-2016>
- Vakili, M., Ebadi, T., and Hajbabaie, M., 2024. A systematic analysis of research trends on the permeable reactive barrier in groundwater remediation." *International Journal of Environmental Science and Technology* (2024): Pp. 1-18. <https://doi.org/10.1007/s13762-024-05775-6>
- Veen, N., and van, P., 2016. Possibilities for rooftop rainwater harvesting for off-grid households: Case study: Serang, Indonesia.
- Walter, M., 2013. The Roles of Knowledge in the Emergence of Co-Management Initiatives for Transboundary Groundwaters: The Case of the Gnois Aquifer. *None* (2013). <https://doi.org/10.1201/b14591-15>
- Wang, S., and Islam, M. Z., 2022. Legal institutional inefficiency and water pollution problem in Bangladesh." *Resources and Environmental Economics, Vol 4 No 2* (2022). <https://doi.org/10.25082/ree.2022.02.004>
- Whitman, E., 2019. A land without water: the scramble to stop Jordan from running dry." *Nature Portfolio* (2019). <https://doi.org/10.1038/d41586-019-02600-w>
- Wilkinson, T., Magagula, R., Hassan. 2015. Piloting a method to evaluate the implementation of integrated water resource management in the Inkomati River Basin." *Water SA, Vol. 41 No. 5* (2015). <https://doi.org/10.4314/WSA.V41I5.06>
- Wilson, L., Hayes, W. J., Jones, N., Eaves, L. A., Wait, K., George, A., Freeman, B., Mize, W., Fowlkes, J., Currie, J., Burchell, M., Gray, K. M., Fry, R. C., and Pieper, K., 2024. Lead occurrence in North Carolina well water: importance of sampling representation and collection techniques. *Environmental Research Letters. 19* (2024) 044020. <https://doi.org/10.1088/1748-9326/ad2b2c>
- Yacob T. Tesfaldet, A. Puttiwongrak, and Arpornthip, T., 2023. Spatial and temporal variation of groundwater recharge in shallow aquifer in the Thepkasattri of Phuket, Thailand. 2023-08-24 15:17:15. <https://doi.org/10.19637/J.CNKI.2305-7068.2020.01.002>
- Zaki, T., Jahan, I. T., Hossain, M. S., and Narman, H. S., 2021. An IoT-Based Complete Smart Drainage System for a Smart City." *IEEE Annual Information Technology, Electronics and Mobile Communication Conference*. <https://doi.org/10.1109/iemcon53756.2021.9623149>
- Zerouali, B., Bailek, N., Islam, A. R. M. T., Katipoğlu, O. M., Ayek, A. A. E., Santos, C. A. G., and Elbeltagi, A., 2024. Enhancing groundwater potential zone mapping with a hybrid analytical method: the case of semiarid basin. *Groundwater for Sustainable Development* 26 (2024): 101261. <https://doi.org/10.1016/j.gsd.2024.101261>

