



Groundwater quality assessment for potable using WQI and GIS technology in the south of Iran

Amir Bahrami¹ · Mehdi Bahrami² · Elaheh Haghani³

Received: 28 July 2023 / Accepted: 27 August 2024
© The Author(s), under exclusive licence to Springer Nature Switzerland AG 2024

Abstract

The uncontrolled abstraction of groundwater aquifers in arid and semi-arid regions, such as Iran, can cause serious consequences to these vulnerable resources, including pollution. Therefore, monitoring the groundwater quality in these areas is of great importance. This study aimed to assess the groundwater quality for potable uses and determine the physico-chemical properties of groundwater in Fasa Plain, located in Fars Province, southern Iran. To achieve this, 204 well water samples were collected during 2018 and 2019, and their physicochemical parameters were analyzed. The water quality index was also calculated, and the geographic information system (GIS) was applied to produce the numerical spatial distribution of the variables using analytical outcomes. The maps were drawn using the GIS interpolation method with the lowest error. The analysis results indicated that the concentration of all parameters approximately all over the plain in both years was within the allowable range of drinking water according to the World Health Organization. Additionally, the increased rainfall in the second year resulted in an improvement in water quality. The water quality index values revealed that in 2018, 76.05% and 23.95% of the aquifer area were classified as excellent and good quality, respectively. In 2019, these values were 89.62% and 10.38%, respectively. However, there are signs of the vulnerability to pollution by fertilizers and wastewater especially in southern areas of the plain. Therefore, proper management and prohibiting unnecessary utilization of this water resource should be fulfilled to prevent a decline in water quality.

Keywords Arid and semi-arid region · Drinking water · Groundwater · Water quality index · Iran

Introduction

Access to clean water is a fundamental human right and an essential component of sustainable development (Kumar et al. 2018, 2022). However, it remains a distant dream for many people across the world. Water contamination is linked to several Sustainable Development Goals, including Goal No. 3: Good health and well-being, Goal No. 6: Clean water and sanitation, Goal No. 11: Sustainable cities and communities, Goal No. 12: Responsible consumption

and production, Goal No. 13: Climate action, and Goal No. 15: Life on land (Sharma et al. 2022). The United Nations General Assembly has recognized these goals, and their achievement is crucial for a better future for our planet (Kumar 2022; Shakya and Kumar 2023). Over the last two decades, different countries have implemented several measures to ensure clean water. Water can be divided into two categories: surface water and groundwater. Surface water is more susceptible to contamination as it is easily exposed to human settlements. Even though groundwater is protected by layers of the earth, human activities such as industrial effluent discharge and agriculture have contributed significantly to its contamination (Khatri et al. 2023).

Groundwater is widely recognized as an important source of drinking water in low-income areas. The population growth, urbanization, industrialization, climate change, water contamination, and weak water resources management have caused to decline in the water resources quantity and quality and intensive water shortages for human beings (Bahrami et al. 2020a Vörösmarty et al., 2010). On

✉ Mehdi Bahrami
bahrami@fasau.ac.ir

¹ Department of Soil Science, Faculty of Agriculture, Tarbiat Modares University, Tehran, Iran

² Department of Water Engineering, Faculty of Agriculture, Fasa University, Fasa, Iran

³ Department of Water Engineering, Faculty of Agriculture, Shiraz University, Shiraz, Iran

average, harvesting the nonrenewable water has led aquifers' water tables to decrease by about 0.5 m y^{-1} across Iran (Noori et al. 2021). Whereas meteorological and hydrological droughts treat as stimuli and exacerbate the discharge rate in country-wide groundwater storage (e.g., Shiraz, Yazd-Ardakan, and Neishabour plains), basin-scale groundwater discharges in Iran are primarily occasioned by immense human water extractions (Ashraf et al. 2021; Noori et al. 2021). These have led to numerous obstacles, such as over-harvesting and declining water quality, subsidence, and groundwater salinization. Therefore, conserving groundwater sustainability in terms of quality and quantity is vital (Ashraf et al. 2021; Barakat et al. 2020; Gharahi and Zamani-Ahmadmahmoodi 2020). Iran, as an arid and semi-arid vast country ($1.648 \text{ million km}^2$), has faced with water crisis due to inappropriate agricultural management, low precipitation (In 2021, the precipitation rate was 36% lower than the average of the previous 52 years), and unfavorable rainfall distribution (Abbasnia et al. 2019; Khosravi et al. 2017). These factors have placed a massive amount of pressure on the country's groundwater resources, quantitatively and qualitatively. Therefore, water decision-makers must monitor groundwater quality parameters to prevent water resources' vulnerability to extensive agricultural activities.

In the southern regions of Iran, groundwater resources are not only for drinking purposes, but also widely used to supply water for agriculture, domestic, and industrial. These arid and semi-arid regions have been facing intensive water scarcity due to the increasingly severe water use in the agriculture sector and the profound impact of long-term droughts on the quantity and quality of groundwater (Bahrami et al. 2020b; Honarbakhsh et al. 2019). Assessing groundwater quality requires proper tools and approaches for processing qualitative data because water quality evaluation is harsh due to the incredible amount of data that must be analyzed (Bahrami et al. 2020a). Generally, groundwater exposure to contamination can be appraised considering three kinds of techniques, namely (a) geographical information system (GIS)-based qualitative, (b) process-based, and (c) statistical approaches (e.g., artificial intelligence techniques) (Kong et al. 2019). These strategies are assigned for the evaluation of groundwater vulnerability and generally render various constraints like high cost, unavailable code, and a lack of functionality toward the flexible usage of vulnerability indices and their map comparison (Duarte et al. 2019).

The generation, manipulation, analysis, and visualization of geographic information are provided by applying various layers of information and large data sets in GIS in a flexible and integrated procedure. It, therefore, meets the needs of complex hydrogeological conceptual techniques that frequently need a comprehensive and multidisciplinary

perspective to acquire an explicit demonstration of the spatial variability of groundwater vulnerability. Also, GIS is used to dominate other fields of groundwater vulnerability evaluation such as (1) requiring the comparison of several indices result and highlighting the benefits and detriments of each model (Draoui et al. 2008), and (2) a composition of various indices to acquire more practical outcomes that separately show the vulnerability status in topsoil, unsaturated zone, and aquifer (Aschonitis et al. 2016).

For sustainable development to improve human lives and protect the environment, ending poverty and other exclusions must be accompanied by strategies that develop health and education, reduce inequality, accelerate economic growth, cope with climate change and attempt to preserve natural resources. Hence, the hydro-chemical properties of groundwater are essential for surveying the groundwater quality and specifying its compatibility for different consumptions. Accordingly, many researchers have revealed that natural and manufactured parameters affect groundwater chemistry (Abanyie et al. 2020; Saha and Paul 2019; Sunkari et al. 2020; Tolera et al. 2020). Various tools like quality indices, fuzzy water quality index, and artificial intelligence are performed to specify water quality conditions (Lermontov et al. 2009; Egbueri and Agbasi 2022; Egbueri et al. 2023a, b; Agbasi et al. 2023). Among them, the water quality index (WQI) assesses the composing effect of the overall quality as a practicable and relatively easy technique. This index reflects the combined impacts of several water quality variables (Singh and Hussian 2016; Egbueri et al. 2023a; Abba et al. 2023; Singh et al. 2024).

By 2030, one of the sustainable development goals (SDGs) is to reclaim water quality by decreasing contamination, omitting to discharge and minimizing the dangerous materials released, halving the unrefined wastewater ratio, and significantly enhancing recycling and secure reuse universally (Katila et al. 2020). However, providing food for human beings without ruining nature will grow increasingly hard and finally impracticable under a steady population increment. Agriculture is currently the main reason for environmental vulnerability, and more land-use change for agricultural usage will have destructive subsequences for our biodiversity and climate. Consequently, previous attainments are rapidly overturned as population growth outstrips the developments. Even now, billions of humans do not have access to safe drinking water, sanitation, and hygiene. To address this, SDGs are presented as a scheme for reaching a superior and more sustainable future all over the World. Hence, universal problems such as destitution, imparity, climate change, environmental destruction, peace, justice, as well as safe water and sanitation are addressed (Sachs et al. 2021). Almost all SDGs connote sustainable resource management, especially water, soil, and waste. The

groundwater levels in the Fasa Plain have been decreasing over the past ten years due to excessive groundwater withdrawals and consecutive droughts, leading to an increase in groundwater salinity. Despite the significance of the aquifer, there has been no comprehensive research on the potable water quality based on WQI and hydrogeochemical processes. The present study aims to address this research gap and investigate the groundwater quality status and controlling parameters in the Fasa aquifer, with a specific focus on its suitability for drinking purposes. The main objectives of this study are to test groundwater suitability temporally and spatially for drinking using the chemical substances maps drawn via geographical information system (GIS) technology, to evaluate and delineate the temporal and spatial changes of groundwater quality for potable purposes using the water quality index (WQI), and characterize groundwater type and hydrogeochemical facies based on the Piper diagram.

Materials and methods

Study area

The research region in the present research is Fasa plain, placed in Fars province, southern Iran, with a total area of 4196.93 km², with geographical longitude between 53° 19' to 54° 15' E, geographical latitude between 28° 31' to 29° 24' N, and altitude of 1370.2 m (Fig. 1). At the 2016 census, the county's population was 205,187, in 61,509 families. Based on the De Martonne aridity index, the climate of Fasa Plain is semi-arid (Bahrami and Mahmoudi 2020; Bahrami et al. 2017). The average annual temperature is almost 20.1 degrees Celsius, and the average yearly rainfall is 289 mm. In insomuch the rainfall regime of this area is the Mediterranean, the rainfall is often occurred in the winter months and somewhat in the summer months (under the impression of monsoon rains of the Indian Ocean).

Geologically, the Fasa plain is located in the Zagros Mountains Range and is made up of a series of sub-parallel anticlines and synclines that trend NW-SE (Alavi 2004). The exposed geological formations, listed from oldest to youngest, are as follows: the Hormuz salt formation (Palaeozoic); the Sarvak limestone formation (Cretaceous); the Pabdeh-Gurpi shales and gypsiferous marl formation (Paleocene-Oligocene); the Sachun gypsum formation (Paleocene-Eocene); the Asmari-Jahrom limestone and dolomite formation (Oligocene-Miocene); the Razak evaporite formation (Miocene); the Gachsaran gypsum and marl formation; the Aghajari sandstone formation (late Miocene to Pliocene); the Bakhtiari conglomerate formation (late Pliocene-Pleistocene); and recent alluvium (Fig. 2). The

research area is located in the Quaternary alluvial plain. The deposits in the center of the area are mainly sandy loam and silt, while the sediments near the edges are gravel and sand. The aquifer system in this area often discharges groundwater through springs and is mainly found in highly permeable karstified carbonate rocks. The alluvial aquifer in the region is mainly recharged by subsurface groundwater inflows from the adjacent carbonate rocks and rainfall. Groundwater generally flows from the north to the south of the plain in this region. The primary occupations of the inhabitants of this region are agriculture and raising livestock.

Sampling and analysis

The groundwater specimens were gathered twice in 2018 and 2019 from 34 wells. By considering the three iterations, 204 samples were used for analysis. Then, acidity (pH), electrical conductivity (EC), and total dissolved solids (TDS) were measured in situ immediately after sampling. The other parameters including color, calcium (Ca), magnesium (Mg), sodium (Na), bicarbonate (HCO₃), chloride (Cl), sulfate (SO₄), nitrate (NO₃), nitrite (NO₂), and fluoride (F) were measured according to the APHA methods in the laboratory within 24 h. Also, turbidity and total alkalinity were determined by the nephelometric and titration methods respectively in the laboratory. The precision of the findings was assessed by computing the charge balance error (CBE). The test results are correct just when the CBE ≤ 5%. Also, total hardness (TH) data was calculated using the following formula (Rice et al. 2017);

$$TH = mg \text{ equivalent } CaCO_3 L^{-1} = 2.497 [Ca^{2+}, mg L^{-1}] + 4.118 [Mg^{2+}, mg L^{-1}] \quad (1)$$

The groundwater quality assessment classification scheme used in this study was based on the WHO (2021) standards, taking into account the necessary level of water treatment (Egbueri and Agbasi 2022; Abba et al. 2023). As a result, each water class was assigned the following designations: Class I: Desirable; Class II: Permissible; Class III: Not permissible.

GIS mapping

The water quality parameters were selected based on their effectiveness for drinking purposes. To assess the spatial distribution of groundwater quality, the analytical data were fed into the ArcGIS10.2 software for preparing the maps of the selected parameters. According to the normality test of data using Shapiro-Wilk's statistical method, the interpolation methods including inverse distance weighting (IDW), Kriging, and Co-Kriging with Circular, Gaussian, Spherical,

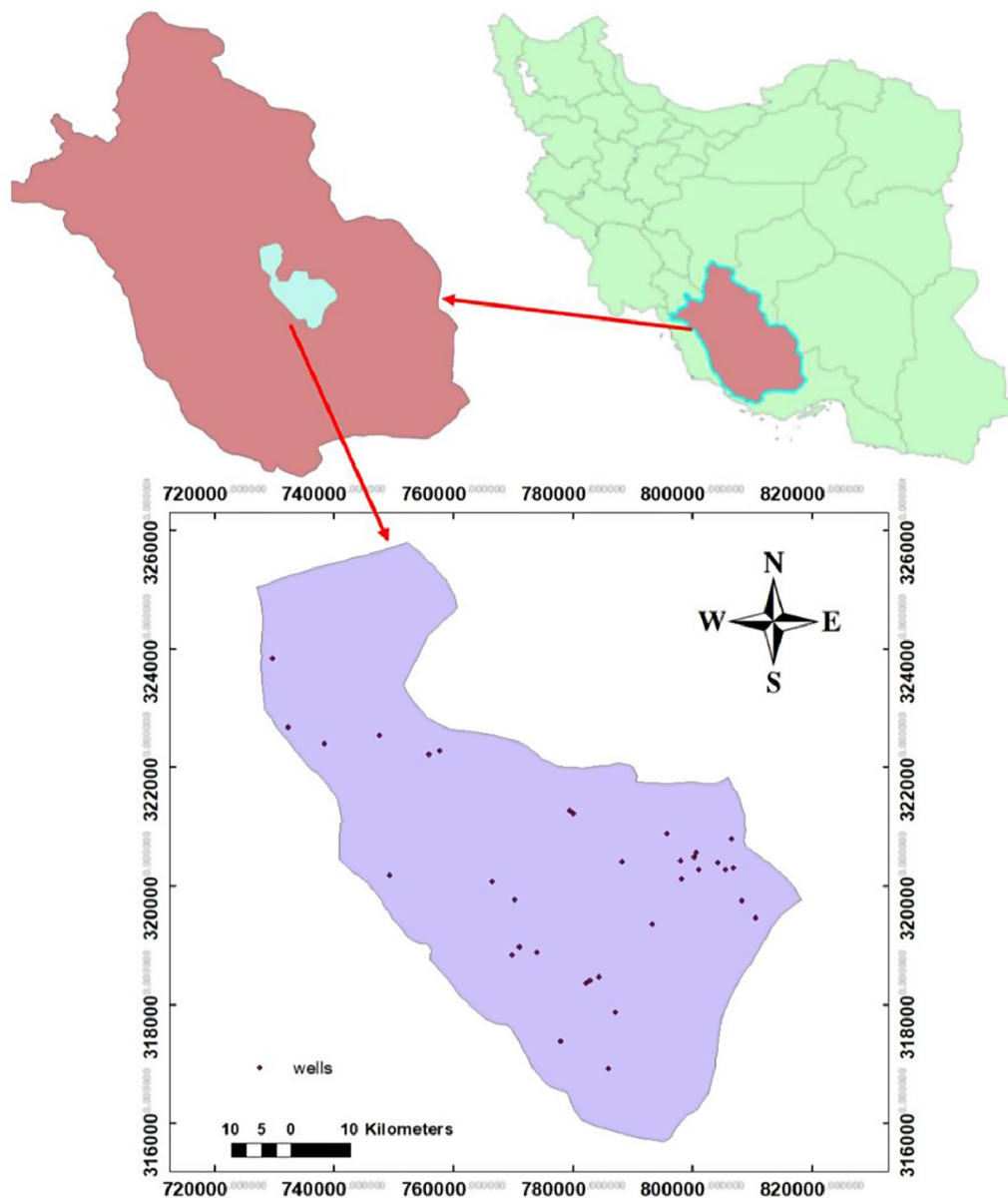


Fig. 1 Situation map of the research area

and lots of other variograms were employed for the analysis of the spatial distribution of different parameters (Bahrami et al. 2021). Based on these maps, water quality was evaluated for drinking purposes.

Water quality index

For more water quality investigation, the water quality index (WQI) was used in light of the appropriateness of groundwater for human utilization. This index is specified as a rating representing the effect of various variables on the general nature of water (Asadi et al. 2019). At first, the relative weight (W_i) of each parameter is calculated using its weight (w_i), which depends on the significance of that

parameter in the general nature of water for drinking purposes (Sreedevi et al. 2019);

$$W_i = w_i / \sum_{i=1}^n w_i \tag{2}$$

where w_i is the weight of each factor and n is the number of factors. The assigned weights to the factors vary from 1 to 5 (Table 1) and are based on the health impacts of the factors. The most weight (5) is given to salinity, fluoride, and nitrate because of their main influence on water quality evaluation and the health implications of the high concentration of these chemical variables in water (Ameur et al. 2016; Derdour et al. 2021). In the present study, a total

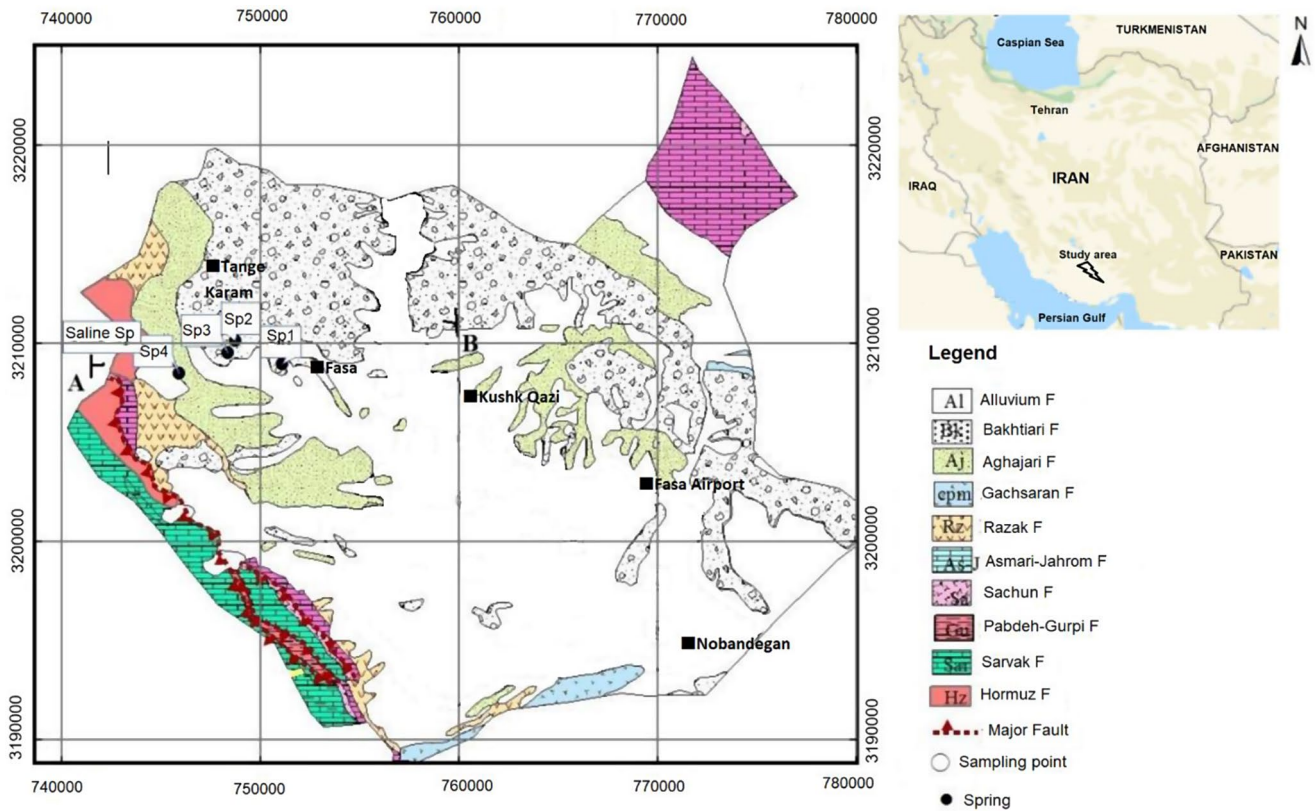


Fig. 2 Geological map of the study area

Table 1 Weight and relative weight values for water quality index calculation

Parameter	WHO (2021)	Weight (w_i)	Relative weight (W_i)
pH	8.5	4	0.085
EC ($\mu\text{mho cm}^{-1}$)	1400	4	0.085
TDS (mg L^{-1})	1500	5	0.106
Turbidity (NTU)	5	2	0.042
TH (mg L^{-1} as CaCO_3)	500	2	0.042
TA (mg L^{-1})	500	2	0.042
Ca^{2+} (mg L^{-1})	200	2	0.042
Mg^{2+} (mg L^{-1})	150	1	0.021
Na^+ (mg L^{-1})	200	2	0.042
HCO_3^- (mg L^{-1})	300	3	0.063
Cl^- (mg L^{-1})	600	3	0.063
NO_3^- (mg L^{-1})	50	5	0.106
NO_2^- (mg L^{-1})	3	3	0.064
SO_4^{2-} (mg L^{-1})	400	4	0.085
F^- (mg L^{-1})	1.5	5	0.106
Sum	8.5	47	1

of 15 parameters (pH, EC, TDS, Turbidity, Total hardness, Total alkalinity, Na^+ , Ca^{2+} , Mg^{2+} , Cl^- , SO_4^{2-} , HCO_3^- , F^- , NO_2^- , and NO_3^-) of 204 water samples were applied to calculate WQI for evaluation of the compatibility of the Fasa

aquifer groundwater for potable purposes. Then, WQI was computed by applying the following formula;

$$WQI = \sum_{i=1}^n (100W_i(C_i/S_i)) \tag{3}$$

where C_i is the concentration of each chemical variable in each water specimen in mg L^{-1} , and S_i is the standard of the World Health Organization for each of the significant variables in drinking water (Asadi et al. 2019). Finally, the calculated WQI values are classified into five classes, namely excellent, good, poor, very poor, and unsuitable water for drinking (Abbasnia et al. 2019; Tlili-Zrelli et al. 2018; Kumar et al. 2016, 2017, 2019).

Statistical analysis

After assessing the normality of whole stations' data in each year, the levels of interrelationship existing between the hydrogeochemical parameters were assessed using Spearman's Rho non-parametric test for non-normal series and the Pearson's parametric test for normal series (Abba et al. 2023). All these correlation tests were performed in the IBM SPSS statistical program (v. 22).

Results and discussion

Temporal and spatial changes of water quality parameters

The range and average quantities of measured physicochemical parameters of the sampled well waters in the studied area are tabulated in Table 2. These results indicate that the specimens were specified by slight to moderate alkalinity (pH quantities varied between 7.22 and 8.29) in both years. There were broad changes in total dissolved solids (TDS) quantities ranging between 202 and 1990 mg L⁻¹ with an average of 535 mg L⁻¹ in 2018 and between 200 and 1974 mg L⁻¹ with an average of 495 mg L⁻¹ in 2019. Of the 34 wells sampled, only well 23 have no TDS quantities within the World Health Organization (2021) and Iranian standard allowable range of 1500 mg L⁻¹ (Organization, 2021); Institute of Standards and Industrial Research of Iran (ISIRI 1992). The electrical conductivity quantities demonstrated a remarkable variation changing from 362 to 3450 with an average of 895 $\mu\text{S cm}^{-1}$ in 2018 and from 348 to 3190 with an average of 820 $\mu\text{S cm}^{-1}$ in 2019. For two consecutive years, respectively, 82% and 88% of the total groundwater specimens are located under the World Health Organization's guidelines of 1400 $\mu\text{S/cm}$ (WHO, 2021), while there is no limit stipulated by Iranian Standards (ISIRI 1992). The average quantities for total hardness were 308 and 283 mg L⁻¹ as CaCO₃ in 2018 and 2019, respectively, denoting that the research area groundwater is very hard and hard.

The spatial distribution of pH, EC, TDS, and TH in Fasa Plain is illustrated in Fig. 3. According to these results, the groundwater of the whole plain area is in the permissible class in terms of pH (6.5–8.5) and total hardness (100–500

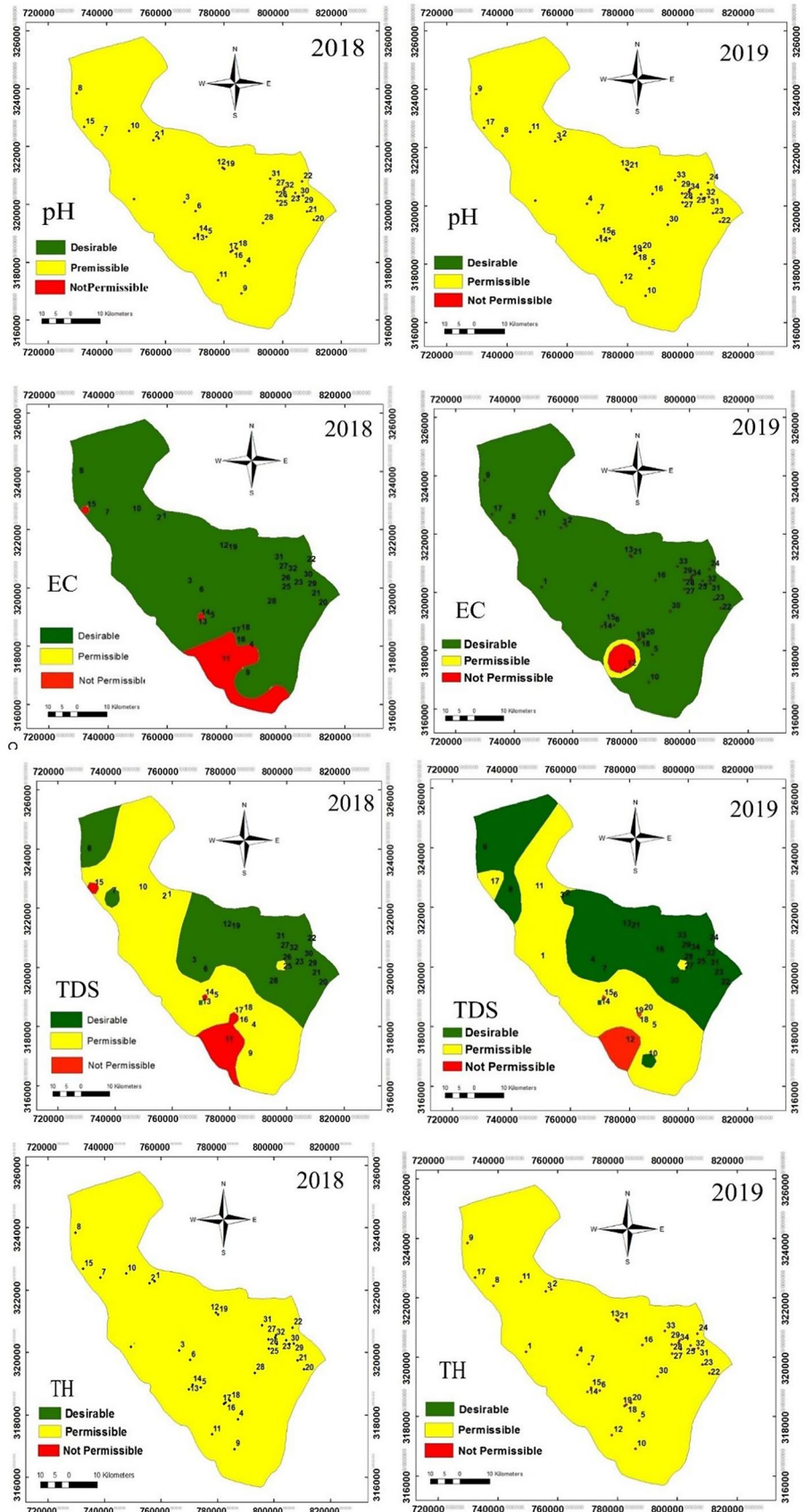
mg L⁻¹ as CaCO₃). Based on EC, in 2018, 90% of the aquifer area is in the desirable class (< 1500 $\mu\text{mhos cm}^{-1}$), 0.5% is in the permissible limit (1500 $\mu\text{mhos cm}^{-1}$), and 9.5% has not permissible water for drinking (> 1500 $\mu\text{mhos cm}^{-1}$). In 2019, groundwater quality improved in terms of EC, as the desirable and permissible classes increase to 95% and 1.15%, and the not permissible class decreases to 3.85%. The spatial distribution of TDS in 2018 is as: 36.4% in the desirable class (< 500 mg L⁻¹), 55.8% in the permissible category (500–1000 mg L⁻¹), and 7.8% in the not permissible limit (> 1000 mg L⁻¹). Similar to EC, the TDS classes have improved in 2019, as the desirable class increased to 45%, while the permissible and not permissible classes decrease to 49.75% and 5.25%. The difference between EC and TDS indicates the predominance of non-ionized ions in the groundwater of this region. Areas with no permissible class in terms of EC and TDS are primarily located in the south of the plain.

Based on Table 2, the major cations (Ca, Mg, and Na) concentrations are within the World Health Organization and Iranian standard allowable ranges in both years (WHO, 2021; ISIRI 1992). However, the concentration of these ions decreases in the second year, and water quality improves. The spatial distribution of Ca, Mg, and Na in the research area is shown in Fig. 4. Based on these results, a more significant percentage of the aquifer area in these cations has desirable water for drinking in both years. Nevertheless, the amount of these elements decreases in 2019, and the main reason can be attributed to the increase in rainfall in 2019 (300.1 mm) compared to 2018 (92.1 mm). In limited areas in the south of the plain, the sodium content of groundwater is higher than the permissible range, and the water in those areas is not suitable for drinking. The groundwater hardness

Table 2 Statistical summaries of the physicochemical parameters

Parameter	Iranian Standard	WHO Standard (2021)	2018				2019			
			Min	Max	Mean	SD	Min	Max	Mean	SD
pH	6.5-9	6.5-8.5	7.22	8.29	7.99	0.21	7.51	8.08	7.82	0.16
EC ($\mu\text{S cm}^{-1}$)		1400	362	3450	895.56	653.46	348	3190	820.41	608.39
TDS (mg L ⁻¹)	1500	1500	202.19	1990.33	534.80	407.68	200.08	1974.48	495.34	392.49
TH (mg L ⁻¹ CaCO ₃)	500	500	160	996	307.88	182.15	148	952	283.24	158.98
TA (mg L ⁻¹ CaCO ₃)			112	290	180.76	35.42	112	288	174.88	34.86
Turbidity (NTU)	5	5	0	3.56	0.28	0.61	0	2.79	0.2	0.49
Color (TCU)	15		0	2	0.21	0.48	0	3	0.18	0.58
Ca ²⁺ (mg L ⁻¹)	200	200	35.2	268.8	69.36	50.85	25.6	240	62.19	40.35
Mg ²⁺ (mg L ⁻¹)	150	150	15.55	95.26	32.68	18.82	14.58	89.91	31.05	17.52
Na ⁺ (mg L ⁻¹)	200	200	8	321.99	74.49	86.51	7.65	330.21	71.48	86.82
HCO ₃ ⁻ (mg L ⁻¹)		300	136.42	353.22	220.17	43.15	136.42	350.78	213.01	42.46
Cl ⁻ (mg L ⁻¹)	400	600	10	588	83.35	115.90	8	560	74.82	110.59
SO ₄ ²⁻ (mg L ⁻¹)	400	400	16	670	149.03	178.35	160	640	136.76	164.33
NO ₃ ⁻ (mg L ⁻¹)	50	50	2	38.8	16.82	10.39	2.1	35.4	16.66	9.09
NO ₂ ⁻ (mg L ⁻¹)	3	3	0.001	0.017	0.007	0.004	0.002	0.030	0.007	0.01
F ⁻ (mg L ⁻¹)	1.7	1.5	0.1	1.73	0.61	0.43	0.12	1.7	0.57	0.42

Fig. 3 Spatial distribution maps of TH, pH, EC, and TDS



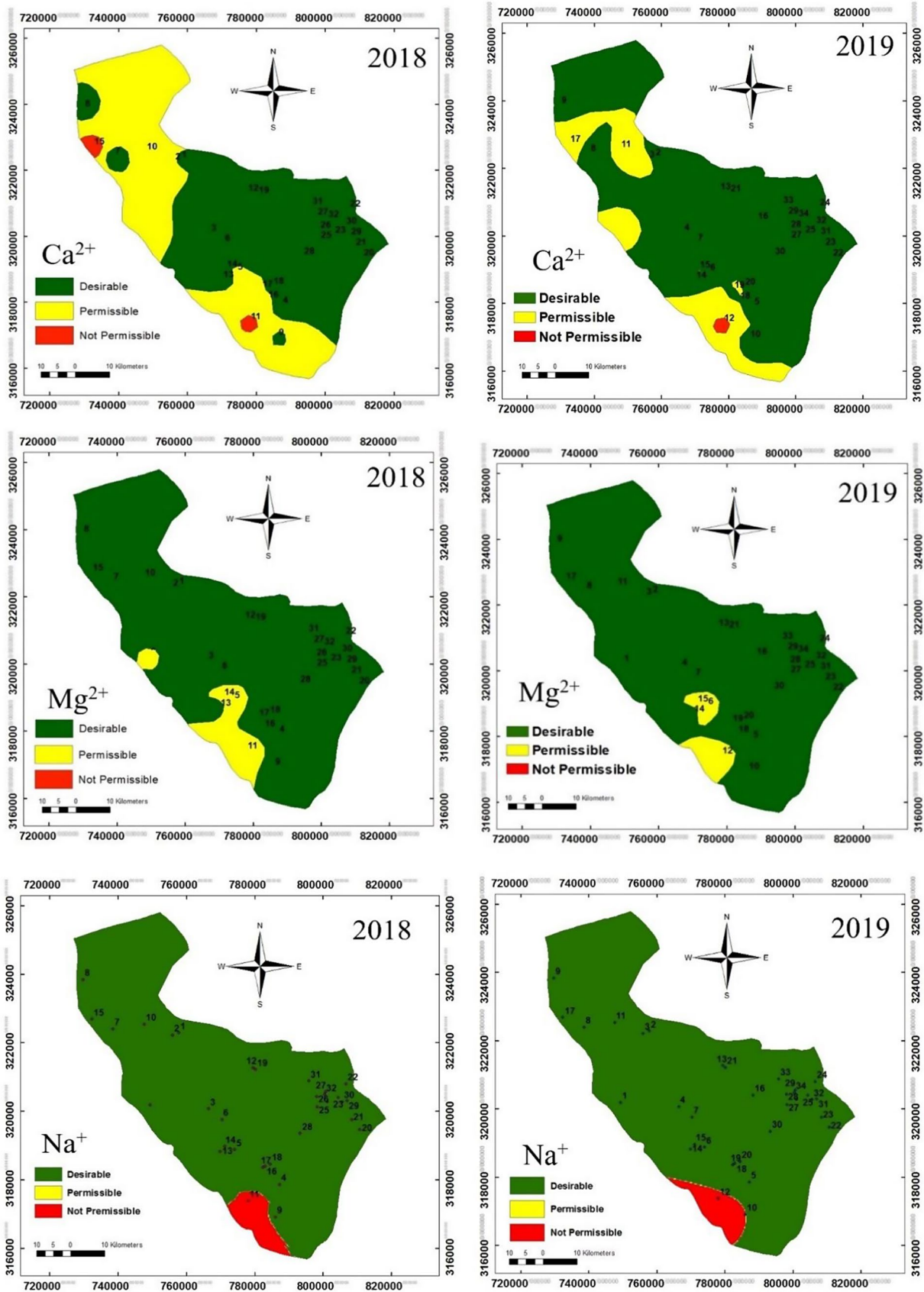


Fig. 4 Spatial distribution maps of Ca, Mg, and Na

in the permissible class can be attributed to the higher concentration of calcium compared to magnesium, so the hardness of this water is more affected by calcium.

The concentration of all anions decreased in the second year (Table 2) due to the rainfall increment. In 2018, the bicarbonate concentration in 9% of the samples was above the allowable limit stipulated by WHO (300 mg L⁻¹), while this was about 6% in 2019. There is no limit specified by Iranian Standards (ISIRI 1992) for bicarbonate. Based on WHO guidelines, chloride quantity was in the allowable range (600 mg L⁻¹) in both years, but according to Iranian standard (400 mg L⁻¹), about 3% of specimens exceed the allowable limit of drinking uses. Sulfate concentrations in the studied years in 12 and 9% of the samples were more than the allowable drinking limit, respectively. Nitrate and nitrite values in both years in all samples were within the allowable drinking range, which indicates the low inflow of agricultural effluent to groundwater resources in this area. Based on the Iranian standard (1.7 mg L⁻¹), the amount of fluoride in all samples was within the permissible drinking range. Still, according to the WHO guidelines (1.5 mg L⁻¹), one of the wells contained excessive amounts of fluoride.

The zoning maps of the classes of these elements in Fig. 5 also confirm these results. The amount of groundwater bicarbonate in the whole plain in both years was included in the permissible drinking class (150–300 mg L⁻¹). In terms of nitrate and nitrite, the whole aquifer had desirable groundwater for potable purposes (nitrate < 50 mg L⁻¹ and nitrite < 3 mg L⁻¹). Based on sulfate, in 2018, 62.23% of the aquifer area is in the desirable class (< 200 mg L⁻¹), 36.03% is in the permissible limit (200–400 mg L⁻¹), and 1.74% has not permissible water for drinking (> 400 mg L⁻¹). In 2019, groundwater quality improved in terms of sulfate, as the desirable class increased to 67.80%, while permissible and not permissible classes decrease to 30% and 1.2%. Most areas with low-quality water in terms of sulfate are located in the southern and eastern parts of the plain. Some of the southern areas are also in the permissible (200–400 mg L⁻¹) and not permissible (> 400 mg L⁻¹) ranges in terms of chloride. The percentage of areas with fluoride in the desired range (< 0.5 mg L⁻¹) in the studied years is equal to 20.53% and 23.28%, respectively, and more in the eastern part of the plain. Other areas of the plain are located in the permissible class (0.5–1.5 mg L⁻¹) (see Fig. 5).

Correlation test

The correlation matrix was utilized for identifying a better relation among the different physicochemical variables of the groundwater specimens (Table 3). The EC quantities are strongly correlated with Na⁺, Ca²⁺, Mg²⁺, Cl⁻, SO₄²⁻, F⁻, and HCO₃⁻ revealing the high conductivity of groundwater

due to the presence of these ions (Mallick et al. 2018). EC also had significant positive correlations with TDS and TH. There are significant positive correlations between EC, TDS, and TH. TDS in water typically correlates with water salinity, EC, and TH. High salinity can have adverse effects on water intended for drinking and irrigation (Egbueri and Agbasi 2022). TDS concentration describes the presence of inorganic salts and small amounts of organic matter in water. EC, on the other hand, measures the water's capacity to conduct electrical current. TDS and EC can originate from geological conditions, seawater, and human activities, such as domestic and industrial waste and agriculture. The relationship between TDS and EC depends on the type and nature of the dissolved cations and anions. Literature suggests that natural geogenic processes, such as rock weathering, mineral processes, and ion exchanges, mostly influence EC, TDS, cations, and anions (Abba et al. 2023). A strong positive correlation between TH with the anions, including HCO₃⁻ shows the simultaneous presence of permanent and temporary hardness of groundwater in both years. Interestingly, there is no strong correlation between nitrate and nitrite with cations, which indicates the low and controlled use of chemical fertilizers in agriculture (Zhang et al. 2021). The significant positive correlation between F⁻, Cl⁻, and SO₄²⁻ anions with Na⁺, Ca²⁺, and Mg²⁺ cations in the samples shows the dominance of these soluble salts.

Water quality index

Based on the spatial distribution maps of WQI in the research area represented in Fig. 6, groundwater throughout the plain is in excellent and good classes for drinking in both years. According to the percentage of each WQI class exhibited in Table 4, excellent and good quality categories are 76.05% and 23.95% in 2018 and 89.62% and 10.38% in 2019, respectively. Pashaeifar et al. (2021) and Ha et al. (2022), in similar studies on spatial assessment of groundwater quality, suggested the treatment of groundwater before using it for drinking. After analyzing the sub-indices, it was observed that certain physicochemical parameters such as pH, EC, HCO₃⁻, and F⁻ had the most impact on WQI. Therefore, it can be concluded that the high WQI values recorded at certain locations are a result of higher concentrations of these parameters present in the groundwater samples.

Hydrochemical characteristics

According to the water chemical composition applying the Piper diagram, water types in the present research were specified (Abdelhafiz et al. 2021). In both years, most of the specimens are in the center of the cation triangle, indicating no dominant type of water. While most of the specimens fall

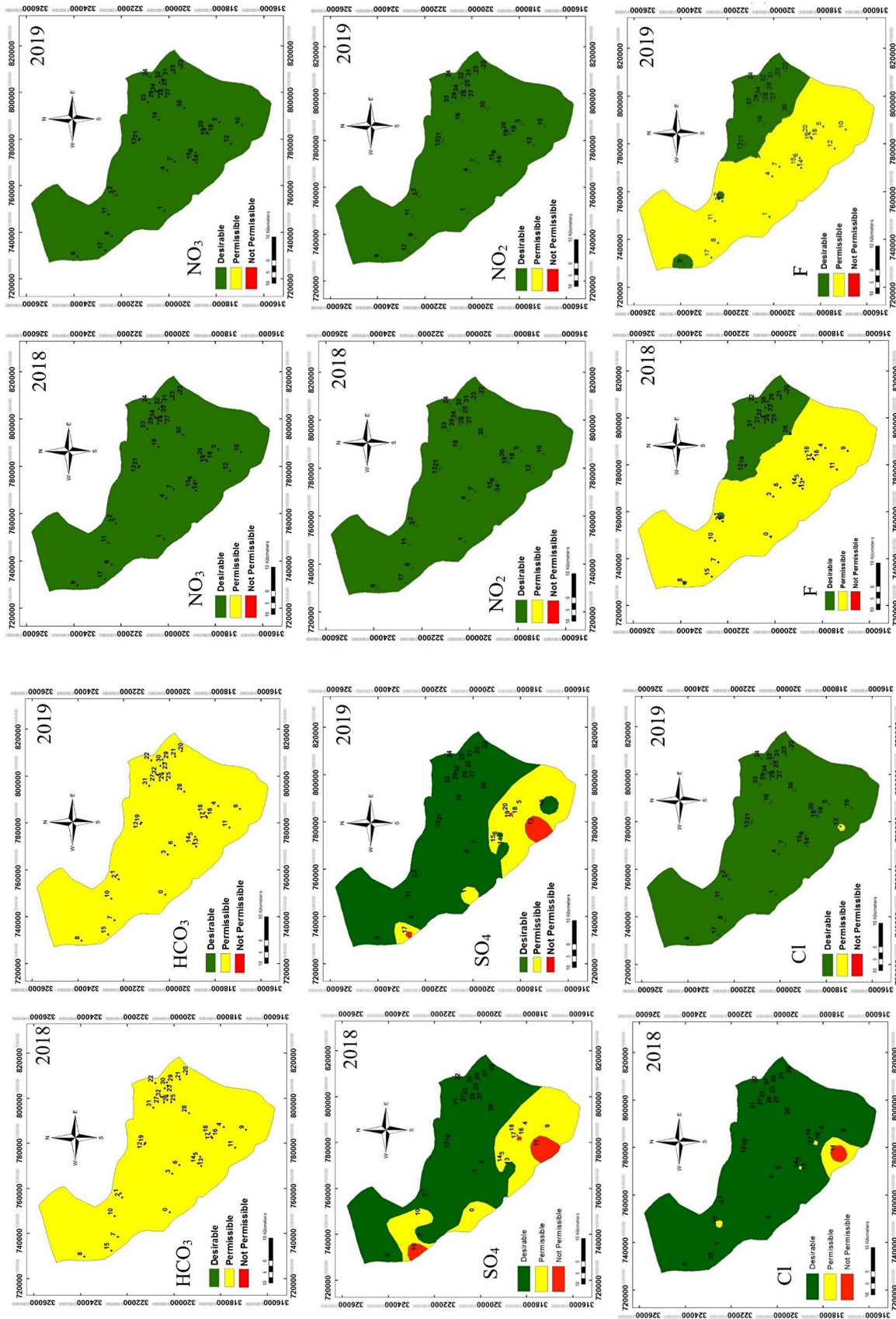


Fig. 5 Spatial distribution maps of HCO₃, SO₄, Cl, NO₃, NO₂, and F

Table 3 Correlation coefficient matrix of physicochemical parameters

	pH	EC	TDS	TH	TA	Turb	Color	Ca	Mg	Na	HCO ₃	Cl	SO ₄	NO ₃	NO ₂	F
pH	1	0.169	0.147	0.254	0.364*	0.269	0.135	0.138	0.335	0.192	0.364*	0.163	0.062	0.138	0.041	0.064
EC		1	0.996**	0.915**	0.424*	0.497**	0.281	0.808**	0.877**	0.821**	0.424*	0.844**	0.944**	0.135	0.288	0.782**
TDS			1	0.906**	0.407*	0.492**	0.281	0.802**	0.867**	0.816**	0.407*	0.838**	0.948**	0.146	0.280	0.793**
TH				1	0.484**	0.519**	0.349*	0.904**	0.933**	0.631**	0.484**	0.709**	0.836**	0.151	0.258	0.665**
TA					1	0.534**	0.402*	0.306	0.535**	0.446**	1.000**	0.372*	0.248	0.288	0.377*	
Turb						1	0.544**	0.422*	0.521**	0.454**	0.534**	0.377*	0.411*	0.310	0.200	
Color							1	0.327	0.352*	0.214	0.402*	0.250	0.231	0.153	0.096	
Ca								1	0.731**	0.530**	0.306	0.645**	0.770**	-0.009	0.318	
Mg									1	0.692**	0.535**	0.726**	0.774**	0.232	0.131	
Na										1	0.446**	0.936**	0.757**	0.201	0.115	
HCO ₃											1	0.372*	0.248	0.288	0.377*	
Cl												1	0.759**	0.104	0.113	
SO ₄													1	0.080	0.265	
NO ₃														1	0.018	
NO ₂															1	
F																1
EC	0.136	1														
TDS	0.156	0.996**	1													
TH	0.131	0.874**	0.867**	1												
TA	-0.185	0.384*	0.360*	0.471**	1											
Turb.	0.148	0.285	0.275	0.191	0.160	1										
Color	0.121	0.364*	0.336	0.339	0.285	0.526**	1									
Ca	0.307	0.804**	0.804**	0.898**	0.326	0.201	0.317	1								
Mg	-0.002	0.820**	0.811**	0.898**	0.458**	0.191	0.350*	0.667**	1							
Na	0.056	0.895**	0.899**	0.648**	0.321	0.317	0.371*	0.579**	0.670**	1						
HCO ₃	-0.185	0.384*	0.360*	0.471**	1.000**	0.160	0.285	0.326	0.458**	0.321	1					
Cl	0.027	0.869**	0.875**	0.720**	0.298	0.308	0.301	0.604**	0.728**	0.911**	0.298	1				
SO ₄	0.309	0.922**	0.931**	0.776**	0.173	0.221	0.351*	0.764**	0.721**	0.842**	0.173	0.788**	1			
NO ₃	-0.176	0.157	0.184	0.107	0.239	-0.064	0.094	0.060	0.137	0.163	0.239	0.109	0.134	1		
NO ₂	-0.351*	0.269	0.275	0.319	0.119	0.034	-0.101	0.162	0.286	0.201	0.119	0.193	0.204	0.219	1	
F	0.099	0.780**	0.777**	0.577**	0.293	0.040	0.345*	0.510**	0.645**	0.766**	0.293	0.685**	0.806**	0.090	0.250	1

* Correlation is significant at the 0.05 level (2-tailed)

** Correlation is significant at the 0.01 level (2-tailed)

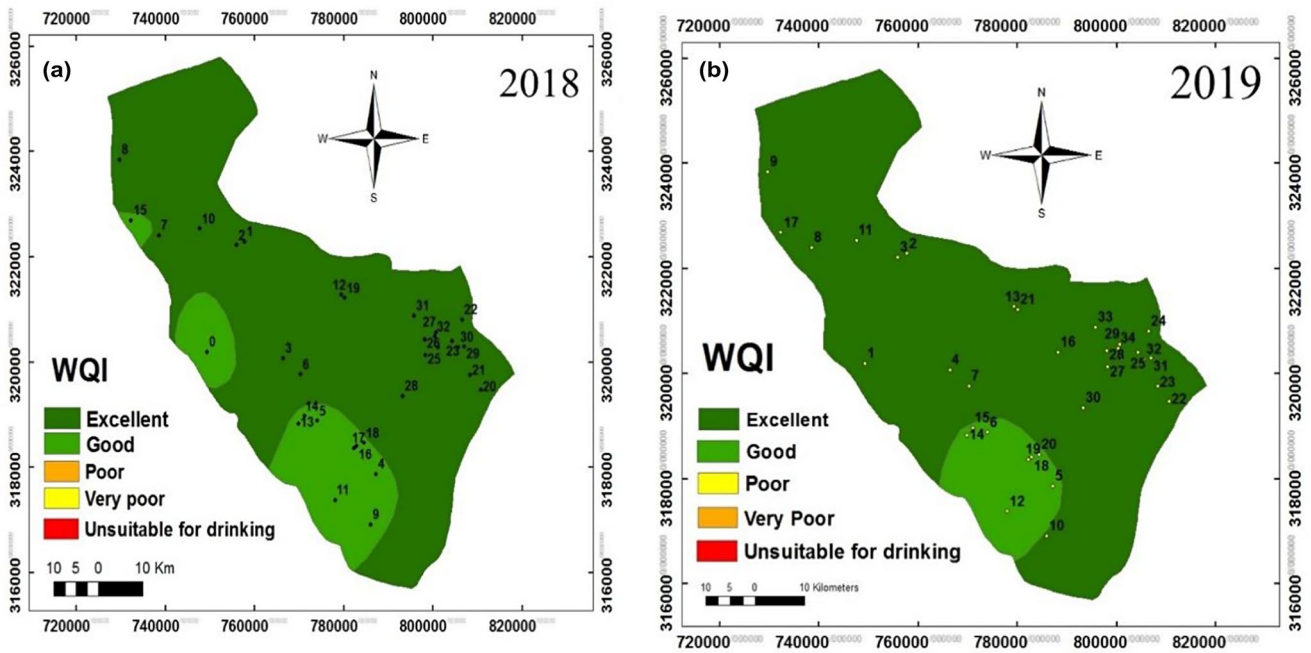


Fig. 6 Spatial distribution maps of WQI for the study area in 2018 (a) and 2019 (b)

Table 4 Water quality index (WQI) ranges and percentage of specimens at the study time

WQI range	Water quality	2018 (%)	2019 (%)
< 50	Excellent	76.06	89.62
50–100	Good	23.94	10.38
100–200	Poor	0	0
200–300	Very poor	0	0
> 300	Unsuitable for drinking	0	0

on the left side of the anion triangle, showing the bicarbonate type of water. The distribution of water samples in the diamond shape also reveals the predominance of $Mg(HCO_3)_2$ and mixed types (Pashaeifar et al. 2021). Shifting a few specimens into the middle of the diamond indicates the vulnerability of these points to pollution by fertilizers and wastewater (see Fig. 7).

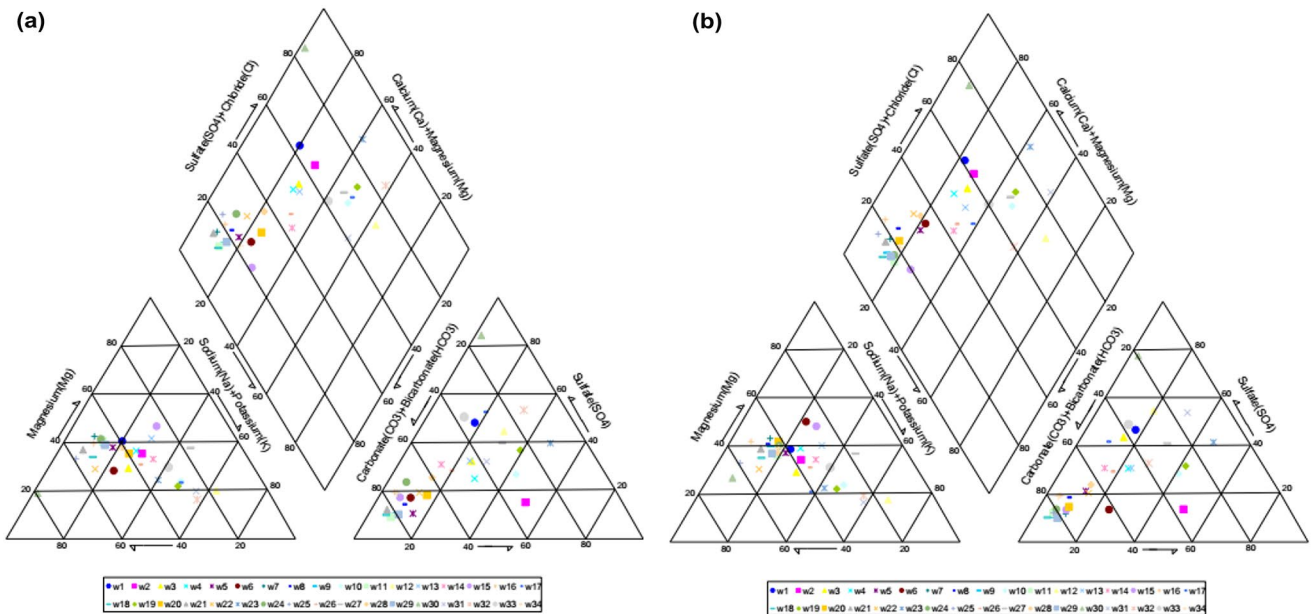


Fig. 7 Piper diagram for the chemical compounds of groundwater for 2018 (a) and 2019 (b)

Conclusion

The investigated specimens of groundwater in the studied region possess desirable and permissible levels of various physical and chemical parameters for drinking during both years. In addition, the water quality situation has improved in the second year, the main reason for which could be more than tripling the amount of rainfall in this plain. Hydrochemical composition analysis reveals that the groundwater in this aquifer contains $Mg(HCO_3)_2$ and mixed types, which are exposed to pollution by fertilizers and wastewater. According to these results, it can result that groundwater in the Fasa plain aquifer is convenient for potable uses. However, the southern and western areas of this plain, which currently have good potable water quality, are in lower classes in the classification of some water quality parameters, which indicates the decline of water quality over time in these areas. Despite this, there is a requirement to fulfill sustainable management for preserving and protecting this precious resource to control pollution.

One limitation of the study is that it did not account for seasonal variations over a long period. It is recommended that future research addresses this issue. Additionally, to enhance monitoring, it is suggested to utilize machine learning and other artificial intelligence techniques. Furthermore, it is important to evaluate the water quality for agricultural and industrial purposes. Lastly, water management authorities in the area should improve their strategies to safeguard groundwater from human-related impacts, especially considering recent droughts in the region.

Data availability All data used during the study are available from the corresponding author by request.

Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

References

- Abanyie SK, Sunkari ED, Apea OB, Abagale S, Korboe HM (2020) Assessment of the quality of water resources in the Upper East Region, Ghana: a review. *Sustainable Water Resour Manage* 6(4):1–18
- Abba SI, Egbueri JC, Benaafi M, Usman J, Usman AG, Aljundi IH (2023) Fluoride and nitrate enrichment in coastal aquifers of the Eastern Province, Saudi Arabia: the influencing factors, toxicity, and human health risks. *Chemosphere* 336:139083
- Abbasnia A, Yousefi N, Mahvi AH, Nabizadeh R, Radfard M, Yousefi M, Alimohammadi M (2019) Evaluation of groundwater quality using water quality index and its suitability for assessing water for drinking and irrigation purposes: case study of Sistan and Baluchistan province (Iran). *Hum Ecol Risk Assessment: Int J* 25(4):988–1005
- Abdelhafiz MA, Seleem E-MM, Nazer E, Zeid HA, Salman SA, S. A., Meng B (2021) Shallow groundwater environmental investigation at northeastern Cairo, Egypt: quality and photo-treatment evaluation. *Environ Geochem Health* 43(11):4533–4551
- Agbasi JC, Chukwu CN, Nweke ND, Uwajingba HC, Khan MYA, Egbueri JC (2023) Water pollution indexing and health risk assessment due to PTE ingestion and dermal absorption for nine human populations in Southeast Nigeria. *Groundw Sustainable Dev* 21:100921
- Alavi M (2004) Regional stratigraphy of the Zagros fold-thrust belt of Iran and its proforeland evolution. *Am J Sci* 304(1):1–20
- Ameur M, Hamzaoui-Azaza F, Gueddari M (2016) Nitrate contamination of Sminja aquifer groundwater in Zaghuan, northeast Tunisia: WQI and GIS assessments. *Desalination Water Treat* 57(50):23698–23708
- Asadi E, Isazadeh M, Samadianfard S, Ramli MF, Mosavi A, Shamshirband S, Chau K-W (2019) Groundwater Quality Assessment for Drinking and Agricultural Purposes in Tabriz Aquifer, Iran
- Aschonitis VG, Castaldelli G, Colombani N, Mastrocicco MA (2016) Combined methodology to assess the intrinsic vulnerability of aquifers to pollution from agrochemicals. *Arab J Geosci* 9:1–0
- Ashraf S, Nazemi A, AghaKouchak A (2021) Anthropogenic drought dominates groundwater depletion in Iran. *Sci Rep* 11(1):1–10. <https://doi.org/10.1038/s41598-021-88522-y>
- Bahrami M, Mahmoudi MR (2020) Rainfall modeling using backward generalized estimating equations: a case study for Fasa Plain, Iran. *Meteorol Atmos Phys* 132(5):771–779
- Bahrami M, Zarei AR, Chakav S (2017) Analysis of drought transitions using log-linear models in Iran. *Int J Water* 11(3):266–278
- Bahrami M, Khaksar E, Khaksar E (2020a) Spatial variation assessment of groundwater quality using multivariate statistical analysis (case study: Fasa Plain, Iran). *J Groundw Sci Eng Vol* 8(3):230–243
- Bahrami M, Zarei AR, Rostami F (2020b) Temporal and spatial assessment of groundwater contamination with nitrate by nitrate pollution index (NPI) and GIS (case study: Fasarud Plain, southern Iran). *Environ Geochem Health* 42(10):3119–3130
- Bahrami M, Bazrkar S, Zarei AR (2021) Spatiotemporal investigation of drought pattern in Iran via statistical analysis and GIS technique. *Theoret Appl Climatol* 143:1113–1128. <https://doi.org/10.1007/s00704-020-03480-1>
- Barakat A, Hilali A, Baghdadi ME, Touhami F (2020) Assessment of shallow groundwater quality and its suitability for drinking purposes near the Béni-Mellal wastewater treatment lagoon (Morocco). *Hum Ecol Risk Assessment: Int J* 26(6):1476–1495. <https://doi.org/10.1080/10807039.2019.1584029>
- Derdour A, Guerine L, Allali M (2021) Assessment of drinking and irrigation water quality using WQI and SAR method in Maâder sub-basin, Ksour Mountains, Algeria. *Sustainable Water Resour Manage* 7(1):1–14
- Draoui M, Vias J, Andreo B, Targuisti K, Messari SE, J (2008) A comparative study of four vulnerability mapping methods in a detritic aquifer under Mediterranean climatic conditions. *Environ Geol* 54(3):455–463. <https://doi.org/10.1007/s00254-007-0850-3>
- Duarte L, Espinha Marques J, Teodoro AC (2019) An open-source GIS-based application for the assessment of groundwater vulnerability to pollution. *Environments* 6(7):86. <https://doi.org/10.3390/environments6070086>
- Egbueri JC, Agbasi JC (2022) Data-driven soft computing modeling of groundwater quality parameters in southeast Nigeria: comparing the performances of different algorithms. *Environ Sci Pollut Res* 29(25):38346–38373
- Egbueri JC, Agbasi JC, Ayejoto DA, Khan MI, Khan MYA (2023a) Extent of anthropogenic influence on groundwater quality and human health-related risks: an integrated assessment based

- on selected physicochemical characteristics. *Geocarto Int* 38(1):2210100
- Egbueri JC, Ayejoto DA, Agbasi JC (2023b) Pollution assessment and estimation of the percentages of toxic elements to be removed to make polluted drinking water safe: a case from Nigeria. *Toxin Reviews* 42(1):146–160
- Gharahi N, Zamani-Ahmadmoodi R (2020) Evaluation of groundwater quality for drinking purposes: a case study from the Beheshtabad Basin, Chaharmahal and Bakhtiari Province. *Iran Environ Earth Sci* 79(4):1–12
- Honarbaksh A, Tahmoures M, Tashayo B, Mousazadeh M, Ingram B, Ostovari Y (2019) GIS-based assessment of groundwater quality for drinking purposes in the northern part of Fars Province. *Marddasht J Water Supply: Res Technology-Aqua* 68(3):187–196. <https://doi.org/10.2166/aqua.2019.119>
- ISIRI (1992) Institute of Standards and Industrial Research of Iran. Chemical specifications of drinking water, ISIRI No. 1053, 4th ed. Tehran: Institute of Standards and Industrial Research of Iran; [cited 27 Jul 2009]. <http://www.isiri.org/std/1053.htm>. Accessed (in Persian)
- Katila P, Colfer CJP, De Jong W, Galloway G, Pacheco P, Winkel G (2020) Sustainable development goals. Cambridge University Press
- Khatri P, Kumar P, Shakya KS, Kirlas MC, Tiwari KK (2023) Understanding the intertwined nature of rising multiple risks in modern agriculture and food system. *Environment, Development and Sustainability*, pp 1–44
- Khosravi R, Eslami H, Almodaresi SA, Heidari M, Fallahzadeh RA, Taghavi M, Khodadadi M, Peirovi R (2017) Use of geographic information system and water quality index to assess groundwater quality for drinking purposes in Birjand City. *Iran Desalin Water Treat* 67(1):74–83
- Kong M, Zhong H, Wu Y, Liu G, Xu Y, Wang G (2019) Developing and validating intrinsic groundwater vulnerability maps in regions with limited data: a case study from Datong City in China using DRASTIC and Nemerow pollution indices. *Environ Earth Sci* 78(8):1–14. <https://doi.org/10.1007/s12665-019-8255-7>
- Kumar P (2022) A critical evaluation of air quality index models (1960–2021). *Environ Monit Assess* 194(5):1–45
- Kumar P, Thakur PK, Bansod BK, Debnath SK (2016) Groundwater vulnerability assessment of Fatehgarh Sahib district, Punjab, India. *Proceedings of India international science festival (IISF)—young scientists' conclave (YSC)*, 8–11
- Kumar P, Thakur PK, Bansod BK, Debnath SK (2017) Multi-criteria evaluation of hydro-geological and anthropogenic parameters for the groundwater vulnerability assessment. *Environ Monit Assess* 189:1–24
- Kumar P, Thakur PK, Bansod BK, Debnath SK (2018) Groundwater: a regional resource and a regional governance. *Environ Dev Sustain* 20:1133–1151
- Kumar P, Thakur P, Debnath S (2019) Groundwater vulnerability assessment and mapping using DRASTIC model. *CRC*
- Kumar P, Sharma R, Bhaumik S (2022) MCDA techniques used in optimization of weights and ratings of DRASTIC model for groundwater vulnerability assessment. *Data Sci Manage* 5(1):28–41
- Lermontov A, Yokoyama L, Lermontov M, Machado MAS (2009) River quality analysis using fuzzy water quality index: Ribeira do Iguape River watershed. *Brazil Ecol Indic* 9(6):1188–1197. <https://doi.org/10.1016/j.ecolind.2009.02.006>
- Mallick J, Singh CK, AlMesfer MK, Kumar A, Khan RA, Islam S, Rahman A (2018) Hydro-geochemical assessment of groundwater quality in Aseer Region. *Saudi Arabia Water* 10(12):1847
- Noori R, Maghrebi M, Mirchi A, Tang Q, Bhattarai R, Sadegh M, Noury M, Haghghi AT, Kløve B, Madani K (2021) Anthropogenic depletion of Iran's aquifers. *Proc Natl Acad Sci* 118(25). <https://doi.org/10.1073/pnas.2024221118>
- Pashaeifar M, Dehghanzadeh R, Ramazani ME, Rafieyan O, Nejaei A (2021) Spatial and temporal assessment of groundwater quality and hydrogeochemical processes in Urmia Lake Basin. *Iran Water Supply* 21(8):4328–4342
- Rice E, Baird R, Eaton A (2017) 2340 hardness. Standard methods for the examination of water and wastewater, 23rd edn. American Water Works Association, American Public Health Association, p 2882. <https://www.standardmethods.org/DOI/10.2105/SMWW> Water Environment Federation
- Sachs J, Kroll C, Lafortune G, Fuller G, Woelm F (2021) Sustainable development report 2021. Cambridge University Press
- Saha P, Paul B (2019) Groundwater quality assessment in an industrial hotspot through interdisciplinary techniques. *Environ Monit Assess* 191(2):1–20. <https://doi.org/10.1007/s10661-019-7418-z>
- Shakya KS, Kumar P (2023) Selection of statistical technique for imputation of single site-univariate and multivariate methods for particulate pollutants time series data with long gaps and high missing percentage. *Environ Sci Pollut Res* 30(30):75469–75488
- Sharma R, Kumar P, Bhaumik S, Thakur P (2022) Optimization of weights and ratings of DRASTIC model parameters by using multi-criteria decision analysis techniques. *Arab J Geosci* 15(10):1007
- Singh S, Hussian A (2016) Water quality index development for groundwater quality assessment of Greater Noida sub-basin. *Uttar Pradesh India Cogent Eng* 3(1):1177155. <https://doi.org/10.1080/23311916.2016.1177155>
- Singh G, Singh J, Wani OA, Egbueri JC, Agbasi JC (2024) Assessment of groundwater suitability for sustainable irrigation: a comprehensive study using indexical, statistical, and machine learning approaches. *Groundw Sustainable Dev* 24:101059
- Sreedevi P, Sreekanth P, Ahmed S, Reddy D (2019) Evaluation of groundwater quality for irrigation in a semi-arid region of South India. *Sustainable Water Resour Manage* 5(3):1043–1056
- Sunkari ED, Abu M, Zango MS, Wani AML (2020) Hydrogeochemical characterization and assessment of groundwater quality in the Kwahu-Bombouaka Group of the Voltaian Supergroup, Ghana. *J Afr Earth Sc* 169:103899. <https://doi.org/10.1016/j.jafrearsci.2020.103899>
- Tlili-Zrelli B, Gueddari M, Bouhlila R (2018) Spatial and temporal variations of Water Quality of Mateur Aquifer (Northeastern Tunisia): suitability for Irrigation and drinking purposes. *Journal of Chemistry*
- Tolera MB, Choi H, Chang SW, Chung I-M (2020) Groundwater quality evaluation for different uses in the lower Ketar Watershed, Ethiopia. *Environmental geochemistry and health*, 1–20. <https://doi.org/10.1007/s10653-019-00508-y>
- Van Le Ha QK, Le Vo P, Nguyen HQ, Mukherjee A (2022) An assessment of groundwater quality for drinking and agricultural purposes in Ca Mau peninsula, Vietnamese Mekong Delta. *IOP Conference Series: Earth and Environmental Science*
- Vörösmarty CJ, McIntyre PB, Gessner MO, Dudgeon D, Prusevich A, Green P, Glidden S, Bunn SE, Sullivan CA, Liermann CR, Davies PM (2010) Nature 467:555–561. Global Threats to Human Water Security and River Biodiversity <https://doi.org/10.1038/nature09440>
- World Health Organization (2021) Manganese in drinking water: background document for development of WHO Guidelines for drinking-water quality

Zhang Q, Qian H, Xu P, Hou K, Yang F (2021) Groundwater quality assessment using a new integrated-weight water quality index (IWQI) and driver analysis in the Jiaokou Irrigation District, China. *Ecotoxicol Environ Saf* 212:111992

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Springer Nature or its licensor (e.g. a society or other partner) holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.