



## RESEARCH ARTICLE - ENGINEERING

### Hydrochemistry of Groundwater in AL Jallam Desert, Salah Al-Din Governorate, Iraq

Farid M Alatar<sup>1</sup>, Alhassan H. Ismail<sup>2\*</sup>, Muntasir A. Shareef<sup>2</sup>, Corina Boncescu<sup>3</sup>

<sup>1</sup> Engineering Technical College - Baghdad, Middle Technical University, Baghdad, Iraq

<sup>2</sup> Institute of Technology / Baghdad, Middle Technical University, Baghdad, Iraq

<sup>3</sup> Faculty of Energy Engineering, University Politehnica of Bucharest, Romania

\* Corresponding author E-mail: [alhassan\\_hayder@mtu.edu.iq](mailto:alhassan_hayder@mtu.edu.iq)

#### Article Info.

#### Abstract

##### Article history:

Received  
02 July 2023

Accepted  
26 July 2023

Publishing  
30 August 2023

The present paper assesses the hydrochemistry of groundwater in AL JALLAM desert and its suitability for human consumption and irrigation. Nine groundwater samples were taken, and they were analyzed for major ions to determine the Piper diagram and Gibbs plot. The results showed that the evaporation process is the primary control of the water quality in the study area. Water Quality Index (WQI) method was utilized to assess the suitability of water for human consumption, whereas different geochemical parameters were used to evaluate the irrigation suitability. Generally, the groundwater in the study area is not suitable for drinking and irrigation. Based on cluster analysis (CA), it was found that two levels of pollution levels in the AL JALLAM desert.

This is an open-access article under the CC BY 4.0 license (<http://creativecommons.org/licenses/by/4.0/>)

Publisher : Middle Technical University

**Keywords:** Groundwater; Hydrochemistry; Iraq; AL JALLAM Desert.

## 1. Introduction

MENA region, including Iraq, is located in an arid and semi-arid area facing a water crisis during the last decades. Water shortage in Iraq is based on several factors such as population growth, water quality deterioration, climate change, unfair use of water quota of neighboring countries, and mismanagement of water resources [1-3]. Drought and groundwater are closely related in Iraq. For many years, the nation has had a severe water shortage, which has caused groundwater supplies to be depleted. Drought is a serious problem in Iraq, particularly in the southern and central regions of Iraq. Droughts have become more frequent and more severe, and the country's water resources have been severely depleted [2].

Tigris and Euphrates rivers have decreased in their flow rate due to the launching of the Southeastern Anatolia Project (GAP) project. Iraq has a number of rivers and lakes that are important sources of water for the country. However, due to a variety of factors, the quality of surface water in Iraq has deteriorated in recent years. One of the main factors contributing to this decline is pollution from industrial and agricultural sources. The discharge of untreated wastewater into rivers and other bodies of water is a major problem [4]. Furthermore, the concentration of Total Dissolved Solids (TDS) has increased in the rivers due to fewer amounts of water and evaporation phenomena [5, 6]. This led people to search for alternative sources of water such as groundwater. Groundwater quality can be affected by various natural and human-induced factors. The natural factors include geology, climate, and soil characteristics, while human-induced factors include land-use practices, pollution, and industrial activities [7].

Many natural processes help to protect and improve groundwater quality. These include the natural filtration provided by soils, the attenuation of contaminants by subsurface geological materials, and the dilution and natural degradation of contaminants by microbiological processes. However, human activities such as poorly designed wastewater treatment systems, inadequate land use practices, careless disposal of chemicals, and industrial activities have accelerated the degradation of groundwater quality [8]. Contamination and pollution of groundwater are serious issues as they affect the quality of water available for consumption by humans and aquatic life [9]. Contaminants can enter the groundwater system through seepage from landfills, illegal dumping, and chemical applications, while pollution from nitrogen and phosphorus from agricultural activities can result in excess nitrates in groundwater [10]. Numerous studies were conducted to explore the groundwater hydrochemistry and investigate their suitability for different uses [11-17].

Nomenclature & Symbols			
WQI	Water Quality Index	BWQI	Bascaron water quality index
CA	Cluster Analysis	EC	Electrical Conductivity
MENA	Middle East and North Africa	%Na	Sodium Percentage
GAP	Southeastern Anatolia Project	MH	Magnesium Hazards
TDS	Total Dissolved Solids	SAR	Sodium Adsorption Ratio
APHA	American Public Health Association		

AL JALLAM desert is located north of Baghdad. It has no available source of surface water nearby this area. People in this area use groundwater for different uses. To comprehend the geochemical processes that control the water quality in the research area, an effort has been made to examine the hydrochemistry of groundwater. In addition to evaluating the Bascaron water quality index (BWQI) and geochemical indicators to evaluate the suitability of the groundwater for human and irrigation uses in the AL JALLAM desert.

## 2. Materials and Methods

### 2.1. Study area

The AL JALLAM desert is roughly 119 kilometers north of Baghdad. It is situated between latitudes 34°40'0" and 34°20'0" North and longitudes 43°45'30" and 44°7'30" East (Fig. 1). The region, which is located in Salah Al-Din Governorate and has a total area of 933 km<sup>2</sup>, is distinguished by desert land. The area has an average annual rainfall of 14.5 millimeters, with an arid to semi-arid environment. In the summer (June to August), the air temperature approaches 45 °C [18]. The groundwater is the primary source in AL JALLAM desert.

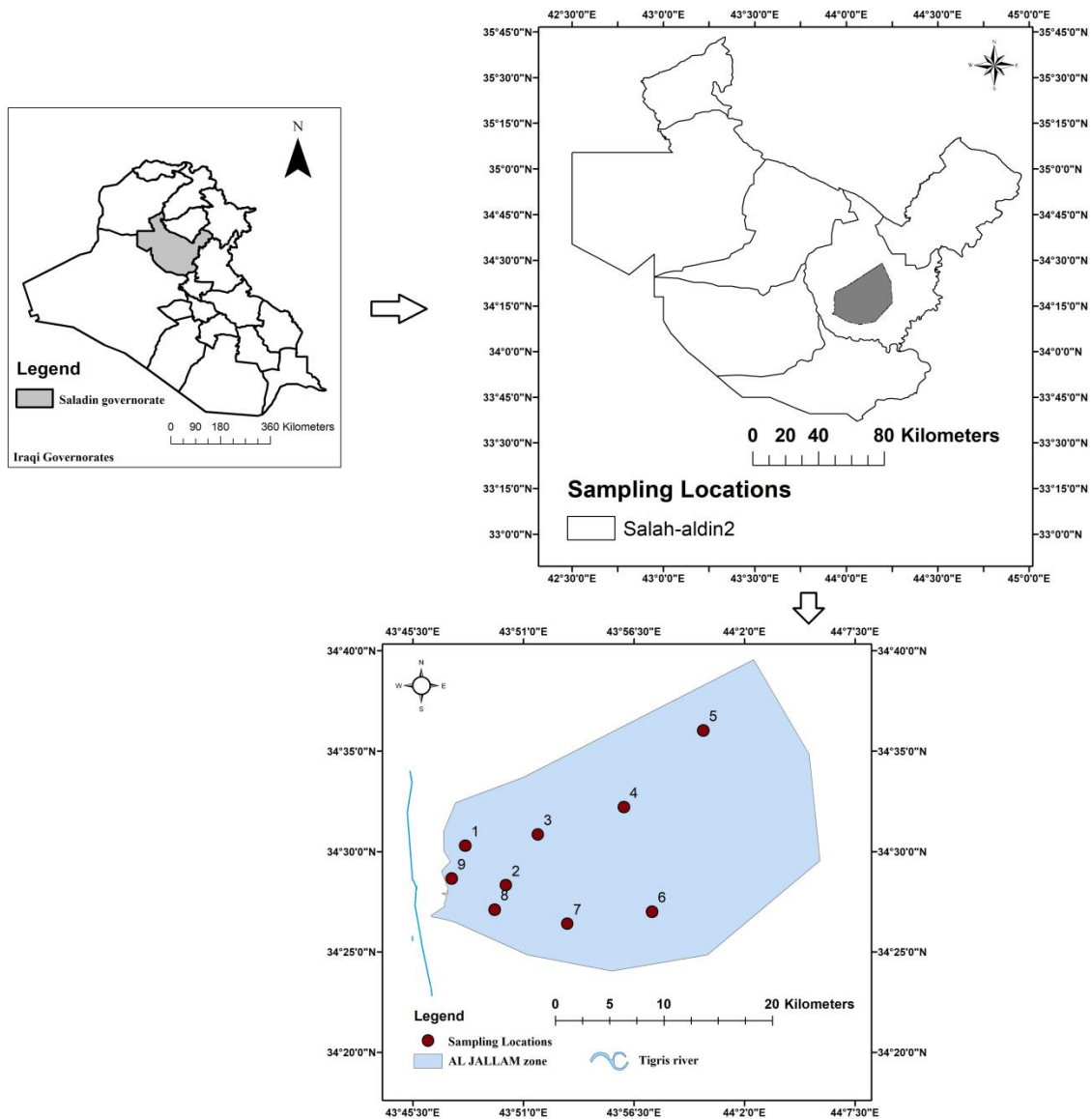


Fig. 1. The study area

### 2.2. Sampling and analysis

In May 2018, nine groundwater samples from tube wells were sampled in 1 litre sterilized polypropylene container. Fig. 1 shows the sampling locations in the study area. Water quality parameters including pH, TDS, EC, Ca<sup>2+</sup>, Mg<sup>2+</sup>, Na<sup>+</sup>, K<sup>+</sup>, Cl<sup>-</sup>, SO<sub>4</sub><sup>2-</sup>, HCO<sub>3</sub><sup>-</sup>, and NO<sub>3</sub><sup>-</sup> were measured in the samples. Standard procedures advised by the American Public Health Association (APHA) were used to conduct the analyses [19]. With the aid of portable equipment, Potential of Hydrogen (pH) and Electrical Conductivity (EC) were determined on-site.

2.3. Cluster analysis

CA is a statistical technique that is used to group the nine groundwater sampling points into clusters based on their similarity. The goal of cluster analysis is to create groups or clusters of groundwater sampling points that are more similar to each other [20]. On several occasions, CA has been used to describe the relationship between the groundwater variables more clearly [20]. In the current paper, the hierarchical agglomeration was created using Ward's approach of linking, and the similarity distance was calculated using the squares Euclidean distance method and visualized using a dendrogram [21] Normality distribution test were conducted prior to CA. International Business Machines-Statistical Package for Social Sciences (IBM-SPSS) 25 for Windows was used to implement the statistical calculations [7].

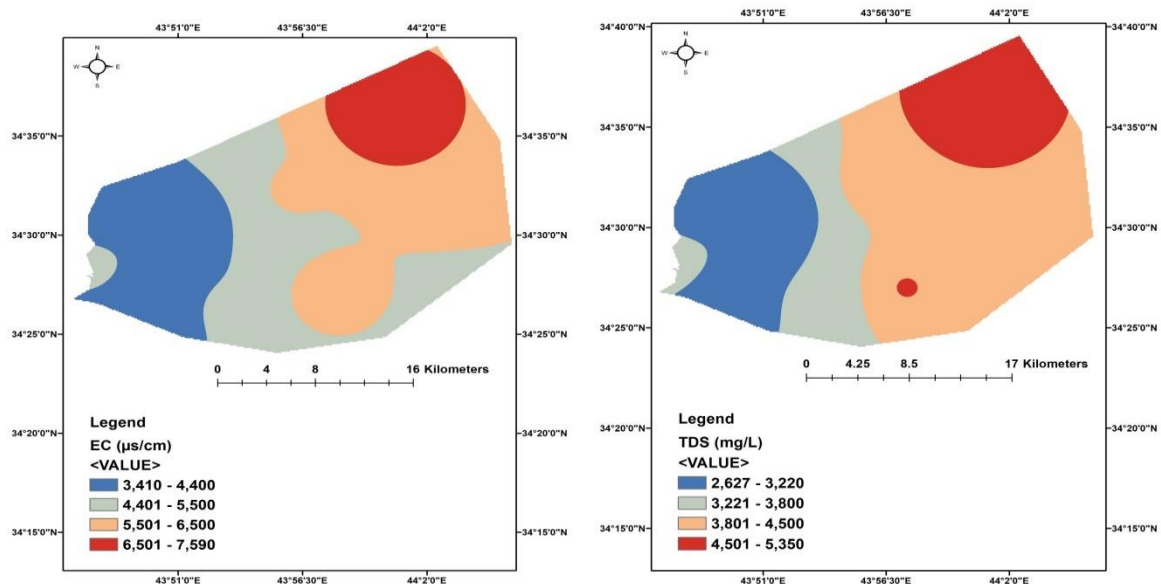
3. Results and Discussion

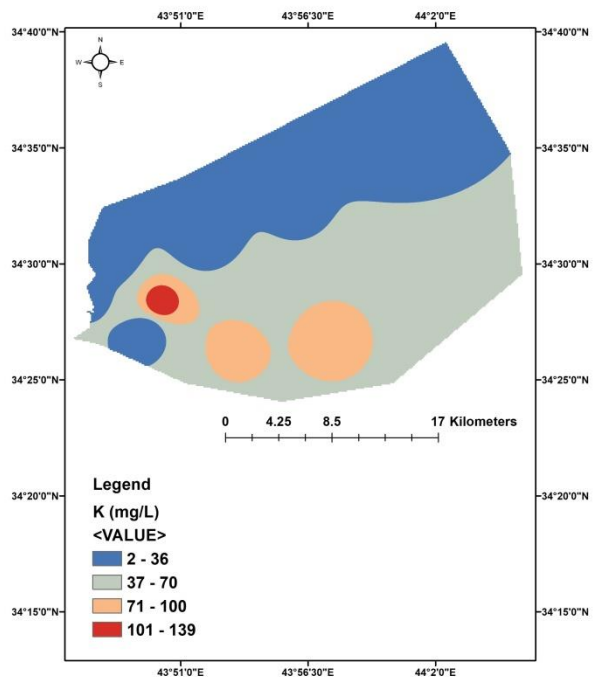
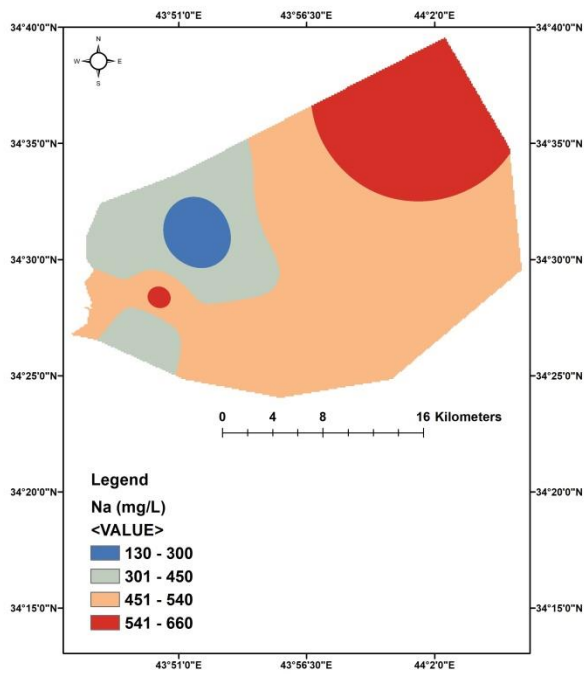
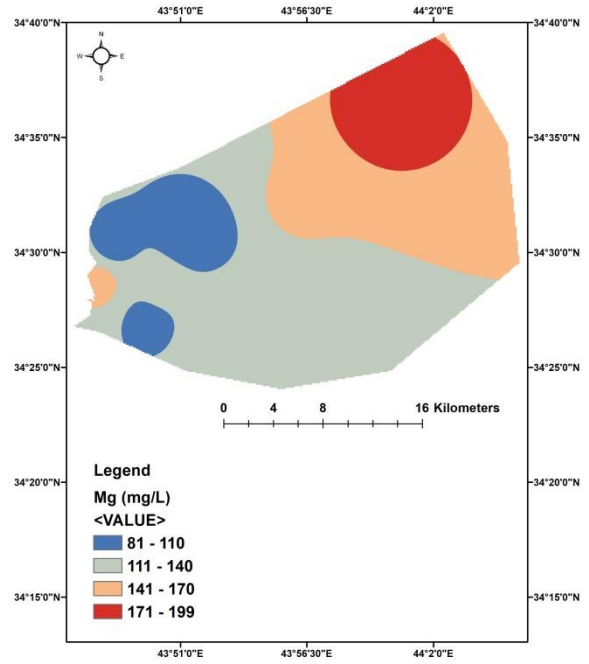
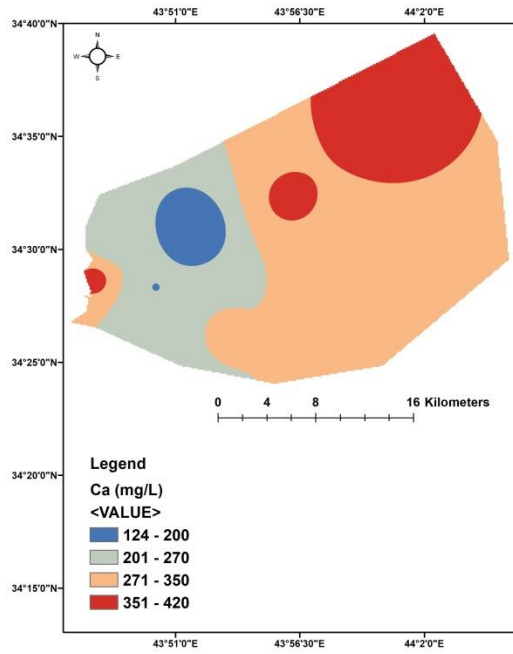
3.1. Hydrochemistry of groundwater

Table 1 displays the results of the primary ion parameters for groundwater quality. The pH of the groundwater in the AL JALLAM desert ranges from 7.16 to 7.81, with an average value of 7.45. In the ALJALLAM desert, the average values for EC and TDS were 4810.67 μS/cm and 3566.22 mg/L, respectively (Table 1). These values are considerably high. Referring to the maximum values of EC and TDS (7590 μS/cm and 5355 mg/L) in AL JALLAM desert, the groundwater cannot be used for irrigation. Ca<sup>2+</sup>, Mg<sup>2+</sup>, Na<sup>+</sup> and K<sup>+</sup> ions have average concentrations of 276.78, 130.11, 460.00, and 44.22 mg/L, respectively. Geochemical processes such as ion exchange, evaporation, and weathering can be attributed to the presence of Ca and Mg. They can originate from a variety of places, including carbonate minerals such as calcite and dolomite as well as silicates like plagioclase, amphibole, and mica. Na and K may have come from anthropogenic sources, saline incursion, or the ion exchange mechanism. In the study region, the average concentrations of the anions Cl<sup>-</sup>, SO<sub>4</sub><sup>2-</sup>, HCO<sub>3</sub><sup>-</sup> and NO<sub>3</sub><sup>-</sup> were 603.33, 1041.11, 323.67, and 2.37 mg/L, respectively (Table 1). Cl<sup>-</sup> can be impacted by a variety of sources or processes, including atmospheric deposits, anthropogenic sources, and solutions of related minerals in evaporated deposits that contain halite (NaCl). Fig. 2 shows the major ions variation of groundwater quality parameters in the AL JALLAM desert.

Table 1. The analytical results of the groundwater in the AL JALLAM desert

Well No.	pH	EC	TDS	K <sup>+</sup>	Na <sup>+</sup>	Mg <sup>2+</sup>	Ca <sup>2+</sup>	Cl <sup>-</sup>	SO <sub>4</sub> <sup>2-</sup>	HCO <sub>3</sub> <sup>-</sup>	NO <sub>3</sub> <sup>-</sup>
1	7.71	3500	2640	3	370	95	220	515	740	300	3
2	7.19	3410	2830	139	580	127	199	641	1245	116	1.3
3	7.81	4020	2802	10	130	81	124	241	541	67	4
4	7.71	5666	4122	31	528	150	370	710	1385	322	2
5	7.70	7590	5355	20	660	198	415	780	1076	566	2
6	7.33	6020	4540	80	465	130	290	640	1090	450	2
7	7.20	4590	3388	80	520	139	283	651	1170	480	4
8	7.16	3480	2627	2	360	90	210	500	730	285	2
9	7.20	5020	3792	33	527	161	380	752	1393	327	1





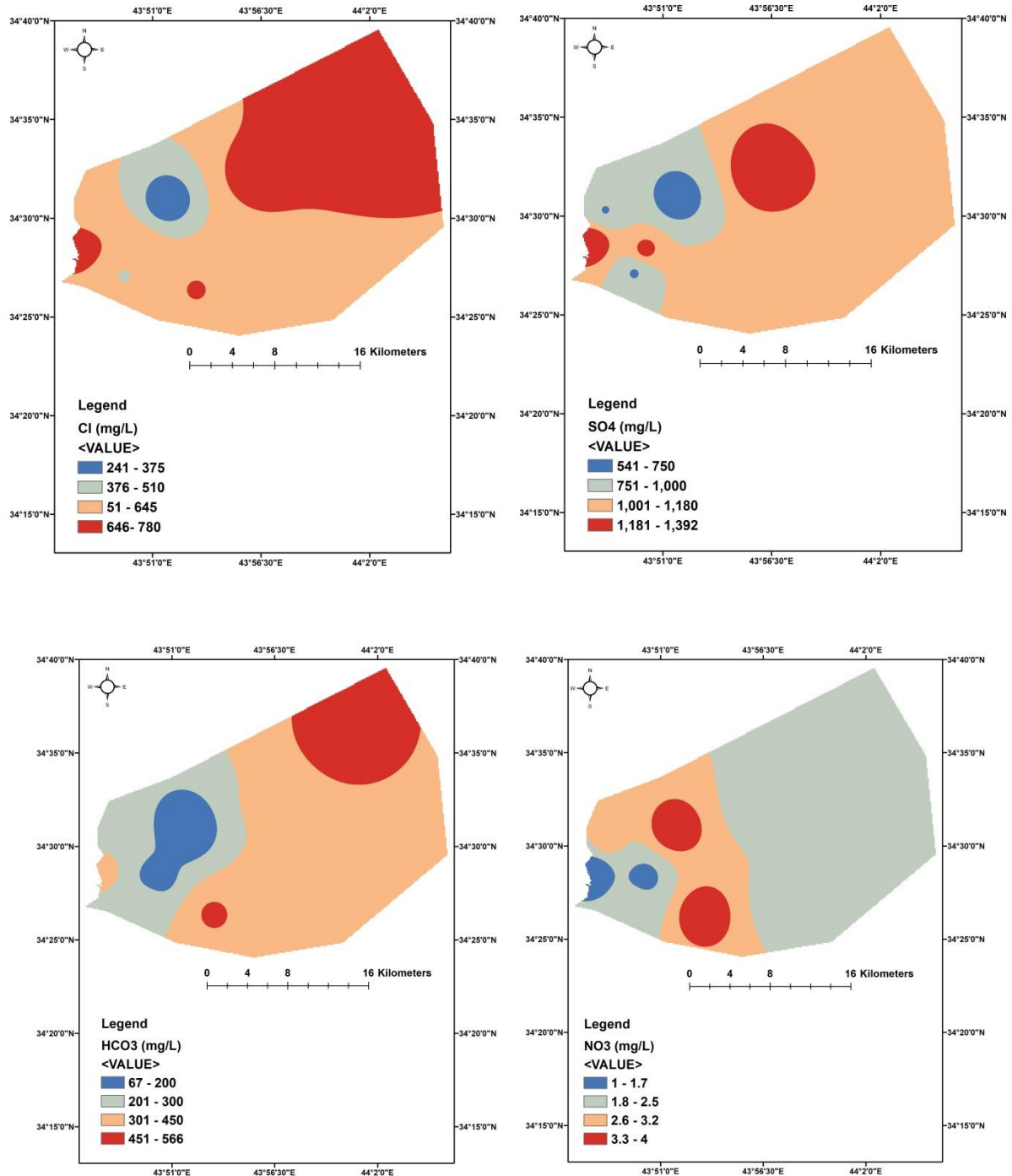


Fig. 2. Major ions variation of groundwater quality parameters in the AL JALLAM desert

### 3.2. Piper and Gibbs plot

Hydro-chemical classification and relationships were studied through piper plot [22] to classify and analyse the chemical composition of groundwater samples. The plot was performed using AquaChem. The plot was drawn using AquaChem (Fig. 3). This diagram helps in identifying the dominant water types and provides insights into water chemistry, such as the presence of different minerals or the water's origin. From Fig. 3, it can be seen that the groundwater samples are divided into three different sorts: mixed Ca-Mg-Cl water types, Na-Cl type, and Ca-Cl type. This observation implies the high saline water in AL JALLAM desert.

The Gibbs plot, also known as the Gibbs diagram or the triangular diagram, is a graphical representation used in geochemistry to analyse and interpret the composition of rocks, minerals, or chemical systems [23]. It can be seen from Fig. 4 that this ratio gives an expression to analyse and interpret the composition of rocks, minerals, or chemical systems. In the present paper, and according to the Gibbs plot, all of the groundwater samples were collected in the zone where evaporation predominates. This result suggests that the evaporation process controls groundwater chemistry primarily in the examined area.

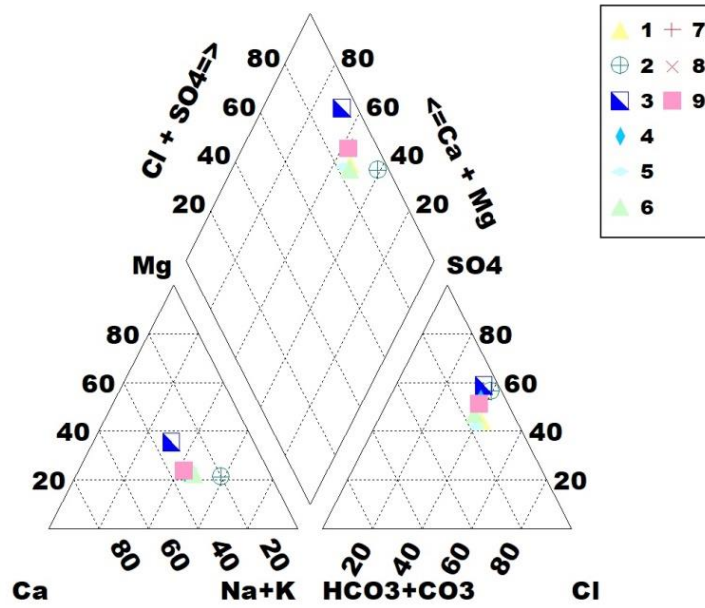


Fig. 3. Piper plot

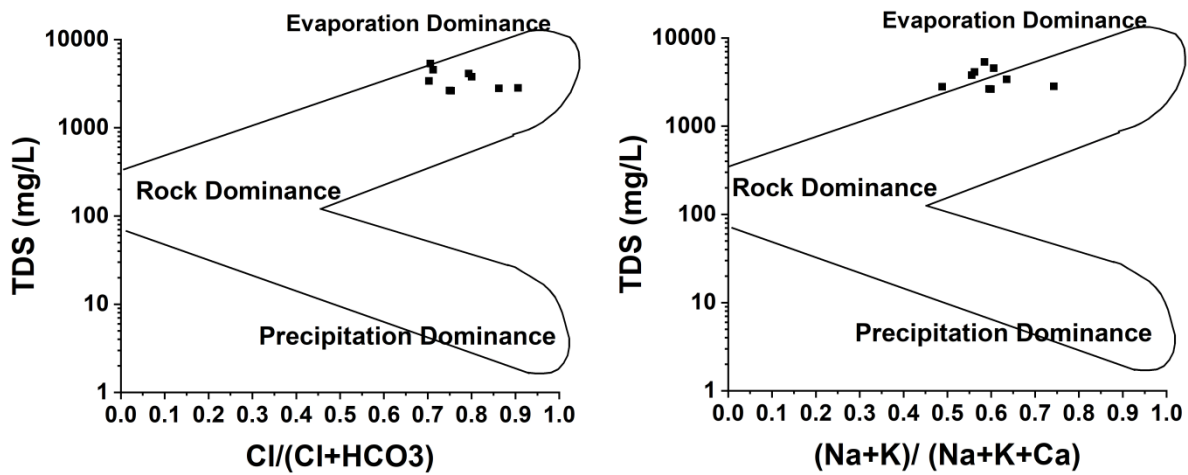


Fig. 4. Gibbs plot

### 3.3. Drinking suitability

Using the WQI model, groundwater samples are assessed for their appropriateness for human consumption. WQI is a popular technique used to evaluate groundwater for different uses [15, 24, 25]. Numerous models of WQI have been developed in the literature [26]. In this paper, Bascaron (BWQI) [27] was selected as it was widely applied [28-30], besides the ability to include many water quality parameters that have already normalization factors by previous research [28, 29]. The final value of BWQI can be calculated as:

$$WQI = \frac{\sum_{i=1}^n C_i P_i}{\sum_{i=1}^n P_i} \quad (1)$$

Where:

$n$  = The sum of variables.

$C_i$  = value of the factor  $i$  after the appropriate normalization.

$P_i$  = proportional weight associated with each factor which has the range of 1 - 4 depending to its impact on water usability.

Eight water quality parameters were evaluated in the present study namely, Nitrate, sulphate, chloride, magnesium, calcium, TDS, EC, and pH.  $HCO_3$ , Na, and K were excluded in the above calculations because they have no normalized and weighted parameters.

The following classification was considered in order to classify water quality:

- “Excellent”: 90-100



- “Good”: 71-90
- “Medium”: 51-70
- “Bad”: 26-50
- “Very bad”: 0-25

Table 2 shows the calculated sub-indices as well as the final values and categories of the water suitability for human consumption, which is found to be “medium” to “bad”. Fig. 7 depicts the variation of BWQI in the AL JALLAM desert.

Table 2. The sub-index values, relative weights, final values of BWQI and categorization values of BWQI index.

Well No.	Sub-index values ( $C_i$ )								BWQI	Categorization
	pH	EC	TDS	Mg	Ca	Cl	SO <sub>4</sub>	NO <sub>3</sub>		
1	90	30	40	60	50	30	20	80	49.09	Bad
2	90	30	40	50	50	30	10	90	48.18	Bad
3	90	30	40	60	70	50	30	80	54.54	Medium
4	90	20	30	50	40	20	10	90	43.63	Bad
5	90	20	20	40	30	20	10	90	40	Bad
6	90	20	30	50	50	30	10	90	45.45	Bad
7	90	30	30	50	50	30	10	80	44.54	Bad
8	90	30	40	60	50	40	20	90	51.81	Medium
9	90	20	30	40	40	20	10	90	42.72	Bad
Relative weight ( $P_i$ )	1	1	2	1	1	1	2	2	$\sum P_i = 11$	

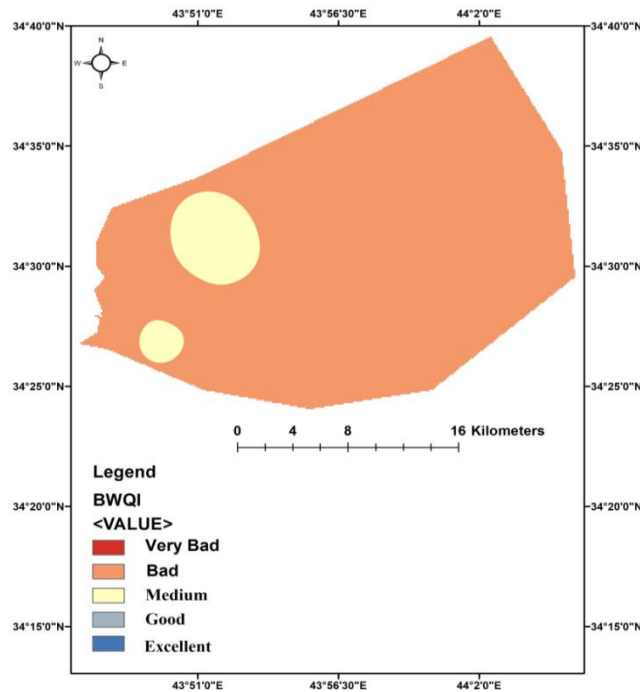


Fig. 5. Map of drinking suitability in AL JALLAM desert

### 3.4. Irrigation suitability

Different geochemical factors, including the US salinity diagram, sodium percentage (%Na), and MH, were taken into consideration in order to determine the appropriateness of groundwater for irrigation. For the US salinity diagram, suggested by [31], the SAR is plotted as opposed to EC.

SAR, %Na and MH were calculated as the following:

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \tag{2}$$

$$Na\% = \left[ \frac{Na^+ + K^+}{Na^+ + K^+ + Ca^{2+} + Mg^{2+}} \right] \times 100 \tag{3}$$

$$MH = \left[ \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} \right] \times 100 \tag{4}$$

Where all values are expressed in milliequivalent per liter.

%Na in the study area shows that the majority of the samples are permissible for irrigation (Fig. 6).

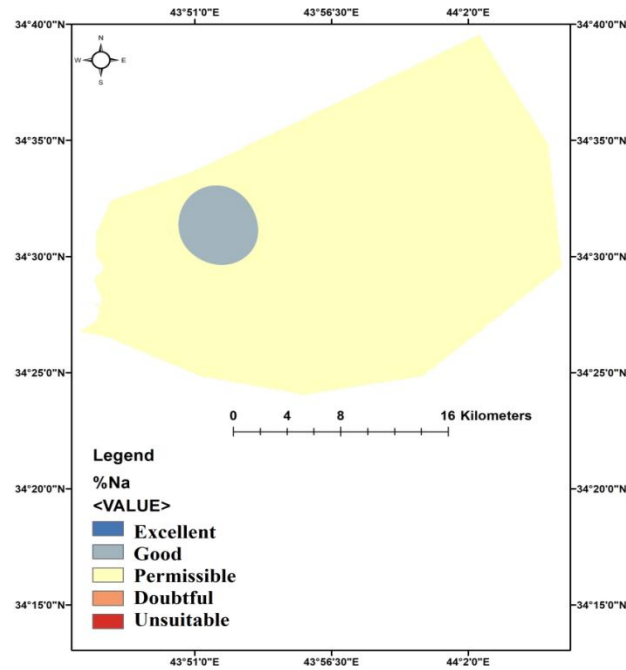


Fig. 6. Map of irrigation suitability in AL JALLAM desert based on %Na

According to the MH results in the research region [32], 82% of the samples have a value of less than 50, indicating that the water is appropriate for irrigation (Fig. 7).

All groundwater samples in the research area were found to fall into the C4S1, C4S2, and C4S3 zones of the US salinity diagram, suggesting that the water would be of very low quality if utilized for irrigation (Fig. 8).

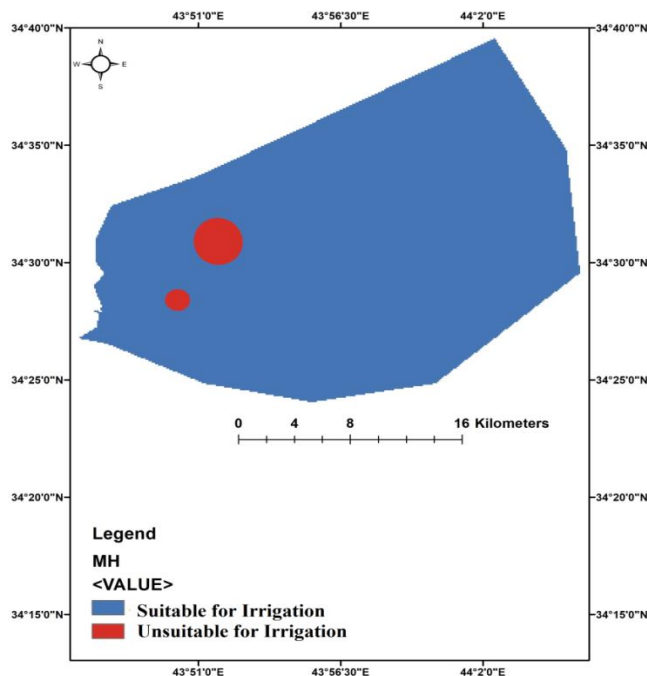


Fig. 7. Map of irrigation suitability in AL JALLAM desert based on MH



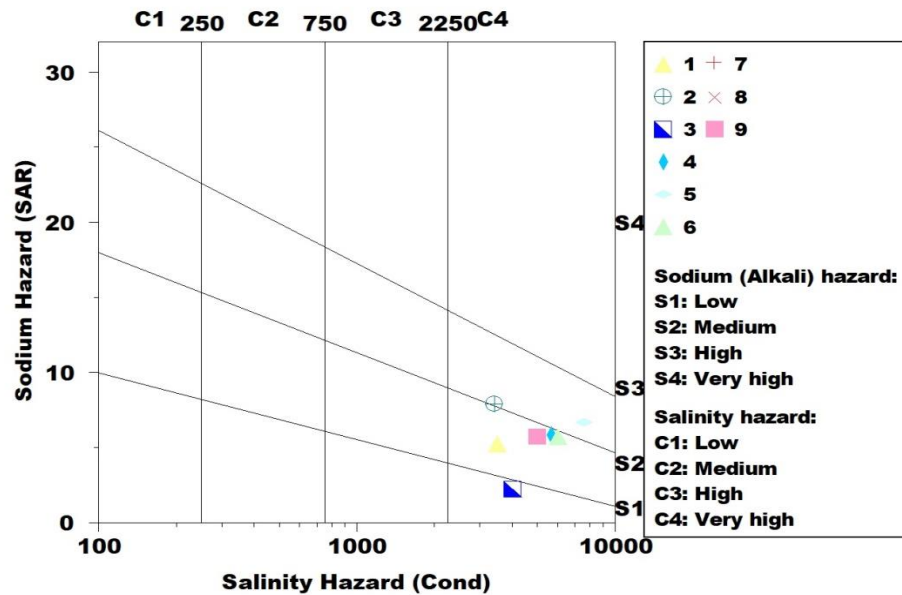


Fig. 8. USSL plot of AL JALLAM desert

### 3.5. Cluster analysis (CA)

Cluster analysis is a statistical technique that is used to group objects or data points into clusters based on their similarity. Hierarchical CA is used to assess the spatial differences between the sampling sites, and the results are represented as a dendrogram in Fig. 9. The groundwater samples were divided into two clusters. The group of samples 1, 2, 3, and 8 are associated with locations that are relatively less polluted. The other cluster, which corresponds to somewhat moderately contaminated areas, includes samples 4, 5, 6, 7, and 9. In the western portion of the research area, close to the Tigris River, are the less polluted sites. This demonstrates that the recharge mechanism from the Tigris River controls the quality of the groundwater in the research area.

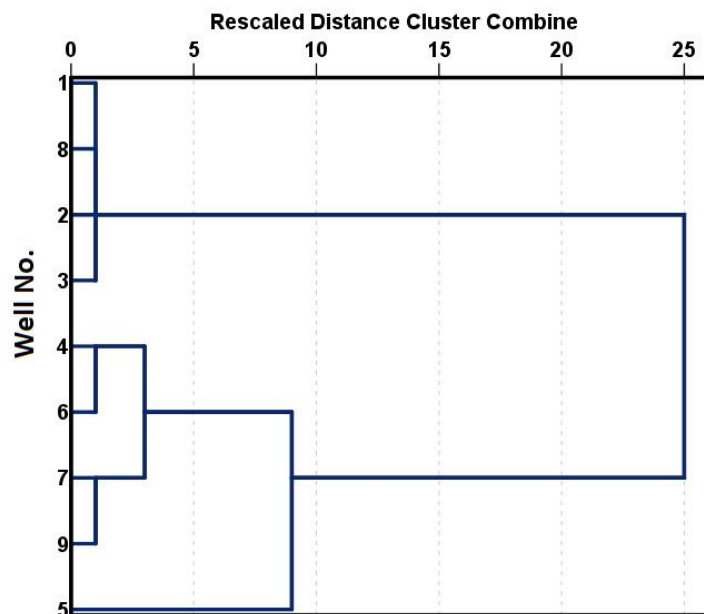


Fig. 9. CA output in the AL JALLAM desert

## 4. Conclusions

In general, the study found that the AL JALLAM desert was at serious risk of pollution. High concentrations of major ions were observed in the north part of the study area and the groundwater quality was relatively low near the Tigris River. Groundwater samples are categorized by Piper plot as mixed Ca-Mg-Cl water types, Na-Cl type, and Ca-Cl type, which indicates the study location, has highly salinized water. All of the groundwater samples fell inside the evaporation dominance zone, according to a Gibbs plot, demonstrating that the evaporation process predominantly regulates the chemistry of groundwater in the studied area. Regarding whether groundwater is fit for drinking, it has been determined that the water is not. Furthermore, the groundwater is unsuitable for irrigation based on US salinity diagram. CA showed two groups

indicating that the study area reflecting relatively moderately contaminated sites to less polluted sites. The output of CA revealed that the recharge process from Tigris River control the quality of groundwater in the study area.

### Acknowledgement

It is our honor and pleasure to thank the General Commission for Groundwater for their valuable help and support.

### Reference

- [1] A. H. Ismail, M. A. Shareef and F. M. Alatar, "Hydrochemistry of Groundwater and its Suitability for Drinking and Irrigation in Baghdad, Iraq", *Environ Process*, vol. 6, pp. 543-560, 2019, <https://doi.org/10.1007/s40710-019-00374-x>.
- [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", *Groundw Sustain Dev*, vol. 10, p. 100300, 2020, <https://doi.org/10.1016/j.gsd.2019.100300>.
- [3] K. Yürekli, M. Erdoğan, A. H. Ismail and M. A. Shareef, "How far can hydrochemical characteristics of surface water meet drinking and irrigation criteria: a pragmatic study for the Euphrates river basin, Turkey", *Sustain Water Resour Manag*, vol. 7, no. 25, pp. 1-11, 2021, <https://doi.org/10.1007/s40899-021-00507-x>.
- [4] H. B. Ghalib, "Groundwater chemistry evaluation for drinking and irrigation utilities in east Wasit province, Central Iraq", *Appl Water Sci*, vol. 7, no. 7, pp. 3447-3467, 2017, <https://doi.org/10.1007/s13201-017-0575-8>.
- [5] B. S. Abed, A.A.-R. Farhan, A. H. Ismail and S. Al Aani, "Water quality index toward a reliable assessment for water supply uses: a novel approach", *Int J Environ Sci Technol*, vol. 19, pp. 2885–2898, 2021, <https://doi.org/10.1007/s13762-021-03338-7>.
- [6] K. G. Sabeeh, M. T. Mustafa, A. H. Ismail and C. Boncescu, "Evaluation of Water Quality at the Confluence Region of Diyala and Tigris Rivers Based on the Weighted Arithmetic Method", *Journal of Techniques*, vol. 5, no. 1, pp. 58-65, 2023, <https://doi.org/10.51173/jt.v5i1.1088>.
- [7] A. H. Ismail, A. S. Muntasir and M. Mahmood, "Hydrochemical characterization of groundwater in Balad district, Salah Al-Din Governorate, Iraq", *J Groundw Sci Eng*, vol. 6, no. 4, pp. 306-322, 2018, <https://doi.org/10.19637/j.cnki.2305-7068.2018.04.006>.
- [8] O. R. Ekwule, A. K. Simeon and M. A. Amer, "Coupling hydrochemical characterization with geospatial analysis to understand groundwater quality parameters in North Central Nigeria", *Sustain Water Resour Manag*, vol. 9, no. 100, pp. 1-17, 2023, <https://doi.org/10.1007/s40899-023-00882-7>.
- [9] N. Adimalla, P. Li and S. Venkatayogi, "Hydrogeochemical Evaluation of Groundwater Quality for Drinking and Irrigation Purposes and Integrated Interpretation with Water Quality Index Studies", *Environ Process*, vol. 5, pp. 363-383, 2018, <https://doi.org/10.1007/s40710-018-0297-4>.
- [10] H. Choi, D. C. Koh and Y. Y. Yoon, "Spatial investigation of water quality and estimation of groundwater pollution along the main stream in the Geum River Basin, Korea", *Environ Geochem Health*, 2023, <https://doi.org/10.1007/s10653-023-01643-3>.
- [11] R. Nagarajan, N. Rajmohan, U. Mahendran and S. Senthamilkumar, "Evaluation of groundwater quality and its suitability for drinking and agricultural use in Thanjavur city, Tamil Nadu, India", *Environ Monit Assess*, vol. 171, no. 1-4, pp. 289-308, 2010, DOI: 10.1007/s10661-009-1279-9.
- [12] H. Wang, X. Li and Y. Xie, "Hydrochemical evaluation of surface water quality and pollution source apportionment in the Luan River basin, China", *Water Sci Technol*, vol. 64, no. 10, pp. 2119-2125, 2011, DOI: 10.2166/wst.2011.794.
- [13] R. Umar and F. Alam, "Assessment of hydrogeochemical characteristics of groundwater in parts of Hindon–Yamuna interfluvial region, Baghpat District, Western Uttar Pradesh", *Environ Monit Assess*, vol. 184, no. 4, pp. 2321-2336, 2012, <https://doi.org/10.1007/s10661-011-2120-9>.
- [14] B. Zhang, X. Song, Y. Zhang, D. Han, C. Tang, Y. Yu and Y. Ma, "Hydrochemical characteristics and water quality assessment of surface water and groundwater in Songnen plain, Northeast China", *Water Research*, vol. 46, pp. 2737-2748, 2012, <https://doi.org/10.1016/j.watres.2012.02.033>.
- [15] A. Nagaraju, A. Thejaswi and L. Sun, "Statistical Analysis of High Fluoride Groundwater Hydrochemistry in Southern India: Quality Assessment and Implications for Source of Fluoride", *Environ Eng Sci*, vol. 33, no. 7, pp. 1-7, 2016, <https://doi.org/10.1089/ees.2015.0511>.
- [16] N. S.Kawo and S. Karuppanan, "Groundwater quality assessment using water quality index and GIS technique in Modjo River Basin, central Ethiopia", *J African Earth Sci*, vol. 147, pp. 300-311, 2018, <https://doi.org/10.1016/j.jafrearsci.2018.06.034>.
- [17] A. S. Jasrotia, A. K. Taloor, U. Andotra, B. D. Bhagat, "Geoinformatics based groundwater quality assessment for domestic and irrigation uses of the Western Doon valley, Uttarakhand, India", *Groundw Sustain Dev*, vol. 6, pp. 200-212, 2018, <https://doi.org/10.1016/j.gsd.2018.01.003>.
- [18] MOT. Ministry of Transportation /Iraqi Metrological Organization and Seismolog, 2010, (unpublished materials).
- [19] APHA, Standard methods for the examination of water and waste water, 21st edn. American Public Health Association, Washington DC, 2005.
- [20] A. H. Ismail, B. S. Abed, S. Abdul-Qader, "Application of Multivariate Statistical Techniques in the surface water quality Assessment of Tigris River at Baghdad stretch", *Journal of Babylon University*, vol. 22, pp. 450-462, 2014.
- [21] U. K. Singh, M. Kumar, R. Chauhan, P. K. Jha, A. L. Ramanathan and V. Subramanian, "Assessment of the impact of landfill on groundwater quality: A case study of the Pirana site in western India", *Environ Monit Assess*, vol. 141, pp. 309-321, 2008, <https://doi.org/10.1007/s10661-007-9897-6>.
- [22] A. M. Piper, "A graphical procedure in the geochemical interpretation of water", *Trans Am Geophys Union*, vol. 25, pp. 914-928, 1944, <https://doi.org/10.1029/TR025i006p00914>.
- [23] R. J. Gibbs, "Mechanisms controlling world's water chemistry", *Science*, vol. 170, pp. 1088-1090, 1970, DOI: 10.1126/science.170.3962.1088.
- [24] M. Vasanthavignar, K. Srinivasamoorthy, K. Vijayaragavan, R. R. Ganthi, S. Chidambaram, P. Anandhan, R. Manivannan, S. Vasudevan, "Application of water quality index for groundwater quality assessment: Thirumanimuttar sub-basin, Tamilnadu, India", *Environ Monit Assess*, vol. 171, pp. 595-609, 2010, <https://doi.org/10.1007/s10661-009-1302-1>.

- [25] P. N. Rajankar, D. H. Tambekar, S. R. Wate, "Groundwater quality and water quality index at Bhandara District", *Environ Monit Assess*, vol. 179, pp. 619-625, 2011, <https://doi.org/10.1007/s10661-010-1767-y>.
- [26] A. D. Sutadian, N. Muttil, A. G. Yilmaz, B. J. C. Perera, "Development of river water quality indices - a review", *Environ Monit Assess*, vol. 188, no. 58, pp. 1-29, 2016, <https://doi.org/10.1007/s10661-015-5050-0>.
- [27] M. Bascaron, "Establishment of a methodology for the determination of water quality", *Bol Inf Medio Ambient*, vol. 9, pp. 30-51, 1979.
- [28] P. Kannel, S. Lee, Y. Lee, S. Kanel, S. P. Khan, "Application of water quality indices and dissolved oxygen as indicators for river water classification and urban impact assessment", *Environ Monit Assess*, vol. 132, no. 1-3, pp. 93-110, 2007, <https://doi.org/10.1007/s10661-006-9505-1>.
- [29] M. A. Massoud, "Assessment of water quality along a recreational section of the Damour River in Lebanon using the water quality index", *Environ Monit Assess*, vol. 184, no. 7, pp. 4151-4160, 2012, <https://doi.org/10.1007/s10661-011-2251-z>.
- [30] A. H. Ismail, D. Robescu, "Assessment of water quality of the Danube river using water quality indices technique", *Environ Eng Manag J*, vol. 18, no. 8, pp. 1727-1737, 2019, DOI: 10.30638/eemj.2019.163.
- [31] USSSL, Diagnosis and improvement of salinity and alkaline soil, USDA Hand Book no. 60, Washington, 1954.
- [32] I. Szaboles and C. Darab, "The influence of irrigation water of high sodium carbonate content of soils", In Proceedings of 8th international congress of ISSS, Trans, II, 1964 , pp. 803-812.