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Potable groundwater analysis using multivariate Groundwater Quality Index technique

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ABSTRACT

In the current study, the qualitative status of potable well water was assessed using the groundwater quality index during a course of 4 years (2014-2017). This study was carried out with an aim to monitor the drinking water resources from 12 potable wells on the multivariate analysis basis and for determination of groundwater quality index, the following 13 physicochemical parameters including electrical conductivity, total dissolved solids, pH, total hardness, potassium, fluoride, bicarbonate, chloride, calcium, magnesium, sulphate, and nitrate were used. On the basis of Piper diagram, the results revealed that the type and faces of samples were chloride-sodic and bicarbonate-sodic respectively. Groundwater quality index level in the potable well water of case study area was 42.89 to 56.58 and zone water was in the good and medium range. Besides, 66.7% of the wells were in the good range and 33.3% of wells were in the medium range of water quality index. In this study, potassium and fluoride level in all the zone wells was lower than the ideal level and the electrical conductivity, total dissolved solids, sodium, magnesium and sulphate in all the wells was higher than the ideal range for drinking purposes. Based on this study results, the potable water quality of most of the study area wells generally in 2017 vis-à-vis 2014 had reduced and its main reason was the presence of geology formations, agricultural runoffs and absorbing wells in this zone.

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INTRODUCTION

In the past decades, with increasing population growth and development of industrial and agricultural applications, water demand from groundwater resources is on rising. The health and hygiene of human life in close communication with groundwater quality are considered as the most important resource of water consumption in most regions of the world (Rezaei and Sayadi, 2014; Shekari *et al.,* 2017; Jacintha *et al.,* 2017). Although the water qualitative issues have a compatible and meaningful relationship with quantitative matters of the water, the water quality information especially the quality of potable water resources, is one of the noteworthy and important points for the decision-making in the strategic and planning management of the population (Rezaei and Sayadi, 2014; Sayadi *et al.,* 2015). The groundwater quality of a zone up to a large extent *via* natural processes (i.e. geology), and human activities (i.e. evacuation of varied urban, rural and industrial wastewaters, entry of agricultural fertilizers, leakage from reservoirs and oil transportation lines, garbage disposal areas) is exposed to reduction and pollution leakage (Muhammad *et al.,* 2011; Gupta and Misra, 2018). Therefore, water resources control and their optimal use encounter a very high priority. Inline is apparent that qualitative status determination of water resources for the adoption of suitable alternatives to prevent water quality reduction and or its improvement is essential (Zereg *et al.,* 2018). In the groundwater quality assessment use of suitable tools and techniques, data processing is very efficient because water quality assessment with the availability of high data volume is difficult (Belkhiri *et al.,* 2010). In the majority of the countries, water resources quality monitoring is one of the main programs of organizations associated with water in a manner that most of the countries avail instructions to monitor their water resources (Kim *et al.,* 2015). In these instructions, for better determination and understanding of water resources quality, the specific indices are used. In these indices with the exploitation of conducted experiments results on the physicochemical characteristics of water and using mathematical correlation, a number is obtained wherein with its acquisition and reference to the tables, water quality status of that resource or zone is attained descriptively. One of the useful methods for water quality assessment is the Groundwater Quality Index (GWQI) (Tomaszkiewicz *et al.,* 2014; Lobato *et al.,* 2015; Sharma and Chhipa, 2016). GWQI is one of the most applicable indices in the locative alterations assessment of groundwater quality from the drinking viewpoint, wherein different analogs are integrated with one another and communicates with global criterions such as World Health Organization or WHO. Different studies have been carried out *via* adoption of this method whereby the study of Andrade and Stigter, (2009) in Portugal, stated that GWQI even monitors the agricultural impacts on the groundwater quality and evaluates it with drinking water standards and resultantly is the direct evaluation of its portability. In the other study carried out in India, the analysis of groundwater samples which were collected from different locations of Bikaner and Kolayat, it was reported that in some samples, the water qualitative parameters (total alkalinity, pH, hardness, total dissolved solids, sulphate, chloride, nitrate, calcium, magnesium and iron) was more than the WHO standard permissible level (Kaur and Singh, 2011). In a study, in Dudu city in Rajasthan, India, carried out on groundwater samples showed that pH level measured was at its permissible level. In 13 samples, EC was over the permissible level. It is said that this water cannot be used for drinking purpose. Considering the mentioned studies and importance of groundwater water quality assessment on one side and intensity dependence of people of this zone on these groundwater resources, the assessment of altering processes in the water quality seems needful and imperative (Ranjana, 2009). In this research, using the GWQI and Geographical Information System (GIS), the quality of potable wells in Qaen County was evaluated and with reference to water quality degree in different wells, the probable contaminant resource surrounding them was determined so that a more successful groundwater resources management is enforced.This study has been carried out in Qaen County, South Khorasan Province, Iran in 2018.

MATERIAL AND METHODS

Considering the different chemical, physical and biological conditions dominating the groundwater, several variables are effective on the groundwater quality whereby usually all of them cannot be analyzed and assessed. In this research for the assessment of groundwater, the qualitative groundwater data of Regional Water Department, South Khorasan

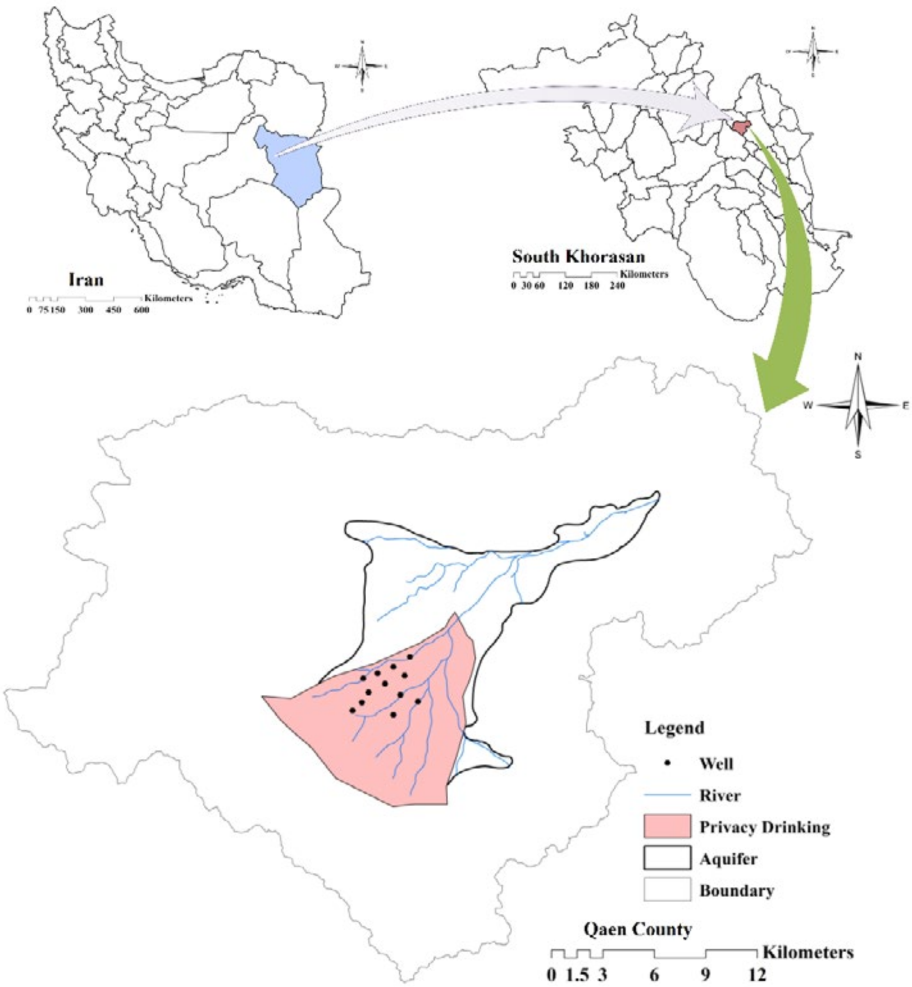

Fig. 1: Geographic location of the study area along with the sampling points in Qaen County, South Khorasan Province in Iran

Province was used. The aforesaid data included 12 water samples of potable wells (drinking) at Qaen County, in 2014, 2015, 2016 and 2017 in the case study area. In this research, 13 parameters *viz*. EC, pH, TH, TDS, K^+, F^-, HCO_3^-, Na^+, Cl^-, Ca^{2+}, Mg^{2+}, SO_4^{-2}, and NO_3^- that have been categorized in the standard table of World Health Organization (WHO, 2011) were used for the calculation of GWQI.

Study area

The Qaen study area was from the sub-basins of Khaf-Petragan playa of Iran (Code 51) in South Khorasan Province between 58º 53´ till 59º 24´ East longitudes and 33º 32´ till 33º 52´ North latitudes (Fig. 1). It is confined from north and north-west to Khezri range, from east to Esfeden range and from the south- west and south to Chahak Mousavieh range. The median altitude in this range is 1663 m, the maximum altitude is 2320 m in the peak altitudes of the south-west basin and the minimum altitude in this range is 1300 m in the external plain section i.e. Kaal Khunik. The median precipitation in this range using the rainfall contours was 186.6 mm annually and median annual temperature of the range using the isotherm contours was equivalent to 13 ºC. Moreover, the median precipitation of plain with an area of 317 sq km was 179.2 mm and altitudes with an area of 635 sq km were recorded 189.5 mm.

Calculation of Groundwater Quality index (GWQI)

GWQI was calculated using weight arithmetic index method. In the current study, the parameters

Table1: Classification of groundwater based on GWQI index

GWQI index	Groundwater quality	Colour
0-25	Very good	Blue
25-50	Good	Green
50-75	Medium	Yellow
75-100	Weak	Orange
100-125	Very weak	Brown
More than 125	Unsuitable	Red

considered for GWQI computation were EC, TDS, pH, TH, K, F, HCO_3^-, Na^+, Cl^-, Ca^{2+}, Mg^{2+}, SO_4^{2-} and NO_3^-. For determining GWQI, the following steps were followed:

Step 1: Calculating the quality rating scale (Qi)

Calculation of the quality rating scale was followed by Eq. 1.

Qi = 100 ×Vm – Vi/Vs – Vi (1)

Where,

Qi = Quality rating of its parameter for a total of n water quality parameters

Vm - Measured value of the water samples for quality parameters estimated from analysis

Vi - Ideal value of that water quality parameter can be obtained from the standard tables Ideal value is equal to zero for most parameters except for

pH = 7 and F = 1.0 mg/L

Vs - Standard of the water quality parameter given by WHO.

Step 2: Calculating the relative unit weight (Wi)

Wi is inversely proportional to standard value (Si) of the parameter; therefore relative unit weight (Wi) was calculated using Eq. 2.

Wi = K/Si (2)

Where,

Wi – Relative unit weight of nth parameter

Si – Standard value of nth parameter

K = Proportionality constant = 1

Step 3: Calculating water quality index (WQI)

The overall WQI was calculated by using Eq. 3.

$$WQI = \sum Qi \cdot \frac{wi}{\sum Wi} \quad (3)$$

Where,

Qi = Quality rating

Wi = Relative Weight

The GWQI scale used for in this study is given in Table 1. The groundwater was divided into 6 classes and rated into very good, good, medium, weak, very weak and unsuitable classes based on the GWQI values. This scale has been used by several researchers for evaluating the groundwater quality for drinking purpose (WHO, 2011).

RESULTS AND DISCUSSION

In Table 2, the descriptive statistics of existing parameters in the groundwater such as maximum, minimum, average and standard deviation has been demonstrated. EC and TDS values in all the wells were higher than the standard level for drinking purpose. The highest annual average value of EC and TDS pertained to well number 5 at the rate of 3952 microsiemens and 2647 mg /L and the lowest annual average value pertained to well number 10 at the rate of 1552 microsiemens and 1039 mg/L, respectively. The maximum permissible EC level introduced *via* WHO is (750 microsiemens/cm). The high EC values have usually been related to the high salinity and mineral content of the sample collection area (Gupta and Misra, 2018). Moreover, high EC values can arise from the ionic exchange and dissolubility phenomenon in an aquifer (Moussa *et al.,* 2009). Even groundwater TDS values have a direct relationship with water salinity (Yang *et al.,* 2016). Based on the International Water Management Institute (IWMI), TDS does not have a direct role in the formation of hygienic dangers, but causes delayed absorption

Table 2: The statistical analysis results on the case study area groundwater data

Years		EC (µS/cm)	TDS (mg/L)	pH	TH (mg/L)	K (mg/L)	F (mg/L)	HCO_3 (mg/L)	Na (mg/L)	Cl (mg/L)	Ca (mg/L)	Mg (mg/L)	SO_4 (mg/L)	NO_3 (mg/L)
2014	Max	4182	2802	7.9	681	5.3	0.6	509	550	810	84.9	152	598	49.0
	Min	1579	1058	7.3	252	3.5	0.5	236	300	156	15.6	50.2	159	15.1
	Average	2524	1706	7.7	418	4.6	0.5	397	402	349	31.5	89.3	361	31.6
	SD	885	587	0.2	144	0.5	0.0	94	97	212	19.6	30.3	150	12.6
2015	Max	4179	2800	7.9	609	5.4	0.6	575	550	810	85	140	756	55.3
	Min	1562	1046	7.3	231	3.5	0.5	243	295	161	15	52	190	15.5
	Average	2590	1734	7.7	371	4.6	0.5	408	406	344	31	82	400	32.3
	SD	877	588	0.2	134	0.6	0.0	104	97	213	18	27	174	13.0
2016	Max	4024	2695	7.8	672	5.5	0.6	539	556	790	88	150	545	57.6
	Min	1546	1036	7.0	240	3.2	0.5	322	290	167	18	45	192	14.0
	Average	2518	1687	7.6	407	4.4	0.5	453	402	367	31	86	318	31.1
	SD	816	546	0.2	152	0.7	0.0	74	100	210	19	34	121	13.1
2017	Max	3612	2420	7.9	663	5.6	0.6	628	553	810	85	130	565	64.9
	Min	1500	1005	7.1	208	3.5	0.5	250	286	172	15	45	150	16.6
	Average	2361	1582	7.5	382	4.4	0.6	471	407	372	33	78	345	34.2
	SD	773	518	0.2	147	0.7	0.0	125	99	214	19	26	135	14.5
MAX		4182	2802	7.92	681	5.6	0.62	628	556	810	88	152	756	64
Min		1500	1005	6.98	208	3.2	0.45	236	286	156	15	45	150	14
Mean		2498	1677	7.62	395	4.5	0.52	432	404	357	32	84	356	32
WHO level		750	500	8/5	500	12	1/5	300	200	200	75	30	200	50
Unit weight (Wi)		0.001	0.002	0.117	0.002	0.083	0.667	0.003	0.005	0.005	0.013	0.033	0.005	0.020

and elimination of dissolved salts in the water in the human body and effectually the base for kidney stone formation increases. High TDS concentration besides reduction of water palatability creates gastrointestinal irritation in the human. The World Health Organization has determined the maximum acceptable concentration of groundwater TDS for residential purposes as 500 mg/L (WHO, 2011).

The high values of TDS in these samples were due to the presence of lime units adjacent to ophiolites in this zone. The well number 5 is good evidence of this case since from TDS as well as EC viewpoint it had the highest values among the samples. It is assumed that limy units caused an increased rate of this parameter in the aforesaid sample. It was observed that permanent hardness rate in well number 7 was the highest annual average level *viz.* 630 mg/L and in the well number 10, the lowest annual average level recorded was 248 mg/L. The permanent hardness is due to combinations except for bicarbonates in the water (phosphate, sodium, etc.) and considering that the recorded concentration of such combinations in the water of well number 10 was higher than the other wells, therefore the permanent hardness in this well was also at the highest level. From the hardness standard viewpoint, that according to the suggestion of the World Health Organization (WHO, 2011) is 500 mg/L, which is considered as the highest permissible concentration for the potable water. 25% of the waters in the zone are nestled in the totally hard range. Considering the WHO standard, the permissible bicarbonate level in the drinking water has been determined as 200 mg/L (WHO, 2011). In the well number 5, the highest annual average bicarbonate recorded was 577 mg/L and in the well number 7, the lowest annual average bicarbonate recorded was 236 mg/L. The bicarbonate measure of groundwater is usually due to CO_2 of the area soil besides calcite and dolomite dissolution. From the viewpoint that calcite and dolomite exist at significant rates in most of the sedimentary basins and due to reason that these minerals dissolve during contact with groundwater enriched with CO_2, the prevailing bicarbonate, anion in most of the regions is the recharge (Lapworth *et al.,* 2008). Considering, it was observed that fluorine and potassium rate in all the wells was lower than the standard level wherein the maximum potassium rate was equivalent to 5.42 mg/L and fluorine rate was equivalent to 0.52 mg/L in the well number 5. Potassium in the water resources of the case study area against other ions encounters a low concentration. The main origin of potassium in the groundwater is feldspars, and some from silicates, clayey minerals and evaporations such as sylvite. The potassium-containing fertilizers and residential wastewaters are sylvite factors, but due to intense adsorption of potassium *via* sedimentation of fine-grained alluvium, the potassium concentration had not increased much (Selvam *et al.,* 2013). The most important natural resources of sodium is the sodium-containing silicate minerals (albite and nepheline) in the pyrogenous stones and halite minerals and mirabilite in the evaporative stones. The permissible sodium level in drinking water is 200 mg/L. The sodium rate in the entire wells of the case study area was more than the standard level and an ideal level for drinking wherein the lowest and the highest annual average concentration of sodium was 300 and 566 mg/L respectively. The chloride ion is a prevalent ion in the groundwater and surface waters that are found along with the sodium and potassium elements. Listonites, the calcite stones and calcite inlets all are nestled in the upper levels of the water resources that contain high chlorine concentration. Indeed even the presence of brines in the zone can be considered as the origin of chlorine (Lapworth *et al.,* 2015). Considering the WHO standard, the permissible chlorine level in the drinking water is 200 mg/L (WHO, 2011). Calcium and magnesium rates are accounted as the main factors of water hardness, the high amount of these elements in the water causes increased water hardness and finally leads to the limitation of varied water consumptions (Shi *et al.,* 2013). Also, it was observed that the highest annual average calcium measured in the well number 11 was equivalent to 85.7 mg/L and the lowest pertained to well number 6 at the rate of 16 mg/L. Calcium is from the main groundwater cations and is present in waters originated from the crystalline stones, the resource providing water calcium, pyroxene silicates, amphiboles, feldspars, and other calcium-rich minerals. The studies have revealed that calcium is released from the Plagioclases and Albite sanctification in the groundwater. In general, in the groundwater system, the factors that control calcium concentration are calcite sedimentation or other calcium containing carbonates, Plagioclases hydrolysis, and sedimentation of secondary calcium containing aluminosilicates besides CO_2 flow rate in the system. In the environments formed from sedimentary stones, the factor providing calcium concentration is the carbonate minerals in the form of calcium carbonate, dolomite, gypsum and anhydrite (Lapworth *et al.,* 2018). Moreover, it was observed that in the entire case study wells, the magnesium rate was more than standard level, wherein for drinking purposes, the maximum permissible magnesium concentration is 30 mg/L (WHO, 2011). The highest annual average level of magnesium recorded in well number 7 was at the rate of 137 mg/L and the lowest level recorded in the well number 10 was at the rate of 57.93 mg/L. The most important magnesium resources in the crystalline stones are Olivine, Biotype, Augite, hornblende and in the metamorphic rocks are Talc, Diopside, and Serpentine. Generally, sulphates in the evaporative minerals like gypsum and anhydrite enter the groundwater (Michael and Voss, 2009). The sulphate rate in most of the case study wells was more than the standard level for drinking purposes. The maximum permissible sulphate concentration is 200 mg/L (WHO, 2011). The highest and the lowest sulphate level recorded in the case study area wells was 545 and 150 mg/L respectively wherein the lowest level pertained to well number 9 and the highest value pertained to well number 11. Gypsum dissolution during dolomitization process is an irrecoverable process and has caused an increase of sulphates concentration such as magnesium and calcium in the groundwater of Qaen County. The other factors for sulphate concentration increase can be correlated to the dominance of single valence ions (Na and K) adsorbed and *via* the surface of clayey minerals in the zone. The presence of these cations, whose origin can be the factor of evaporation and transpiration, causes sulphate adsorption rate reduction on the clay surface and increases their leaching rate towards groundwater (Moller *et al.,* 2016). Probably among the limestone layers, the gypsum and sulphate combinations exist that simultaneously with reaction-interaction of these stones with groundwater and their dissolution in water; the sulphate particles dissolve and cause sulphate concentration increase. The research carried out in America proved that high clay and gypsum level increases sulphate concentration (Hudak and Sanmanee, 2003). The probability of mass sulphides in the splits in the altitudes and upper levels of the main canals especially in the central section of the zone can be considered as the main sulphate factor in the water resources. In fact, conversion of sulphides to sulphate due to weathering and high sulphate dissolution and leaching of sulphate formations causes entry of sulphates from zone stones to the groundwater. The nitrate concentration values in the case study wells were variable from minimal of 15 to maximal of 56.70 mg/L. The variations of nitrate concentration in the potable wells are depicted. The highest nitrate concentration was observed in the well number 1, in a manner that nitrate concentration values in the well were more than the World Health Organization standard in the drinking water (45 mg/L).

Assessment of water samples type and determination of ions origin

Groundwater hydrochemical faces determine the different water masses with geochemical nature. For a description of groundwater chemical differences, the reformed hydrochemical faces is used (Sikdar *et al.,* 2001). The faces are functional of lithology, dynamics of solutions and water flow pattern in an aquifer. The faces classification basis is the values of major cations and anions of groundwater. One of the prevalent methods to determine of hydrochemical facies and type of groundwater is the use of the Piper diagram (Jeyaraj *et al.,* 2016). In this classification, groundwater on cations basis is divided into three faces *viz.* calcic, sodic and etc. even on anions basis is classified into three types; bicarbonate, sulphates and chlorides respectively.

Fig. 2 depicts the Piper diagram of groundwater samples. Based on the diagram, the type and facies of samples were chloride-sodic and bicarbonate-sodic respectively. According to this diagram, 58.3 of wells had bicarbonate-sodic type and

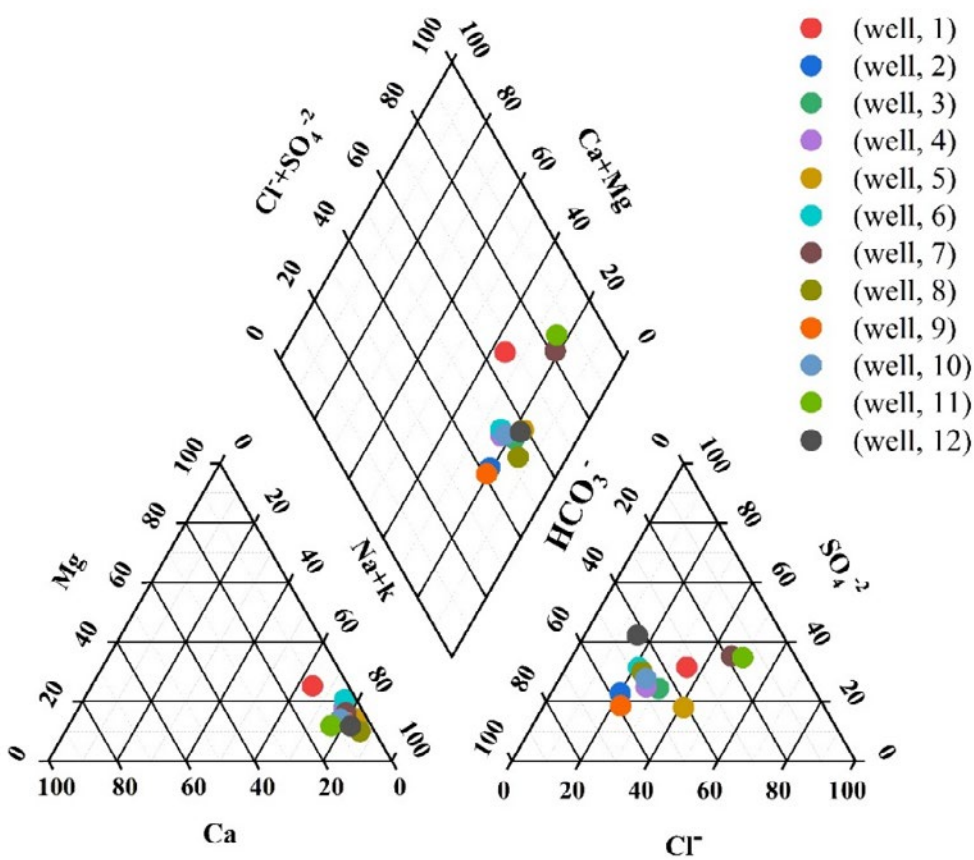

Fig. 2: Piper diagram of assay and analysis of samples

facies which indicated the zone's recharge and youthfulness of groundwater. And 41.7% of wells (1, 3, 5, 7 and 11) had chloride-sodic type and facies. In diamond Piper diagram, most of the wells (1, 3, 4, 5, 6, 7, 8, 10, 11 and 12) were in the Na-Cl (SO_4-Cl-Na-K) water type range which indicated that the groundwater of this zone could be originated from Halite dissolution and or ionic exchange or both, and wells 2 and 4 were located in the Ca-Na-HCO_3 range. These wells were influenced by chemical reactions, calcium, and magnesium-rich solutions and clayey sedimentations enriched with sodium (sodium containing Montmorillonite), the salt solutions (Sodium chloride) that cause the release of high sodium values resultantly create water type with Ca-Na-HCO_3 specifications.

The correlation coefficient

The physiochemical parameters correlation of groundwater resources of the assessed area is tabulated in Table 3. As it was observed, the electrical conductivity and or TDS had a medium and strong correlation with most of the physicochemical parameters except potassium. With sodium parameters, chloride had a strong correlation and with total hardness, magnesium, sulphate, and nitrate showed a medium to powerful correlation. The negative correlation of pH with other ions is related to the high corrosiveness of acidic environment in relation to the host soil and rock which increases the concentration of most ions (Iepure *et al.,* 2017). The correlation coefficient calculation results between physicochemical variables also signified the same fact in a manner that pH showed a highly negative significant correlation with Cl, K and sulphate and a medium correlation with EC, TDS, TH, Na, Ca and NO_3^-. Although pH does not have a direct effect on human health but has a close relationship with the physicochemical variables of water (Garg *et al.,* 2009). The powerful correlation between calcium, magnesium, and sulphate could be due to the process of dolomite and gypsum rocks in an aquifer. The powerful relationship between sodium and chloride can be related to the halite dissolution and contamination due to human activities (Long *et al.,* 2015; Mahato *et al.,* 2018). Even the total hardness had a more strong correlation with calcium, magnesium, and bicarbonate. Calcium and magnesium showed a good correlation with sulphate and this dissolution of gypsum and anhydrite was the controller of groundwater chemical combination in the zone. The origin of sulphate probably is the geological formations related to the Eocene and Oligocene epoch in the adjacent mountain of an aquifer with specific layers of gypsum and anhydrite. A strong and medium nitrate correlation with EC and TDS with cations and anions can be related to the nitrogen fertilizers used for the agricultural lands. The nitrogen fertilizer had more [(NH_4NO_3),($CaCO_3$)] combination. Ammonium oxidation causes the release of a proton (H^+). Therefore, the nitrogen rejuvenated from the fertilizers causes' soil acidity and increases nitrate. The active fertilizers dissolution causes $CaCO_3$ release and eventually H^+ combination obtained from ammonium oxidation and $CaCO_3$ obtained from the fertilizers increases physicochemical parameters in the groundwater

Table 3: Correlation of the main cations and anions and physicochemical parameters in the water samples of the study area

Variables	EC	TDS	pH	TH	K	F	HCO_3^-	Na	Cl	Ca	Mg	SO_4^{-2}	NO_3^-
EC	1												
TDS	0.99**	1											
pH	-0.41**	-0.41**	1										
TH	0.69**	0.69**	-0.41**	1									
K	0.155	0.16	0.26	0.08	1								
F	0.31*	0.31*	-0.53**	0.24	-0.32*	1							
HCO_3^-	-0.29*	-0.29*	0.08	-0.54**	0.42**	-0.20	1						
Na	0.90**	0.90**	-0.45**	0.48**	0.09	0.44**	-0.15	1					
Cl	0.91**	0.90**	-0.58**	0.74**	-0.09	0.56**	-0.46**	0.85**	1				
Ca	0.36*	0.35*	-0.47**	0.51**	-0.50**	0.60**	-0.67**	0.36*	0.64**	1			
Mg	0.67**	0.67**	-0.26	0.85**	0.34	-0.01	-0.29*	0.41**	0.58**	0.12	1		
SO_4^{-2}	0.75**	0.74**	-0.57**	0.59**	-0.01	0.29	-0.33*	0.67**	0.71**	0.38**	0.59**	1	
NO_3^-	0.54**	0.54**	-0.38**	0.87**	0.24	0.30*	-0.42**	0.40**	0.60**	0.47**	0.74**	0.51**	1

**. Correlation is significant at the 0.01 level

*. Correlation is significant at the 0.05 level

Table 4: Factor analysis results in the potable well waters

Variables	PC1	PC2	PC3	PC4
EC	**0.933**	0.114	0.298	0.001
TDS	**0.933**	0.114	0.298	0.001
PH	-0.329	0.448	0.230	**0.755**
TH	**0.867**	0.210	-0.426	0.063
K	0.083	**0.950**	0.010	-0.176
F	0.578	-0.113	**0.696**	0.133
HCO_3^-	**-0.558**	0.522	0.384	-0.437
Na^{+2}	**0.792**	0.056	0.537	-0.088
Cl^-	**0.965**	-0.072	0.210	0.069
Ca^{+2}	**0.662**	-0.444	-0.285	0.374
Mg^{+2}	**0.706**	0.524	-0.450	-0.009
SO_4^{-2}	**0.637**	-0.465	-0.105	-0.530
NO_3^-	**0.766**	0.361	-0.462	-0.020
Eigen Value	6.743	2.286	1.886	1.247
Variability (%)	51.870	17.587	14.510	9.590
Cumulated (%)	51.870	69.457	83.968	93.558

(Martinez-Bastida *et al.,* 2010; Rezaie and Sayadi, 2014).

Factor analysis (Principal component analysis)

Factor analysis has been conducted based on the qualitative parameters including the concentration of main ions. Factor analysis as a multivariate statistical tool has proven highly effective in studies of groundwater quality. The principal component analysis is designed to transform the original variables into new and uncorrelated variables called the principal components, which are linear combinations of the original variables. This technique examines the relationships between variables. It provides information on the most significant parameters due to spatial and temporal variations that describe the whole data set by excluding the less significant parameters with minimum loss of the original information (Sayadi *et al.,* 2014). In this method, the factors were obtained with an analysis method and with principal components and factor load or the effective coefficient of each parameter with the Varimax rotation method. In the first stage, the implementation of this method is based on correlation existence that has been demonstrated in the Table 4. Generally, in factor analysis, the factor loads near one are considered as efficacious factors in the system. Among the components, the first component showed the highest variance and respectively the next components showed lower values of variance. In Table 4, the load or coefficient of each factor has been tabulated and the coefficients over 0.7 and values 0.5-0.7 with average coefficient are determined that is indicative of the effective parameters in that component. Thus, implementation of the principal components analysis method caused extraction of four factors. The results indicated that this component covers 93.56% of the total communion rate. Table 4 depicts the distinctive factor loads and cumulative variance percent of each component. The first component variance approximately accounted for 51.87% of the total cumulative variance and controls more than half of the chemical alterations in the range. In the first component, a powerful relationship between the ions of bicarbonate, sodium, chloride, calcium, magnesium, sulphate, and nitrate existed, besides electrical conductivity, TDS and TH were an indicator of high water-rock equilibrium in the case study area. Considering the fact that halide and gypsum sediments persist in the range, it has caused more increase of EC, TDS, sodium, chloride and sulphate parameters in the groundwater of the zone.

The main chloride origin is sodium chloride, wherein sodium has different resources. The maximum sodium ion origin was a result of ionic exchanges and from (lime + clay) marks of the attitudes towards the plain, the sodium-enriched clay sedimentations (the alluvial sediments from the median to external section of the plain) has reacted with calcium and magnesium and caused sodium release (natural softening) (Katz *et al.,* 2011; Glok

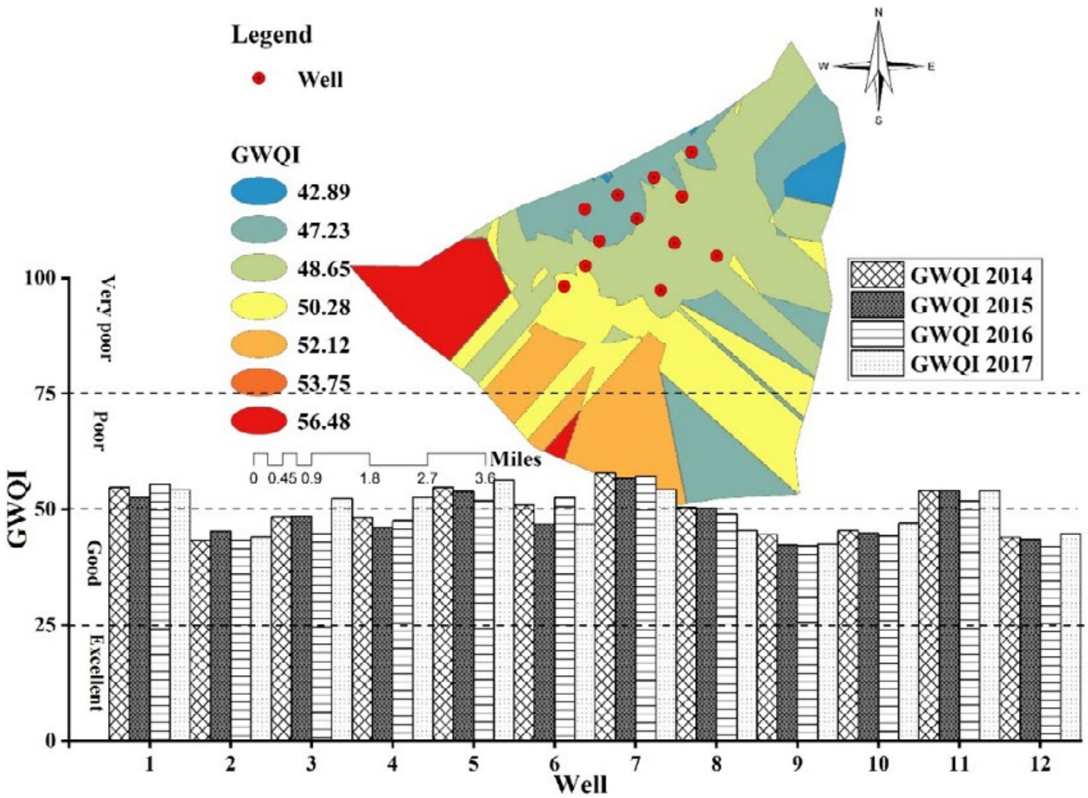

Fig. 3: GWQI index value for the wells

Galli *et al.,* 2014). The sodium and chloride increase was due to precipitation reduction followed by penetration rate reduction, the unsystematic use of an aquifer and evaporation from the water table and ionic exchange that changes the sodium chloride ions level. The sulphate origin considering that in the case study area gypsum sediments could persist and as well use of the sulphate potash fertilizers in the agricultural lands along with agricultural runoffs could arise (Pazand and Hezarkhani, 2013; Sridharan and Senthil Nathan, 2017). The nitrate present in the groundwater is due to agricultural activities and urban as well as rural wastewaters (Rezaei and Sayadi, 2014; Zamorano et al., 2016). In the study area, two nitrate pollution origins can be considered: one of the nitrate factors was from agricultural activities like the western and southwestern of Qaen plain and the other factor was the nitrate due to absorbing wells. The nitrate presence signifies the effect of human processes effects such as the use of nitrogen fertilizers and wastewater disposal wells. In the fourth component, pH with 0.75 factor load due to low variance percent had low impacts on the chemical reactions.

Groundwater Quality Index (GWQI)

The qualitative zoning of groundwater potable wells of the Qaen zone based on GWQI index and using the GIS has been demonstrated in Fig. 3. On the basis of Fig. 3 diagram and above zoning, the status of wells indices in the case study area was rated good and medium. The annual average level of this index for all the wells of the case study area was equivalent to 49.10. In the well numbers 1, 4, 6, 11, the GWQI index level in 2015, was lowest *viz*. 54.08, 46.68, 46.15, 52.53 respectively and in the well numbers 2, 3, 5, 9, 10 and 12 this index in 2016, was the lowest *viz*. 41.97, 44.32, 42.41, 51.87, 44.80 and 45.36 respectively and in the well numbers 7 and 8, this index value, in 2017, was the lowest i.e. 45.42 and 54.28 respectively and of the highest quality. And in well numbers 7, 8 and 9, the GWQI index level in 2014, was the highest *viz*. 44.62, 50.36 and 57.79 respectively and in the well number 2, this index level in 2015, was the highest i.e. 45.27 and in the well numbers 1 and 6, this index level in 2016, was the highest i.e. 52.52 and 55.39 respectively and in well numbers 3, 4, 5, 10, 11 and 12, this index level in 2017, was the highest i.e. 52.28, 52.53, 56.52, 46.91, 46.09 and 44.76 respectively that were of the lowest quality. The GWQI index comparisons for each of the wells is shown in Fig. 3, wherein the groundwater quality in all the wells was at good and medium level (the GWQI index was between 42.89 and 56.48), but considering the electrical conductivity, total dissolved solids, sodium, and magnesium values in all the wells it was recorded more than the standard level. In the study of Dhakad *et al.,* (2008) in Jhabua town, India, the GWQI index level was equivalent to 65 that signified median water quality in this city. The reason for this finding was higher values of total dissolved solids, magnesium, sulphate, sodium and chlorine in the water. In the study of Ramakrishniah *et al.,* (2009) the groundwater quality index of Tumkur Taluk (India) was studied using the following parameters; pH, EC, TDS, TH, anions, and main cations. In their study, the water quality index domain was 66 to 89 and the high GWQI value was due to water hardness, TDS and bicarbonate. The results showed that the groundwater usage of the case study area should be carried out with considerations. In this study between hardness, magnesium, bicarbonate, chlorine, dissolved solids and sulphate a positive and meaningful correlation existed. In the study of Ganesh Kumar *et al.,* (2011) in Tamil Nadu, India, this index value was equivalent to 40, which indicated the good qualitative status of the water. Reza and Singh, (2010) studied the groundwater qualitative status of Orissa, India, using the GWQI. The water samples were collected from 24 wells in the summer and winter. The following components i.e. pH, TDS, TH, turbidity, chloride, calcium, and magnesium were used for calculation of GWQI index. Calcium and magnesium were the effective cations on the water quality. The water quality index nestled at the range of 14 to 57 and 19 to 67 in summer and winter respectively. The dissolved solids concentration in winter was higher which indicated water quality reduction. They reported that excess dissolved salts during precipitation caused water quality reduction in comparison to the summer. In this study, the values of case study indices except for electrical conductivity, total dissolved solids, sodium, magnesium, and sulphate were in the acceptable range. This index value for well number 9 was the lowest (42.89) i.e. the highest quality and for the well number 7, was the highest (56.48) i.e. the lowest quality.

CONCLUSION

Based on the present study results, the GWQI index value in the zone was between 42.89 and 56.48 which signified that the quality of groundwater potable wells of the Qaen County was medium and good and its reason was high values of electrical conductivity, total dissolved solids, sodium, magnesium, and sulphate. In this zone, the values of all the qualitative indices recorded for most of the parameters in some wells were higher than the standard level. Finally with water quality assessment in the case study area, it was reported that the pollution trend of the zone waters with time passage was increasing and this pollution severity in the southern and southwestern sections of this zone was higher and its main reason was existence of geological formations wherein the formations types constituted of anhydrite and halite minerals, agriculture and wastewater disposal wells in the zone. On the other side, with time passage, due to groundwater usage increase, the groundwater drop in this zone was evidenced whereby this factor could as well cause the reducing water quality trend in the zone. Eventually, it can be safely suggested that with comprehensive management the quality reduction of water resources in this zone can be prevented so that the impact of higher damages on the basic resources are hindered.

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CONFLICT OF INTEREST

The author declares that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

ABBREVIATIONS

%	*Percent*
µS/cm	microsiemens/cm
ºC	Centigrade
Ca	Calcium
$CaCO_3$	Calcium carbonate
Cl	Chloride
CO_2	Carbon dioxide
EC	Electrical conductivity
F	Fluoride
GIS	Geographic Information System
GWQI	Groundwater Quality Index
HCO_3	Bicarbonate
IWMI	International Water Management Institution
K	potassium
Mg	Magnesium
mg/L	Milligram per litter
mm	Millimeter
Na	Sodium
NO_3^-	Nitrate
$SO4^{-2}$	Sulphate
sq km	Square Kilomiter
TDS	Total dissolved solids
TH	Total hardness
WHO	World Health Organization
WQI	Water Quality Index

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