American Journal of Sciences and Engineering Research www.iarjournals.com

American Journal of Sciences and Engineering Research

E-ISSN– 2348–703X, Volume 9, Issue 1, 2026

Examination of Biological Contamination and Suitability of Some Alternative Water Sources (Four Wells) For Drinking or Irrigation

Ali Abdulhadi Al-Rawi[1], Mohammed H. M. Abdulrazzaq[2], Hussein, Adnan Neama[3]

Center of desert studies, university of Anbar. Ramadi 31001, Iraq

---

ABSTRACT: *Water is the main element of life, and due to the scarcity of water sources and the increase in pollutants, it has become necessary to search for other alternative sources such as wells. Four wells were studied at the site of Anbar University in western Iraq as an example of using well water as an alternative for the purpose of determining the suitability of this water for human consumption, animals, or irrigation. The study included the collecting of groundwater samples, which were then submitted to a comprehensive physicochemical study. To calculate the WQI, it is necessary to take into consideration thirteen factors, which are as follows: electrical conductivity (EC dSm^{-1}), Total dissolved salts (TDS), pH, NaCl%, K^+, Na^-, HCO_3^{-2}, SO_4^{-2}, PO_2^{-2}, Cl^-, N^{-2}, Ca^{+2}, and Mg^{+2}.*

Twelve groundwater samples were taken from four locations in this study over three months (August 2024, December 2024, and April 2025) to check if the well water is safe to drink, using the Global, Iraqi, and American Water Quality Index and the biological contamination (Escherichia coli). The methodologies for assessing water quality indices on global, Iraqi, and American levels necessitate the application of specific physical and chemical standards for accurate calculations. The elevated values of the water quality index can be attributed to the significant concentrations of electrical conductivity, Ca^{2+}, SO_4, K^+, and Mg^{2+}. This is clearly demonstrated by the strong correlation coefficient observed between them. The present investigation reveals that certain wells may be suitable for drinking water following basic treatment and the elimination of bacteria, and it is suitable for livestock or irrigation.

Key Word: *Biological contamination, Water suitability, Wells, EC, Elements.*

I. INTRODUCTION

Recent years have seen a significant increase in the amount of research conducted on groundwater in the Middle East, particularly in Iraq [1] [2]. Up until 1970, Iraq's water requirements were met by surface water resources derived from the rivers Tigris and Euphrates, as well as their tributaries. Hydrological projects in riparian nations have caused a steady decrease in this water [3]. In addition to the other factors that have contributed to the scarcity of surface water in Iraq and the other neighboring states in the Middle East, climate change has also helped [4]. As a result of these factors, there has been an increase in the demand for groundwater over the course of the last three decades [5].

Precipitation, which includes rain and ice that melts, is the source of groundwater. This precipitation seeps into the soil and is stored in the spaces between rocks and soil particles that are found within geological formations. Groundwater comprises approximately 95 percent of the freshwater resources on earth. Geological formations commonly used to supply groundwater include aquifers and confining beds. Sand, gravel, sandstone,

 Received-27-11-2025 Accepted- 28-12-2025

and limestone are examples of geological formations that are used to feed groundwater. An aquifer is a rock formation that is not consolidated and could supply water in quantities that are usable to a well or spring. On the other hand, a limiting bed is a geological unit that has a low hydraulic conductivity and restricts the movement of groundwater into or out of adjoining aquifers[6][7]. Infiltration, lateral inflow, surface runoff, evapotranspiration, and other components of groundwater equilibrium are all included in the equation that determines the depth of groundwater. The primary factor that determines the depth of groundwater is the equilibrium between groundwater recharge and outflow [8].

As water is the primary universal solvent, groundwater typically possesses substantial amounts of dissolved solids in comparison to surface water. The quality of groundwater is influenced by the chemical composition of precipitation, the biological and chemical reactions occurring on the land surface and within the soil zone, and the mineral composition of the aquifers and confining beds that facilitate the horizontal and vertical movement of water between aquifer systems or geological formations within a single system[9][6]. The minimal yearly precipitation and elevated evaporation rates additionally augment groundwater salinity [10].

Examining some parameters of groundwater samples is necessary to determine if groundwater resources are suitable for human use. This line succinctly describes the single-value water quality indicators employed by Global, Iraqi, and American to evaluate temporal variations. [11][12]. The global, Iraqi, and American systems serve as very efficient instruments for the comprehensive measurement of water quality on a global scale [13][14]. The global, Iraqi, and American sources serve as crucial references for individuals and decision-makers to convey knowledge regarding water quality [15].

In this context, groundwater serves as a crucial store of freshwater, warranting optimal exploitation by policymakers. Natural soil and sediment create strata while also rendering it devoid of contaminants. The primary factors affecting groundwater chemistry are regional geological conditions, rock and soil geochemistry, and land-use changes [16].

This study aims to examine the relevance of global, Iraqi, and American standards for human consumption concerning groundwater in Anbar. To achieve this objective, pH, total dissolved solids (TDSs), cations (Ca, Mg, Na, K), and anions (K, Cl, bicarbonate [HCO_3]-, SO_4, NO_3) were examined in 12 samples collected from the water wells within the study area. The water quality in these wells has been clarified by the Global, Iraqi, and American authorities.

The disparity in the study and classification of groundwater in Iraq persists; yet, the development and usage of groundwater commenced in 1935 with the mechanical drilling of the first groundwater well [4]. Conventional techniques for identifying drilling sites and well depths yield unpredictable outcomes regarding groundwater quantity and quality; regrettably, these methods lack reliability.

II. MATERIALS AND METHODS

1. THE STUDY AREA AND SAMPLE SELECTION

The study area covers 1,250,000m2 of the West of the capital, Baghdad, West Iraq, between the latitude 33.4237° N and the longitude 43.3076° E.

The samples collected from the wells were placed in glass containers in the summer of 2024-2025 (Tab. 1). They were then placed in an icebox according to international protocols and transported to the laboratory.

Tab. 1 The locations of the wells from which the samples were collected.

Wells N.	Longitude	Latitude	Depth	The surplus
1	42.261340	33.406900	22.0m	3.0m
2	43.256985	33.405565	7.25m	1.9m
3	43.255370	33.405452	5.20m	1.7m
4	43.260480	33.403193	9.00m	2.0m

2. CHEMICAL ANALYSIS

Twelve samples were collected using polyethylene bottles after cleaning it well for a period of three months (August 2024, December 2024 and April 2025). The collection and analysis of samples have been carried out based on standard roads approved. After collecting samples parameters such as pH methods, TDS and EC are measured in the Lab. Anions in addition cations were measured in all groundwater samples in the laboratory. By flame photometer cations such as Ca^{2+}, Na^{+}, and K^{+}, have been analysis and by EDTA titration method Ca^{2+}, Mg^{2+} has been analysis. HCO_3^- analyzed by H_2SO_4 titration method and Cl- by $AgNO_3$ titration method [17] Tab. 2.

Tab. 2 The devices that were used in the sample analysis

Summary of device table	
The compound	Main devices
NO_3^-	UV-Vis Spectrophotometer
K^+ , Na^+	Flame Photometer
Ca^{2+} , Mg^{2+}	AAS
HCO_3^-	Titration
SO_4^{2-}	UV-Vis Spectrophotometer
P	UV-Vis
Cl^-	Ion-Selective Electrode

III. RESULTS AND DISCUSSION

3.2.1. THE PH VALUE

The World Health Organization recommendations stipulate that the acceptable pH range for drinking water is 6.5 to 8.5. The pH levels of groundwater in the research area ranged from 7.2 to 8.5, signifying slightly acidic to somewhat basic water. All these pH levels fell inside the acceptable boundaries. The WHO states that a pH below 6.5 or above 9.2 significantly compromises the potability of drinking water. The pH level typically does not directly affect human health; however, elevated pH values can promote scale formation in water pipes and diminish the disinfection efficacy of chlorine. Increased alkalinity in water necessitates an extended contact duration or a heightened free residual chlorine concentration at the conclusion of the contact period for sufficient disinfection. At pH 6–8, the free residual chlorine must be maintained at 0.4–0.5 mg/L; at pH 8–9, it increases to 0.6 mg/L, and chlorination may become ineffective above pH 9 [18].

3.2.2. THE EC VALUE

Electrical conductivity (EC) indicates the concentration of ionized solutes in water. The maximum allowable concentration of electrical conductivity for potable water is 1400 µs/cm[18]. The EC values of samples from these wells ranged from 3.3 to
5.5 EC dsm^{-1}, showing elevated EC levels exceeding the permitted limit for drinking water. Chebotarev [19] studied how groundwater changes as it moves and stated that there is a type of water with bicarbonate, sulfate, and chloride from where it comes from to where it goes. Aside from the Chebotarev sequence, the primary explanation for the increase in EC in well 4 is attributable to the total soil composition.

As stated in [20], elevated EC levels diminish the osmotic activity of plants, hence hindering their ability to absorb water and nutrients from the soil. The high level of EC is due to higher amounts of Ca^{2+} , Mg^{2+} , and Cl^- , as shown by the strong connection between these ions.

3.2.4. THE TOTAL DISSOLVED SOLIDS VALUE

Total dissolved solids (TDS) comprise inorganic salts, including calcium, magnesium, potassium, sodium, bicarbonates, chlorides, and sulfates, together with trace amounts of organic materials dissolved in water. The

WHO indicated that total solid concentrations exceeding 1500 mg/liter would significantly compromise water potability. TDS concentrations exceeding 1000 mg/liter can cause scaling in water pipelines, heaters, boilers, and domestic equipment. The maximum allowable concentration of total dissolved solids (TDS) in drinking water is 1000 mg/liter, determined by taste factors[18]. A universal scale for salinity, developed by this author and Arumugan [21]. The total dissolved solids (TDS) values of samples in this study area ranged from 340 to 700 mg/L.

SODIUM ADSORPTION RATIO (SAR %)

The Sodium Adsorption Ratio (SAR) is one of the important criteria for determining the suitability of water for irrigation. Sodium is an essential part of salinity and remains dissolved in exchangeable sodic soils and waters. The Sodium Adsorption Ratio (SAR %) can be extracted using the following equation[22] Tab. 3.

$$SAR = \frac{Na}{\sqrt{ca+mg}\ /2} X100$$

Tab. 3 evaluates irrigation water based on sodium adsorption ratio [23]**.**

Water quality and its suitability for irrigation	Sodium adsorption percentage (%)
Excellent for irrigation	Less than 10
Good for irrigation	10-18
Suitable for irrigation	19-26
Not suitable	Greater than 26

THE PERCENTAGE OF SODIUM NA%

The percentage of sodium dissolved in water to the rest of the salts (potassium, calcium, and magnesium) is one of the basic criteria used to determine the suitability of water for agricultural irrigation purposes. This is because the interaction of sodium ions with soils imparts alkaline and basic properties, which affects the plant and makes it difficult for it to obtain water and nutrients Tab. 4. The percentage of sodium is calculated according to the following equation[24]:

$$\text{Na\%} = \frac{\text{Na}}{\text{Na+k+Ca+Mg}} \times 100$$

Tab. 4 Wilcox Classification for Evaluating Irrigation Water Quality [25]**.**

Type of water	Code	Sodium percentage
Excellent	A	Less than 20
Good	B	21-40
Acceptable	C	41-60
doubts its validity.	D	61-80
Not valid	E	81 and above

IV. RESULTS AND DISCUSSIONS:

Evaluating the suitability of well water for irrigation purposes:

The study area (the university campus) suffers from a lack of water, especially in the summer, causing plants to struggle and die. Therefore, alternatives to water sources must be found, leading to the idea of drilling wells that should have water suitable for irrigating plants and even for drinking if necessary. The suitability of water for various purposes primarily depends on the sodium ion percentage (Na %) and the sodium adsorption ratio (SAR %). It is evident from Tab.5 compared to Tab. 6 that the wells in the study area, during the times the samples were analyzed, have good and suitable water for irrigation. Based on this classification, it can be used for irrigating agricultural crops.

Tab. 5. evaluates well water based on sodium content.

NO	August		December		April	
	Na%	Water quality	Na%	Water quality	Na%	Water quality
1	30.1	Good water	31.5	Good water	32.1	Good water
2	27.8	Good water	27.7	Good water	29.5	Good water
3	32.2	Good water	32.2	Good water	33.6	Good water
4	26.8	Good water	26.7	Good water	28.3	Good water

Tab. 6. Evaluates Well Water Based on Sodium Adsorption Ratio

NO	August		December		April	
	SAR%	Water suitability	SAR%	Water suitability	SAR%	Water suitability
1	19.9	Suitable for irrigation	20.2	Suitable for irrigation	20.2	Suitable for irrigation
2	16.8	Good for irrigation	16.2	Good for irrigation	16.2	Good for irrigation
3	20.7	Suitable for irrigation	20.2	Suitable for irrigation	20.2	Suitable for irrigation
4	16	Good for irrigation	15.2	Good for irrigation	15.2	Good for irrigation

The results in Tab.5. compared to Tab.6 showed the suitability of sodium adsorption ratio in the studied well waters at different times well-studied, indicating the possibility of using this water for agricultural irrigation.

THE SUITABILITY OF GROUNDWATER FOR DRINKING PURPOSES:

Groundwater in the study area is considered an alternative source that can be recommended for use during water shortages after studying and determining its suitability for drinking purposes. One of the important characteristics of drinking water is that it should be free from chemical and biological substances that affect human health. The classification of water for drinking purposes depends on several attributes such as dissolved salts and positive ions (potassium, sodium, magnesium, calcium) and negative ions (sulfates, chlorides, bicarbonates). The classification of groundwater in the study area relied on Iraqi, international, and American standards. The permissible maximum limit of total dissolved salts is (1000) mg/L according to the approved Iraqi and international specifications, while the American specifications allow a maximum limit of (500) mg/L. Through the analysis of the data in Tab. 7 and its comparison with Tab. 8, it was found that most of the wells are not suitable for drinking due to the high salt content exceeding the permissible limit. Even if they are suitable for a certain element, another element may not be suitable, which can have health effects if used for drinking purposes. Any change in one of the elements, even if minor, can have an impact, and it is not recommended for drinking. However, it can be used for cleaning and other daily uses.

Tab. 7 Global, Iraqi, and American Standards for Determining the Potability of Drinking Water [26][27]**.**

Parameter	World Health Organization specifications 2011, WHO (mg/L)	Iraqi Standard Specifications 2010, IQS (mg/L)	Specifications of the US Environmental Protection Agency 1975 USEPA (mg/L)
pH	8.5	8.5	-
K+	12	-	20
Ec	15	-	-
Na+	400	200	200
Mg+2	150	150	125
Ca2+	200	200	200
Cl-	600	600	250
SO4-2	400	400	250
HCO-3	500	-	500
TDS	1000	1000	500
NO3	45	50	-

Tab. 8 Water specifications for the study area according to WHO, Iraqi, and American standards

Parameter	World Health Organization specifications 2011, WHO (mg/L)			Iraqi Standard Specifications 2010, IQS (mg/L)			Specifications of the US Environmental Protection Agency 1975 USEPA (mg/L)		
	August	December	April	August	December		August	December	April
pH	All of them are suitable.	All of them are suitable.	All of them are suitable.	All of them are suitable.	All of them are suitable.		-	-	-
Ec	All of them are fine.	All of them are fine.	All of them are fine.	-	-		-	-	-
K+	None of them are suitable.	None of them are suitable.	None of them are suitable.	-	-		None of them are suitable.	None of them are suitable.	None of them are suitable.
Na+	None of them are suitable.	None of them are suitable except for number2.	None of them are suitable except for number 2.	None of them are suitable.	None of them are suitable.		None of them are suitable.	None of them are suitable.	None of them are suitable.
Mg^{2+}	None of them are suitable.	None of them are suitable.	None of them are suitable.	None of them are suitable.	None of them are suitable.		None of them are suitable.	None of them are suitable.	None of them are suitable.
Ca2+	None of them are suitable.	None of them are suitable.	None of them are suitable.	None of them are suitable.	None of them are suitable.		None of them are suitable.	None of them are suitable.	None of them are suitable.
Cl^-	All of them are suitable.	All of them are suitable.	All of them are suitable.	All of them are fine.	All of them are fine.	All of them are fine.	None of them are suitable	None of them are suitable.	None of them are suitable.
SO_4^{2-}	None of them are suitable.	None of them are suitable.	None of them are suitable.	None of them are suitable.	None of them are suitable.		None of them are suitable.	All of them are fine.	None of them are suitable.
HCO^{3-}	All of them are fine.	All of them are fine.	All of them are fine.	-	-		All of them are fine.	All of them are fine except for number 1.	All of them are fine.
TDS	All of them are fine.	All of them are suitable.	All of them are suitable.	All of them are suitable.	All of them are suitable.	All of them are suitable.	All of them are not suitable except for 3.	All of them are fine except for number 1.	All of them are fine except for number 1

The examination of water samples in Tab. 9 revealed the presence of *Escherichia coli* bacteria in the water, which is an indicator of biological bacterial contamination in most samples. The levels of contamination varied in bacterial counts, which are an important measure of drinking water pollution. The samples ranged from low contamination (+), which is considered acceptable, to medium contamination (++), which requires treatment and caution when using the water for drinking, and finally (+++) the contaminated water that is not suitable for drinking.

The variation in results is due to the distance and proximity of water sources to service buildings and excavated heavy water tanks, leading to the transfer of pollutants, primarily *E. coli*, to nearby groundwater.

Tab.9 Amount of biological pollution with *E. coil* in water samples from the study area in two different environments.

NO	August		December		April	
	Nutrient Agar	MacConkey Agar	Nutrient Agar	MacConkey Agar	Nutrient Agar	MacConkey Agar
1	+++	+++	+++	+++	+++	+++
2	+	+	++	++	++	++
3	++	++	+	+	++	++
4	++	++	++	++	++	++
Low growth (+), Medium growth (++), High growth (+++)						

Finally, we can recommend conducting more recent studies on the use of advanced technologies that facilitate the assessment of well water, detection of water quality index based on artificial intelligence, groundwater, as well as detection of nitrate contamination and other indicators [28], [29]. Also, focus should be placed on studying the remaining cations and anions as follows: Na+ >Mg2+ >Ca2+ [30]. And the rest of the salts such as HCO-3, Cl-1, SO-24 [31], Total dissolved solids (TDS) and chloride (Cl−) levels should also be studied, respectively. Therefore, boiling, activated carbon filters, rainwater harvesting, and appropriate coatings for metal surfaces of water supply pipes, among other effective strategic measures, are proposed to provide safe water for drinking, irrigation, and industrial purposes[32].

Tables 10 and 11 show the well water values measured over three different time periods, along with an Anova table 11 for statistical analysis.

Tab.10 Cations and anions values in well water at three different time periods.

	NO	NO3	K	Na	Ca	Mg	HCO3	SO4	P	Cl
August	1	33.1	34	557	944	314	111	2832	0.09	485
	2	35	33.9	439	837	269	117	2775	0.08	405
	3	28	30.1	577	807	380	98.4	2393	0.08	353
	4	29	25	447	812	384	107.9	2940	0.07	572
December	NO	NO3	K	Na	Ca	Mg	HCO3	SO4	P	Cl
	1	28.2	33.1	540	852	289	104	2703	0.09	463
	2	32.1	32.4	398	799	208	109	2560	0.07	394
	3	26.4	29.5	534	780	311	91.2	2140	0.09	351
	4	26.3	23.8	404	767	320	99.4	2560	0.06	561
April	NO	NO3	K	Na	Ca	Mg	HCO3	SO4	P	Cl
	1	26.4	32.1	523	825	248	90.2	2701	0.08	433
	2	30	30.2	395	714	198	98	2554	0.07	371
	3	24.2	28.3	529	716	300	83	2138	0.09	325
	4	25.1	22.7	401	709	286	83.1	2557	0.06	537

Table 11: Some indicators of well water values measured in three different time periods.

	TDS m g/L	*EC dS m-1*	*NaCl %*	*pH*
August	700	4.5	7	8
	550	5	11	7.5
	460	3.9	10.7	7.2
	570	5.4	15	8.4
December	*TDS m g/L*	*ECdSm-1*	*NaCl %*	*pH*
	600	4.3	6.2	8
	480	4.8	9	7.8
	370	3.6	7.4	7.6
	480	5.5	14.9	8.5
April	*TDS m g/L*	*ECdSm-1*	*NaCl %*	*pH*
	510	4.1	5.8	8.1
	450	4.4	8.5	7.6
	340	3.3	6.6	7.4
	450	5.2	13.7	8.5

Table. 12 Anova

Ca

Month	W1	W2	W3	W4	Average
Aug	944.000	837.000	807.000	812.000	850.000
Sep	852.000	799.000	780.000	738.900	792.475
April	825.000	714.000	716.000	709.000	741.000
Average	873.667	783.333	767.667	753.300	
L.S.D	M	W	M.W		
	13.8	15.94	N.S		

K

Month	W1	W2	W3	W4	Average
Aug	34.000	33.900	30.100	25.000	30.750
Sep	33.100	32.400	29.500	22.930	29.483
April	32.100	30.200	28.300	22.700	28.325
Average	33.067	32.167	29.300	23.543	
L.S.D	M	W	M.W		
	0.588	0.679	1.175		

Cl

Month	W1	W2	W3	W4	Average
Aug	485	405	353	572	453.75
Sep	463	394	351	540.4	437.1
April	433	371	325	537	416.5
Average	460.3333	390	343	549.8	
L.S.D	M	W	M.W		
	8.88		17.76		

Mg

Month	W1	W2	W3	W4	Average
Aug	314	269	380	384	336.75
Sep	289	208	311	308.3	279.075
April	248	198	300	286	258
Average	283.6667	225	330.3333	326.1	
L.S.D	M	W	M.W		

HCO3					
Month	W1	W2	W3	W4	Average
Aug	111	117	98.4	107.9	108.575
Sep	104	109	91.2	95.76	99.99
April	90.2	98	83	83.1	88.575
Average	101.7333	108	90.86667	95.58667	
L.S.D	M	W	M.W		
	1.799	2.077	3.598		

NO3					
Month	W1	W2	W3	W4	Average
Aug	33.1	35	28	29	31.275
Sep	28.2	32.1	26.4	25.34	28.01
April	26.4	30	24.2	25.1	26.425
Average	29.23333	32.36667	26.2	26.48	
L.S.D	M	W	M.W		
	0.539	0.623	1.079		

Na					
Month	W1	W2	W3	W4	Average
Aug	557	439	577	447	505
Sep	540	398	534	389.2	465.3
April	523	395	529	401	462
Average	540	410.6667	546.6667	412.4	
L.S.D	M	W	M.W		
	9.83	11.35	19.66		

SO4					
Month	W1	W2	W3	W4	Average
Aug	2832	2775	2393	2940	2735
Sep	2703	2560	2140	2466.1	2467.275
April	2701	2554	2138	2557	2487.5
Average	2745.333	2629.667	2223.667	2654.367	
L.S.D	M	W	M.W		
	45.24	52.23	90.47		

P					
Month	W1	W2	W3	W4	Average
Aug	0.09	0.08	0.08	0.07	0.08
Sep	0.09	0.07	0.09	0.0578	0.07695
April	0.08	0.07	0.09	0.06	0.075
Average	0.086667	0.073333	0.086667	0.0626	
L.S.D	M	W	M.W		
	0.0016	0.00184	0.00319		

V. Reference

[1] A. Baba, R. A. L. Karem, and H. Yazdani, "Groundwater resources and quality in Syria," *Groundwater for Sustainable Development*, vol. 14, p. 100617, 2021.

[2] A. H. Ismail, G. Hassan, and A.-H. Sarhan, "Hydrochemistry of shallow groundwater and its assessment for drinking and irrigation purposes in Tarmiah district, Baghdad governorate, Iraq," *Groundwater for Sustainable Development*, vol. 10, p. 100300, 2020.

[3] N. Al-Ansari, N. Abbas, J. Laue, and S. Knutsson, "Water scarcity: Problems and possible solutions," *Journal of Earth Sciences and Geotechnical Engineering*, vol. 11, no. 2, pp. 243–312, 2021.

[4] N. Abbas, S. Wasimi, N. Al-Ansari, and N. Sultana, "Water resources problems of Iraq: Climate change adaptation and mitigation," *Journal of Environmental Hydrology*, vol. 26, 2018.

[5] H. S. Al-Bahrani, Z. Abbas, and A. Y. Insaf, "Environmental assessment of groundwater in Najaf governorate (Iraq) for irrigation purposes," *Kufa journal of engineering*, vol. 11, no. 4, pp. 46–57, 2020.

[6] R. C. Heath, *Basic ground-water hydrology*, vol. 2220. US Department of the Interior, US Geological Survey, 1998.

[7] F. A. O. Otieno, I. O. Olumuyiwa, and G. M. Ochieng, "Groundwater: Characteristics, qualities, pollutions and treatments: An overview," *African journal of agricultural research*, 2012.

[8] E. Krogulec, J. J. Małecki, D. Porowska, and A. Wojdalska, "Assessment of causes and effects of groundwater level change in an urban area (Warsaw, Poland)," *Water*, vol. 12, no. 11, p. 3107, 2020.

[9] S. AlJawad, N. Al-Ansari, N. Adamo, V. K. Sissakian, J. Laue, and S. Knutsson, "Groundwater quality and their uses in Iraq," *Journal of Earth Sciences and Geotechnical Engineering*, vol. 8, no. 3, pp. 123–144, 2018.

[10] M. Mosaffa, S. Nazif, Y. K. Amirhosseini, W. Balderer, and H. M. Meiman, "An investigation of the source of salinity in groundwater using stable isotope tracers and GIS: a case study of the Urmia Lake basin, Iran," *Groundwater for Sustainable Development*, vol. 12, p. 100513, 2021.

[11] G. Krishan *et al.*, "Assessment of groundwater quality for drinking purpose by using water quality index (WQI) in Muzaffarnagar and Shamli Districts, Uttar Pradesh, India," *Hydrol Current Research*, vol. 7, no. 227, p. 2, 2016.

[12] S. M. Shirazi, M. I. Adham, N. H. Zardari, Z. Ismail, H. M. Imran, and M. A. Mangrio, "Groundwater quality and hydrogeological characteristics of Malacca state in Malaysia," *Journal of Water and Land Development*, 2015.

[13] S. Benrabah, B. Attoui, and M. Hannouche, "Characterization of groundwater quality destined for drinking water supply of Khenchela City (eastern Algeria)," *Journal of Water and Land Development*, vol. 30, no. 1, p. 13, 2016.

[14] A. L. Hernandez Cordero, P. J. Tango, and R. A. Batiuk, "Development of a multimetric water quality indicator for tracking progress towards the achievement of Chesapeake Bay water quality standards," *Environmental Monitoring and Assessment*, vol. 192, no. 2, p. 94, 2020.

[15] D. Sukumaran, R. Saha, and R. C. Saxena, "Ground water quality index of Patna, the capital city of Bihar, India," *American Journal of Water Resources*, vol. 3, no. 1, pp. 17–21, 2015.

[16] M. Kumar, A. L. Ramanathan, M. S. Rao, and B. Kumar, "Identification and evaluation of hydrogeochemical processes in the groundwater environment of Delhi, India," *Environmental geology*, vol. 50, pp. 1025–1039, 2006.

[17] S. Z. Jassim, D. H. Hagopian, and H. A. Al-Hashimi, "Geological Map of Iraq, scale 1: 1,000,000," *Iraq Geological Survey Publications, Baghdad, Iraq*, 1986.

[18] W. H. Organization, *assessing microbial safety of drinking water improving approaches and methods: Improving approaches and methods*. OECD Publishing, 2003.

[19] I. I. Chebotarev, "Metamorphism of natural waters in the crust of weathering—1," *Geochimica et Cosmochimica Acta*, vol. 8, no. 1–2, pp. 22–48, 1955.

[20] N. S. Rao, "Hydrogeology and hydrogeochemistry of Visakhapatanam Ph," *D Thesis unpublished*, 1986.

[21] K. Arumugam and K. Elangovan, "Hydrochemical characteristics and groundwater quality assessment in Tirupur region, Coimbatore district, Tamil Nadu, India," *Environmental geology*, vol. 58, pp. 1509–1520, 2009.

[22] M. K. Al-Tememi, "Groundwater quality and origin within Dibdibba aquifer near Jabel Sanam area southern of Basrah Governorate, Iraq," *Mesopot. J. Mar. Sci*, vol. 30, no. 1, pp. 47–56, 2015.

[23] L. A. Richards, *Diagnosis and improvement of saline and alkali soils*, no. 60. US Government Printing Office, 1954.

[24] I. A. Alwan, H. H. Karim, and N. A. Aziz, "Groundwater aquifer suitability for irrigation purposes using multi-criteria decision approach in Salah Al-Din Governorate/Iraq," *AgriEngineering*, vol. 1, no. 2, pp. 303–323, 2019.

[25] A. N. Al-Fatlawi and Q. Y. Al-Kubaisi, "Hydrochemistry for Umm Er Radhuma Aquifer–West of Iraq,"

Euphrates Journal of Agriculture Science, vol. 4, no. 1, pp. 1–14, 2021.

[26] N. M. Ramli, "Microalgae-bacteria interactions: a key for improving water quality in recirculating aquaculture systems?," 2018, *Wageningen University and Research*.

[27] A. I. Mohammed, S. Naimi, and A. S. Dawood, "Evaluation of the drinking and irrigation quality of groundwater in Basrah, Iraq," *Journal of Ecological Engineering*, vol. 24, no. 9, 2023.

[28] S. S. Soundharyaa, V. Amudha, and S. V. Lakshmi, "An Artificial Intelligence (AI) based Water Quality Index Detection and Ground Water Potential," *Proceedings of the 2023 2nd International Conference on Augmented Intelligence and Sustainable Systems, ICAISS 2023*, pp. 245–251, 2023, doi: 10.1109/ICAISS58487.2023.10250713.

[29] D. V. V. Prasad, L. Y.Venkataramana, and R. Duttulur, "Water Quality analysis of Well Water using Machine Learning Techniques," *Int J Environ Sci*, vol. 11, no. 5s, pp. 115–125, May 2025, doi: 10.64252/S5EWGE38.

[30] N. Subba Rao, P. Surya Rao, G. Venktram Reddy, M. Nagamani, G. Vidyasagar, and N. L. V. V. Satyanarayana, "Chemical characteristics of groundwater and assessment of groundwater quality in Varaha River Basin, Visakhapatnam District, Andhra Pradesh, India," *Environ Monit Assess*, vol. 184, no. 8, pp. 5189–5214, Aug. 2012, doi: 10.1007/S10661-011-2333-Y.

[31] N. Subba Rao, "Groundwater quality from a part of Prakasam District, Andhra Pradesh, India," *Appl Water Sci*, vol. 8, no. 1, Mar. 2018, doi: 10.1007/S13201-018-0665-2.

[32] N. S. Rao, A. Dinakar, M. Sravanthi, and B. K. Kumari, "Geochemical characteristics and quality of groundwater evaluation for drinking, irrigation, and industrial purposes from a part of hard rock aquifer of South India," *Environmental Science and Pollution Research*, vol. 28, no. 24, pp. 31941– 31961, Jun. 2021, doi: 10.1007/S11356-021-12404-Z.