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Assessment of Water Quality Using Water Quality Index (WQI): Case Study of Bakoya Aquifer, Al Hoceima, Northern Morocco

Chaimae Benaissa[1*], Belkacem Bouhmadi[1], Abdelhamid Rossi[1],
Yahya El Hammoudani[2,] Fouad Dimane[2]

[1] Geosciences Research Team on Natural Risks (Georisk), Department of Earth Sciences, Faculty of Science and Technology of Tangier, Abdelmalek Essaâdi University, Avenue Khenifra, Tétouan 93000, Morocco

[2] Engineering Sciences and Applications Laboratory, Department of Energy and Environmental Civil Engineering, National School of Applied Sciences of Al Hoceima, Abdelmalek Essaâdi University, Avenue Khenifra, Tétouan 93000, Morocco

* Corresponding author's email: elhammoudani5@gmail.com

ABSTRACT

This work developed a groundwater quality index for the BAKOYA aquifer of the Al Hoceima city, Morocco, as well as the monitoring of physicochemical and bacteriological parameters of major chemical elements in the water used as drinking water for a large population of the region. The samples were taken in the coastal aquifer Bakoya Al Hoceima. The waters of the Rif region are highly mineralized and marked by sodium chloride or sodium-sulfate facies related mainly to a process of marine intrusion and dissolution of evaporite minerals included in the site rocks. The results obtained with the WQI index showed that 12 samples are eligible for excellent quality, while 18 samples are not good enough for consumption as drinking water. The results show that the groundwater samples studied are characterized by medium to high salinity, exceeding 4000 µS/cm. This mineralization of marine beginning is somewhat because of the severe abuse of groundwater and avalanches, known in the region because of the earthquake, which accelerates the phenomenon of saltwater intrusion in the coastal karstic aquifer. The salinity of this water reaches salinization levels C3 and C4, as classified by the Wilcox diagram, and the waters of the Bakoya massif have been qualified as very hard. Examination of the hydrochemical results with the drinking water quality norms set by the World Health Organization shows that most of the water inspected is not suitable for utilization, mainly because of the high levels of EC, TDS, and linked to marine intrusion, as well as the urban pollution factor that increases the content in the water.

Keywords: groundwater quality, water quality index, physicochemical, bacteriological, Bakoya massif.

INTRODUCTION

Fast population growth and the accelerated pace of industrialization have increased the demand for freshwater. Since old times, groundwater double-dealing has been the favored answer for meeting the developing requirement for water, especially in arid and rural areas.

The World Health Organization (WHO) has dictated a set of water quality standards and guidelines. Indeed, the water intended for human consumption must be of high quality (Tigkas, Vangelis et al. 2012). Consumers, harassed by fierce advertising, are convinced that bottled water is of better quality than tap water. With the indications on the labels, regarding some ions dissolved in the water, they believe that the water from the bottle is richer in nutritional elements and in accordance with the standards of potability. However, the quality of water is not only defined by the few indications mentioned on the labels, but also by three types of parameters: microbiological parameters, physicochemical parameters and comfort parameters. Dissolved chemical substances can be: inorganic, organic and radioactive. They influence the quality of water by their concentration, toxicity and interaction with two physical parameters: temperature and pH.

The determination of water quality is not rigorous if it is based solely on the maximum allowable concentrations (MACs), known as quality, required by the standards in force for each constituent. The MAC values do not define the quality of the water itself; they designate the probable and cumulative risk that water can generate when the value of a parameter exceeds its corresponding MAC. Exceeding MAC does not necessarily mean that there is a health risk to the consumer. The use of a single quality parameter, chemical or physical, taken individually to describe water quality is not always easy to understand, it does not, on its own, fully reflect the overall quality of the water. The parameters are also interdependent; the interference between chemical elements in many cases distorts the judgment made on the quality of the water.

To facilitate managers to properly define water quality (Samantray, Mishra et al. 2009), researchers have developed water quality indices (WQI) which are numerical expressions to merge a large number of quality parameters into a single cumulative factor and present an overall status on water quality (Semiromi, Hassani et al. 2011). It is an efficient method to compare the quality of a large number of water samples based on a single numerical value (Jomet Sebastian and M andYamakanamardi 2013).

Most of the Al Hoceima region inhabitants prefer to consume the water from springs and wells, which does not taste like the chlorine used to treat tap water. The population of Al Hoceima suffers from the poor quality of tap water, which has a high hardness and an unbearable chlorine smell. However, the population is unaware of the spring water quality and its potential deterioration by chemical and microbiological pollutants. Springs and water wells are easily subject to natural or anthropogenic contamination, especially in karst areas where transfer and infiltration rates are high. Saltwater intrusion into aquifers is a phenomenon studied worldwide, especially in the context of over-exploitation of coastal aquifers.

In this context, the objective of this study was to determine the quality of bakoya waters in Morocco using the quality index approach (WQI), and make an attempt to determine the fitness of various water samples collected.

MATERIALS AND METHODS

Study area

The Bakoya massif is a mountain range located in the north-central part of the Rif chain

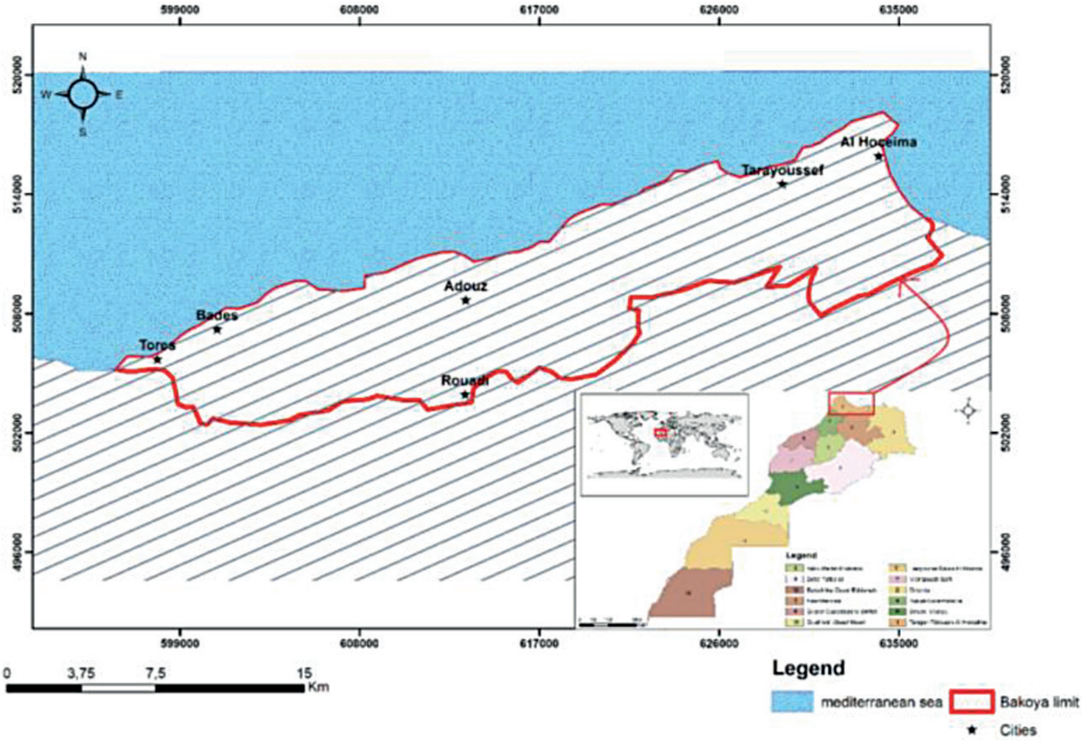

Figure 1. Situation of the Bakoya aquifer

in northern Morocco (El Hammoudani and Dimane 2020, Bourjila, Dimane et al. 2021, El Hammoudani, Dimane et al. 2021) (Fig.1); it extends for about 40 km between the city of Al Hoceima in the east and the village of Torres in the west width of about 10 km, and an altitude between 0 and 700 m.

Due to cultural factors, natural spring and well water are perceived as having a better taste and are widely consumed by the local population.

Hydrochemical characterization can provide the information on the lithology of the aquifers, chemical facies of the waters, and, therefore, the type of use for which the groundwater can be used. Therefore, groundwater quality studies are crucial, especially for drinking water. In order to be used, the water must meet specific standards that vary according to the type of use.

Groundwater chemistry depends on several factors, such as the general geology, the degree of chemical alteration of the different rock types, the quality of the recharge water, and the different energy sources. These factors and their interaction result in complex groundwater quality. In addition, the physicochemical quality of groundwater is related to the lithology of the region—the hydrogeological and hydrochemical properties (principal components).

Geological setting

The Bokoya Massif is a piece of the Internal Domain that outcrops in the north-central part of the Rif Range. It is represented mainly by the external limestone Dorsal, which supports tectonic clippers of land belonging to Sebtides, Ghomarides nappes, and the internal limestone Dorsal. The whole massif rests on the Tisirene flysch nappes through the marly series of the Predorsal (Fig.2). These structural units are composed of several tectonic scales of variable importance, stacked one on top of the other. Their structuring, characterized by essentially brittle deformations of the upper structural level, results from the superposition of several compressive and distensive phases that succeeded one another from the Eocene to the present day.

Sampling

This work analyzed 30 water samples taken from different wells with varying depths and exploited by the local population. These points were chosen according to those most used by the population. During this study, 23 parameters were determined, some performed immediately in the field and others in the research center. The field estimations of the gathered examples concern

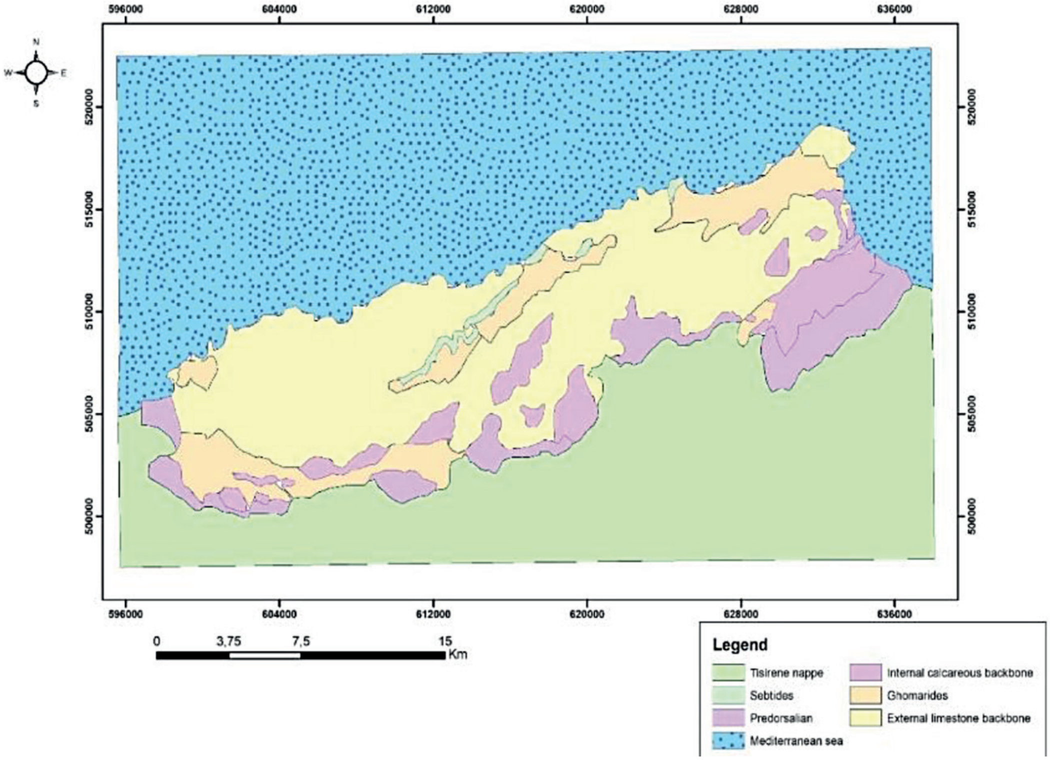

Figure 2. Lithological map of the Bakoya aquifer

actual boundaries like temperature (T°C), hydrogen potential (pH), electrical conductivity (EC), and broken down solids (TDS). They were performed following the water tests and collected using a portable device. The water samples were collected in high-density polyethylene (HDPE) bottles of 1.5 liters capacity after rinsing them well with nitric acid and then with distilled water; the bottles were numbered and recorded. The water samples were taken after 15 minutes of pumping to avoid sampling stagnant groundwater in the field; before filling, these bottles were washed three times with the collected water. The filling was done using a Bunsen burner (Chalumeau), and then the cap was screwed on to prevent any gas trade with the environment.

The water samples were then transported in a cooler at 4°C to the laboratory for analysis. The analysis of significant elements such as hardness (TH), calcium (Ca^{2+}), and magnesium (Mg^{2+}) levels was measured by using the EDTA volumetric method. Complete alkalinity (TAC) was analyzed by volumetric titration with HCl N/10. Volumetric titration was also applied to determine the concentration of chlorides (Cl^-) using nitric acid as the titrating solution. Nitrates (NO_3^-) and sulfates (SO_4^{2-}) were determined by colorimetric determination using a spectrophotometer (TB 300 IR). The bacteriological analysis was performed by the membrane filtration method (Jean RODIER 2009). This technique consists in filtering 100 ml of water through a cellulose membrane with a uniform pore size of 0.45 µm; then, this membrane is placed in a culture medium (lactose celose with TTC and tergitol 7 for Coliform Bacteria as well as Escherichia coli, and slanetz and bartley celose for intestinal Enterococci).

Characterization of water samples

The collective water points have been selected and are categorized in (Table 1).

Table 1. Characterization of the water samples in the study area

Samples	Source type	Protection	Presence of pump	Pump type	Presence of another source of pollution
P1	Well	Yes	Yes	Manual	Yes
P2	Spring	Yes	No	-	Yes
P3	Spring	No	No	-	Yes
P4	Well	No	Yes	Electric	Yes
P5	Well	Yes	Yes	Electric	Yes
P6	Well	Yes	Yes	Electric	Yes
P7	Well	Yes	Yes	Electric	Yes
P8	Well	Yes	Yes	Electric	Yes
P9	Well	Yes	Yes	Electric	Yes
P10	Spring	No	No	-	Yes
P11	Spring	Yes	No	-	Yes
P12	Well	No	No	-	Yes
P13	Well	Yes	Yes	Electric	Yes
P14	Well	Yes	Yes	Electric	Yes
P15	Well	Yes	Yes	Electric	Yes
P16	Well	Yes	Yes	Electric	Yes
P17	Spring	Yes	No	-	Yes
P18	Well	No	No	-	Yes
P 19	Spring	Yes	No	-	No
P20	Well	No	No	-	Yes
P21	Well	No	No	-	Yes
P22	Well	No	No	-	Yes
P23	Well	No	Yes	Manual	Yes
P24	Well	No	No	-	Yes
P25	Well	No	No	-	Yes
P26	Well	No	No	-	Yes
P27	Spring	Yes	No	-	No
P28	Well	Yes	Yes	Electric	Yes
P29	Well	Yes	No	-	Yes
P30	Well	No	No	-	Yes

RESULTS AND DISCUSSION

Physicochemical discussions results

The results of the physicochemical analyses of the groundwater in the area showed that the values of electrical conductivity found are quite significant for the different samples. Indeed, these values vary between 747 and 4650 µS/cm, with an average value of 2148.96 µS/cm; it is known that conductivity is generally proportional to the concentration of mineral salts. Ions Cl^- and SO_4^{2-} are the majority anions by mass, and cations Na^+ and Ca^+ are cations by mass. The average molar abundance of major elements (Table 2) varies as follows: For the cations, it is in the order $Na^+ > Ca^{2+} > Mg^{2+} > K^+ > NH_4^+$ and for the anions, it is in the order $Cl^- > SO_4^{2-} > HCO_3^- > NO_3^- > S_iO_2 > NO_2^- > PO_4^{3-}$.

Bacteriological

Groundwater, generally of better quality than surface water, can be vulnerable to contamination, and precautions must be taken to ensure a good

Table 2. Descriptive statistics of the main parameters

Parameter	Minimum	Maximum	Mean	Standard deviation
pH	7020	8,110	7,613	0,311
E.C	747,000	4650,000	2148,967	1149,794
TDS	559,000	3564,200	1582,733	851,252
TAC	15,000	55,000	30,417	8,537
Trb	0,150	2,670	0,731	0,568
TH	20,500	136,000	57,387	28,629
HCO_3^-	183,000	671,000	375,150	104,400
Cl^-	96,200	1204,600	444,730	321,574
Ca^{2+}	34,800	318,300	124,907	73,746
Mg^{2+}	4,800	301,500	60,261	61,669
SO_4^{2-}	19,030	999,400	273,028	233,638
NH_4^+	0,000	0,100	0,013	0,026
NO_3^-	10,000	240,000	80,667	68,929
NO_2^-	0,000	1,000	0,169	0,319
Na^+	93,400	703,300	305,563	177,564
K^+	1,200	31,500	10,950	7,873
S_iO_2	10,560	81,110	23,958	13,767
PO_4^{3-}	0,003	0,670	0,215	0,177

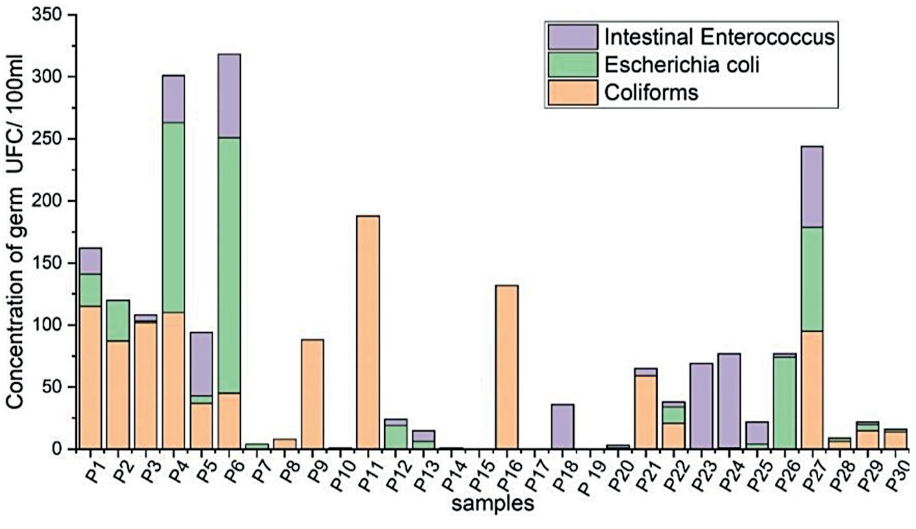

Figure 3. Bacterial analysis of water samples

quality water supply. Analyses were conducted on selected points in the Bakoya Mountains. The water from these water points supplies the population. These analyses aim to look for bacteriological contamination that could affect human health; these analyses are based on the ISO 9308 and ISO 7899 methods. The results obtained from the bacteriological analyses are grouped in Figure 3. They are compared with the maximum permissible values, determined by the 037001 standard, which establishes the quality requirements for water intended for human consumption. Each microorganism found in the samples studied is a fecal indicator. From the figure, it can be seen that most of the points studied are contaminated (Benaissa, Bouhmadi et al. 2020), so it can be said that these points are exposed to contamination of animal or human intestinal origin.

Statistical analysis

Calculation of water quality assessment

The water quality index method for groundwater measures the composite influence of physicochemical water parameters. The groundwater quality was assessed using the equations for WQI against WHO standards, 11 critical parameters (pH, EC, TDS, HCO_3^-, Cl^-, SO_4^-, Ca^{2+}, Mg^{2+}, Na^+, K^+, NO_3^-, NH_4^+, and NO_2^-) were selected to calculate the W QI(Brown R 1970). This index is a water quality classification technique based on comparing water quality parameters with WHO standards (NM03.7.001 2006) and was analyzed in this study. The Water Quality Index summarizes large amounts of water quality data in simple terms (Excellent water, Good water, Permissible water, Doubtful, Water unsuitable). However, weights (*wi*) are assigned to the measured parameters according to their relative importance in the water quality assessment.

Table 3. The weight (wi) and relative weight (Wi) of each chemical parameter to calculate the QWI with the Moroccan standard (NM 03.7.001) for drinking water

Parameters	WHO	Wi	Rwi= wi/∑ Wi
PH	6,5–9,5	4	0.08510638
EC (µS/cm)	1500	4	0.08510638
TDS (mg/l)	1000	5	0.10638298
HCO_3^- (mg/l)	300	1	0.0212766
Cl^- (mg/l)	250	4	0.08510638
SO_4^{2-} (mg/l)	250	4	0.08510638
Ca^{2+} (mg/l)	200	2	0.04255319
Mg^{2+} (mg/l)	150	2	0.04255319
Na^+ (mg/l)	200	3	0.06382979
K^+ (mg/l)	12	3	0.06382979
NO_3^-(mg/l)	50	5	0.10638298
NH_4^+ (mg/l)	0,2	5	0.10638298
NO_2^-(mg/l)	0,2	5	0.10638298
		47	1

The first step in calculating the Water Quality Index is to assign an importance weight (*wi*) to each of the measured parameters on a scale of 1 to 5 (Table 3). The assignment of a weight to a given parameter depends on the relative importance of influencing overall water quality and human health.

The second step is to calculate the relative weights (*Rwi*) using equation (1):

$$Rwi = \frac{Wi}{\sum_{i=1}^{n} Wi} \tag{1}$$

where: Rwi is the relative weight, wi is the weight of each parameter, and n is the number of parameters. (Singh, Raju et al. 2015) With; *Si*: the standard value.

For the third step, a quality rating scale (*qi*) is calculated for each parameter by dividing by its allowable limit value, as defined in NM (03.7.001) and multiplying the result by 100 according to the following equation (2):

$$qi = \frac{Ci}{Si} \times 100 \tag{2}$$

with *qi* as the quality score, *Ci* is the worth of every boundary in each example (focuses in mg/l, EC in µS/cm) and *Si* as the standard expected by WHO for every boundary. Moreover, at last, the Water Quality Index is determined by equation (3):

$$\mathrm{WQI} = \sum Rwi \times qi \tag{3}$$

The classification of groundwater using the water quality index is summarized in Table 4 in five categories (Sahu P 2008):

Table 4. Proposed water quality classification according to WQI (Sahu P 2008)

Water quality	Range of GWQI
Excellent water	<50
Good water	50–75
Permissible water	76–100
Doubtful	100–150
Water unsuitable	>150

After the calculation of the overall quality index WQI using the results of physicochemical analyses and the standard values of the Moroccan drinking water standard, the water quality classification is determined for the 30 samples (Table 5), which shows that three samples were considered as excellent water, 6 had good water, three were characterized by permissible water, 11 were included in a doubtful category, and seven samples were unfit for human consumption, see Table 5 and Figure 4.

Major ion chemistry

The groundwater pH values range from 7.02 to 8.11, with an average value of 7.61, indicating alkaline water. Some of these variations are slightly above the limit allowed by the drinking water standard. The general increase in pH in a sedimentary terrain is related to the weathering of plagioclase feldspar in the sediments, aided by dissolved atmospheric carbon dioxide, resulting in the release of sodium and calcium, which gradually increases the pH and alkalinity of the water. Mean electrical conductivity values ranged from 747 to 4650 µS/cm in the study area. The relatively higher electrical conductivity values of the study area can be attributed to the higher total dissolved salts in the groundwater. The source for this may be the salts in the seawater. The average total dissolved solids concentration varied from 3564 mg/l in the study area. Typically, total dissolved solids in water can come from natural sources and wastewater discharges. Calcium and magnesium ions in coastal groundwater are

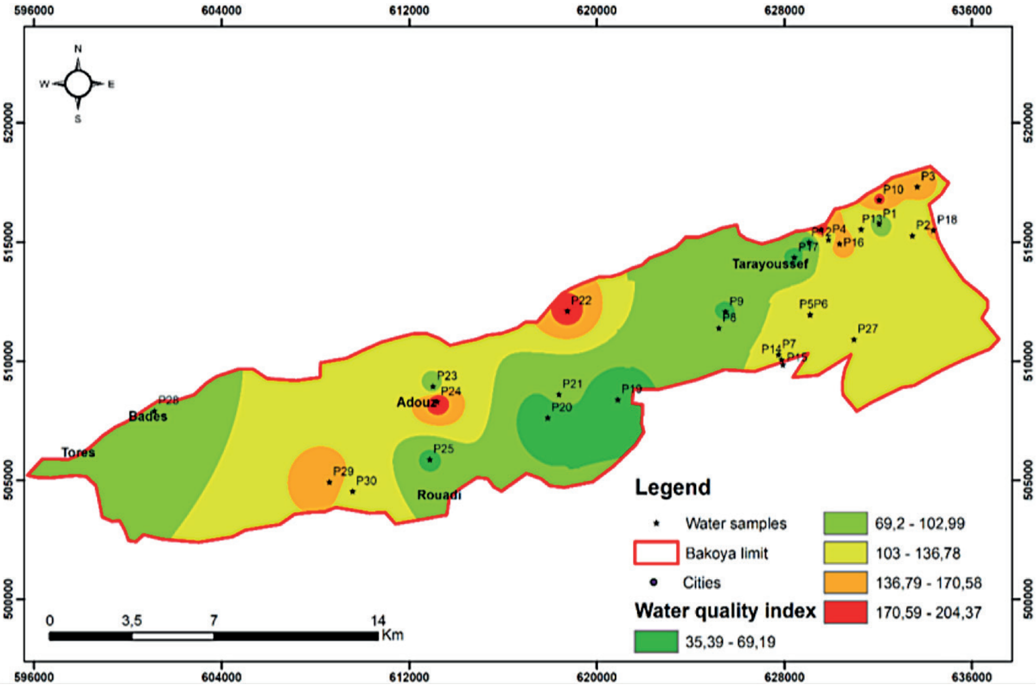

Figure 4. Thematic map of water quality index of water samples

Table 5. Calculation of the water quality index of the water samples

CODE	WQI	Classification	CODE	WQI	Classification	CODE	WQI	Classification
P1	69.70	Good water	P11	205.02	Water unsuitable	P21	79.24	Permissible water
P2	115.11	Doubtful	P12	43.50	Excellent water	P22	183.93	Water unsuitable
P3	140.92	Doubtful	P13	133.38	Doubtful	P23	79.79	Permissible water
P4	110.03	Doubtful	P14	125.67	Doubtful	P24	204.26	Water unsuitable
P5	167.92	Water unsuitable	P15	124.71	Doubtful	P25	62.32	Good water
P6	89.95	Permissible water	P16	164.69	Water unsuitable	P26	121.64	Doubtful
P7	100.34	Doubtful	P17	56.10	Good water	P27	104.77	Doubtful
P8	72.14	Good water	P18	142.87	Doubtful	P28	69.49	Good water
P9	63.50	Good water	P19	40.01	Excellent water	P29	161.81	Water unsuitable
P10	178.11	Water unsuitable	P20	35.37	Excellent water	P30	115.56	Doubtful

mainly derived from the leaching of limestone, dolomites, gypsum, and anhydrite, while calcium ions can be derived from cation exchange. The concentration of calcium varies from 36.8 to 318.3 mg/l. The average sodium concentration varies from 305.5 mg/l in the study area.

The high sodium concentration in groundwater can be attributed to cation exchange and human activities. The high sodium concentration in irrigated areas is also a result of repeated water use. The Na/Cl relationship has often been used to identify the mechanism of salinity acquisition and saline incursion in coastal areas. Bicarbonate ions ranged from 183 to 671 mg/l in groundwater samples. Chloride concentration in groundwater samples in the study on average amounted to 444.7 mg/l. Relatively higher chloride concentration in

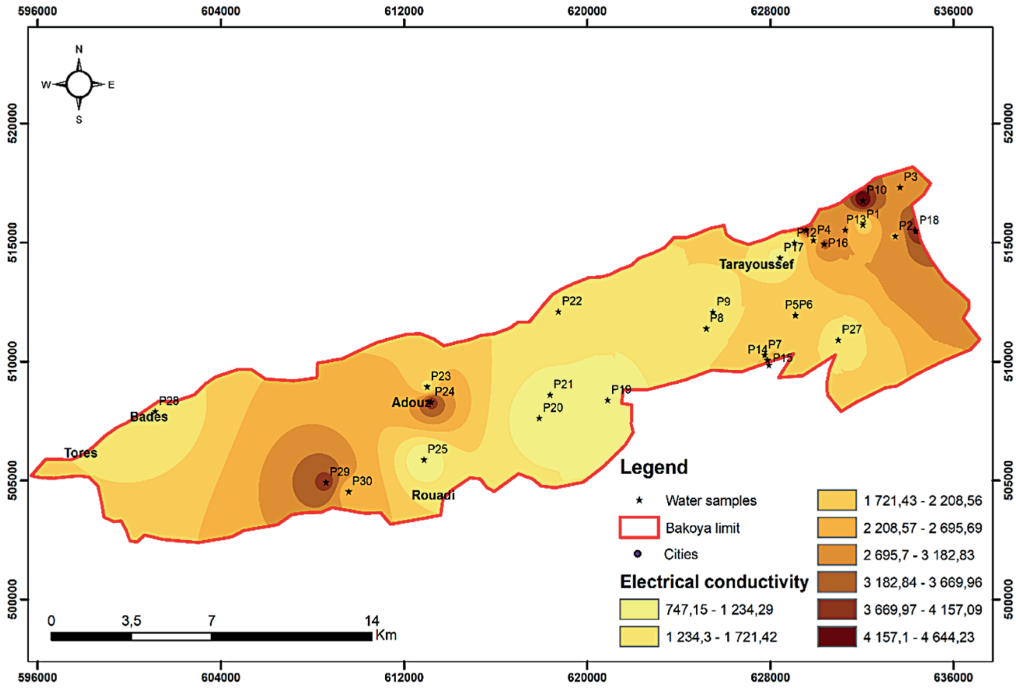

Figure 5. Spatial distribution of EC

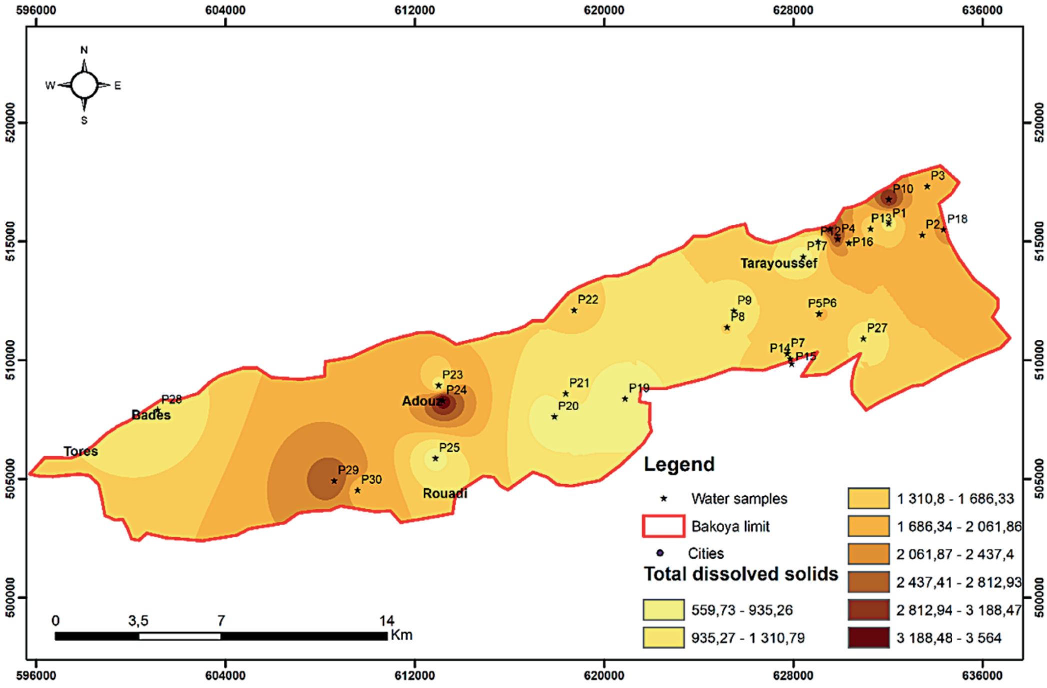

Figure 6. Spatial distribution of TDS

groundwater in the coastal region is attributed to the influence of seawater on the coastal aquifer due to the lowered water table. Sulfate ions ranged from 19 to 999.4 mg/l, and nitrate ions ranged from 10 to 240 mg/l in the study area. Most ion concentrations are high, which may be due to the dissolution of minerals mainly due to agricultural activity and seawater in the shallow aquifer system.

Spatial distribution

The spatial distribution pattern of electrical conductivity and total dissolved solids during the study period is shown in Figure 5 and Figure 6.

The exception is where the higher TDS concentration and higher electrical conductivity (EC) were observed in the northeast direction for P4. This spatial pattern indicates that the high TDS

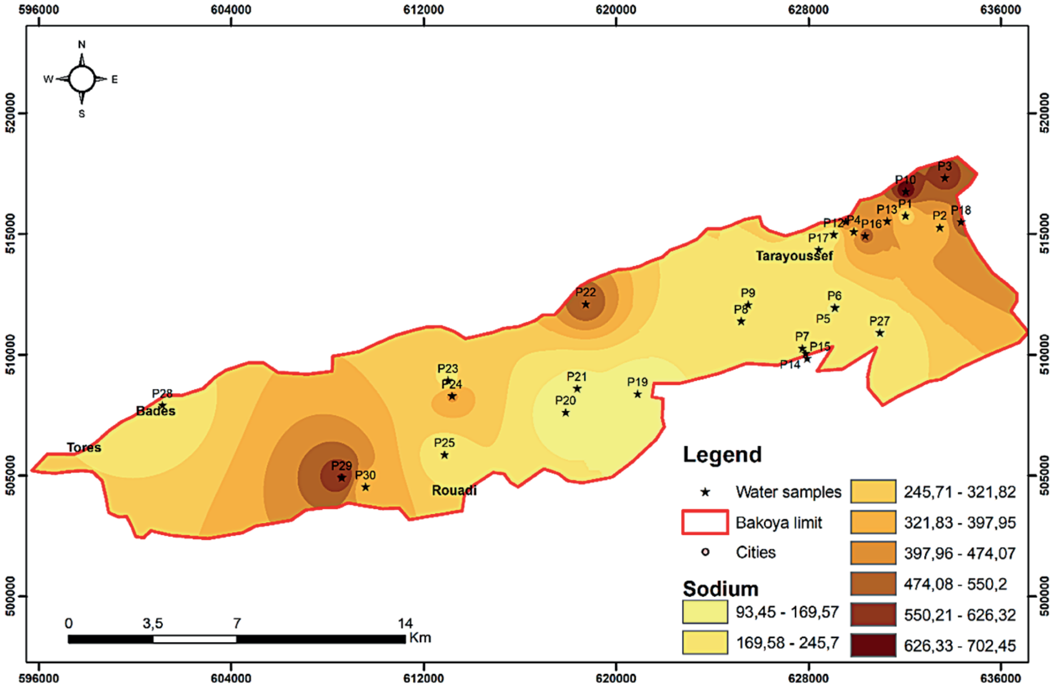

Figure 7. Spatial distribution of sodium

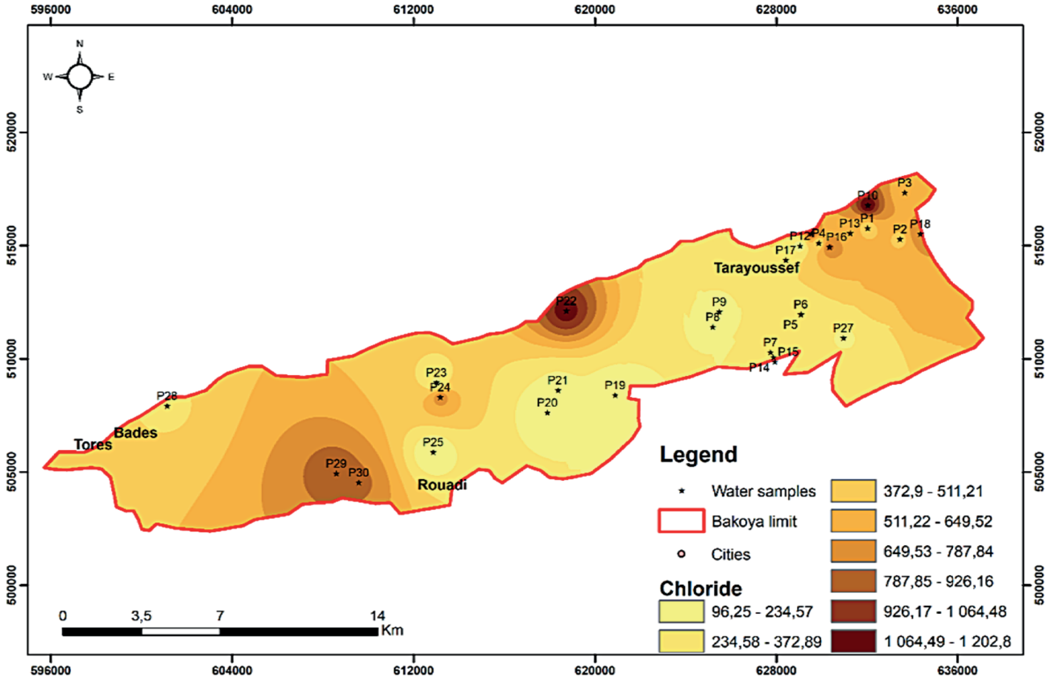

Figure 8. Spatial distribution of chloride

and EC values in groundwater correspond to the influence of seawater in some coastal wells. This phenomenon is widely observed worldwide in freshwater aquifers near the maritime coast.

The spatial distribution pattern of sodium Figure 7 shows a higher concentration on the northeast sides, these wells are near to the coastal zone, and the seawater influences the distribution pattern.

The spatial distribution of chloride during the study period shown in Figure 8 is similar to the spatial distribution of sodium. The spatial distribution of sodium and chloride is determined by seawater intrusion; irrigation return flow from agricultural activity also plays an essential role in determining sodium and chloride.

Hydro geochemical nature

The representation of water samples according to their chemical composition in the Piper diagram (Piper) in Figure 9 is based on the ionic current. The results obtained in the Piper diagram assess groundwater hydrochemistry in the city of Al Hoceima with the help of Aquachem 2014.2 software. The plot shows that most groundwater samples fall in the Na-Cl facies field. However, the remaining samples fall in the Ca-Mg-SO4 facies, indicating seawater and hard water incursion in the study area.

Wilcox classification

The Wilcox diagram is based on the electrical conductivity and percent sodium (%Na) relationship. Generally speaking, an EC value below 2000 μS/cm is acceptable. The Wilcox classification (Fig. 10) shows that only three samples are classified as excellent. Seven samples are considered good quality, seven samples belong to the eligible category, seven samples belong to the poor category, and six samples are of poor quality. Most of the studied samples are considered as non-drinking water.

Richard's diagram

The Riverside guidelines are the most commonly used criteria for assessing the suitability of water and are based on the EC representing the risk of salinity and the Sodium Adsorption Ratio (SAR), signifying the risk of alkalinity of the water to determine salinity. The results obtained from the Richards Riverside diagram in Figure 11 show that the samples studied are classified as C4S1, C4S2, C4S3, C3S1, and C3S2. These classes characterize the water that is generally unfit for drinking or irrigation. In the present study, most groundwater samples are unsuitable for ordinary conditions because they represent a very high salinity risk. Therefore,

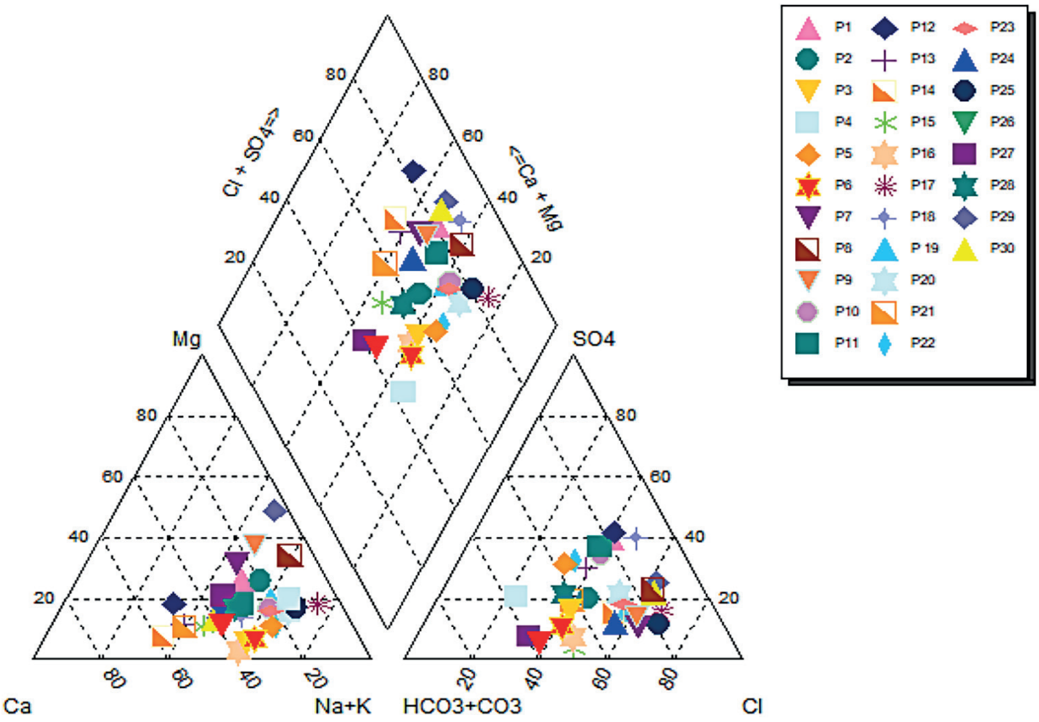

Figure 9. Distribution of the water samples on Piper diagram

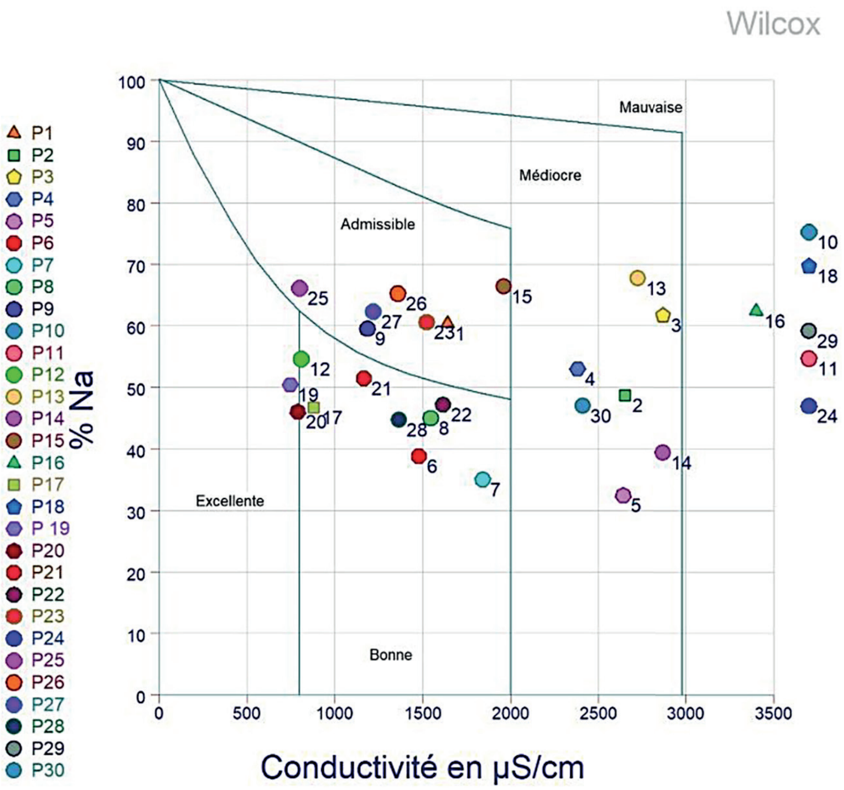

Figure 10. Distribution of the water samples on Wilcox diagram

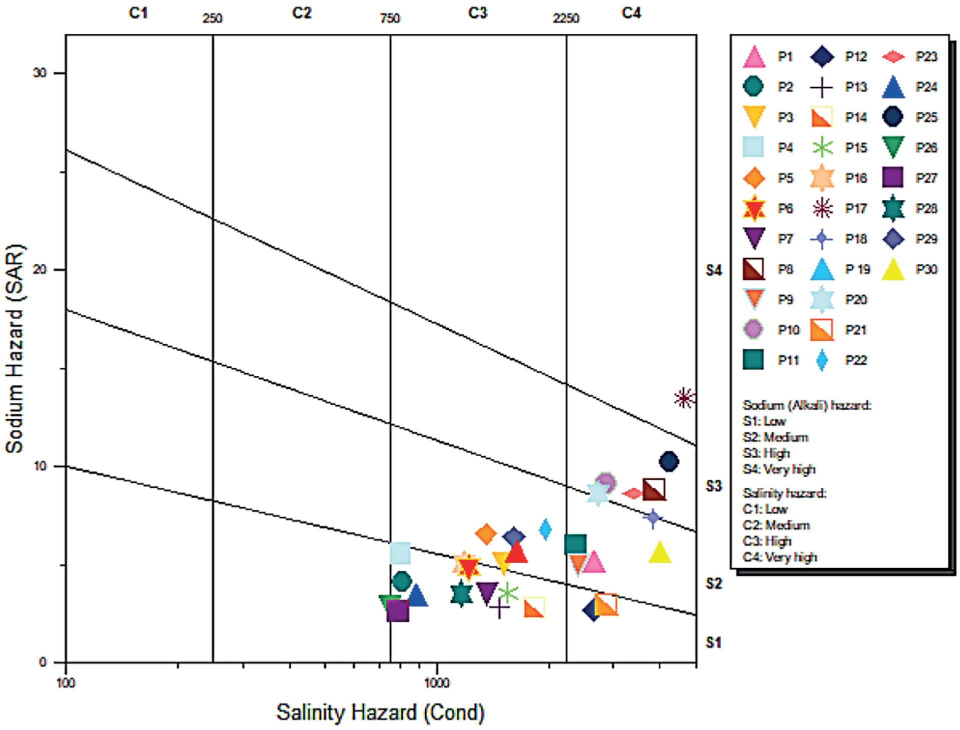

Figure 11. Distribution of the water samples on Richard's diagram

when the results obtained by the Wilcox plot and the Richards plot are considered together, it can be noted that most samples are unsuitable for consumption as drinking water.

Main WQI models

Several models were found in the bibliography. Table 6 presents four examples (CCME, NSFQ, Horton Index, and Fuzzy Interface

System (FIS)). These four models were selected for analysis and comparison. CCME (2001) is a WQI model founded by Colombia and the United Kingdom. This model is widely applied on surface waters. The CCME offers flexibility in the choice of parameters, which is why it is widely applied. Four water quality parameters are required, but their choice remains open. The classes proposed by this model are – Excellent (WQI = 95–100) – Good (WQI = 80–94) – Fair (WQI = 65–79) – Marginal (WQI = 45–64) – Poor (WQI = 0–44).

The NSFQ model has been applied to examine quality in several areas. Brown developed the NSFQ model in 1965, as a modified version of the Horton model. The selection of the eleven quality parameters was done using the Delphi method. These parameters were divided into five groups according to their nature: chemical, physical, nutritive, toxic, and microbiological. Recommendations of Brown (1970) were to add the toxic parameters. The quality index ranges from 0 to 100. The highest value means excellent water quality. Five quality classes are defined: Excellent (WQI = 90–100), Good (WQI = 70–89), Fair (WQI = 50–69), Poor (WQI = 25–49) 5), and Very Poor (WQI = 0–24).

Many researchers from different countries have used the Horton model to examine the freshwater quality. Eight chemical and physical parameters are used by the Horton model. Horton's model has included urban wastewater treatment as one of the parameters. The selection of these parameters was based on their importance, relative influence, and environmental considerations. The Horton model recommends the following five water quality classes for the final water quality index value: Very Good (WQI = 91–100), Good (WQI = 71–90), Poor (WQI = 51–70), Bad (WQI = 31–50), and Very Poor (WQI = 0–30).

The first appearance of fuzzy interface system (FIS) was in 1960. It was applied by several researchers in environmental risk assessment. Researchers have adopted this model in the determination of the water quality index of rivers. It contains the following steps: fuzzy sets and membership function, operations on fuzzy sets, fuzzy logic, and inference rules. The FIS model does not recommend any specific quality parameters. Logic rules and function theory are used for parameter selection. Three quality classes have been proposed to evaluate the quality of surface waters: Clean (81–100), Slightly polluted (60–80), and Polluted (0–59).

CONCLUSIONS

The quality of shallow groundwater in the Bakoya Massif was assessed using the quality

Table 6. WQIs, application domains, and references materials

WQIs	Application domain	Number of parameters	References
CCME	Maharashtra, India	4 WQ parameters	(Tambekar, Waghode et al. 2008)
	Bangladesh		(Ray, Bari et al. 2015)
	Iran		(Mirrasooli, Ghorbani et al. 2017)
	India		(Wagh, Panaskar et al. 2017)
	Iraq		(Hussein, Al-Bayati et al. 2019)
	Canada		(El-Jabi, Caissie et al. 2014)
	China		(Yan, Qiao et al. 2016)
NSFQ	Pará, Brazil	11 WQ parameters	(Medeiros, Faial et al. 2017)
	Brazil		(Lobato, Hauser-Davis et al. 2015)
	Croatia		(Tomas, Čurlin et al. 2017)
	Colombia		(Ortega, Pérez et al. 2016)
Horton Index	Southern Iraq	8 WQ parameters	(Shukla, Ojha et al. 2017)
	India		(Akkaraboyina and Raju 2012)
	Ghana		(Anku, Banoeng-Yakubo et al. 2009)
	France		(Sánchez, Colmenarejo et al. 2007)
Fuzzy Interface System (FIS)	India	7 WQ parameters	(Sahu, Mahapatra et al. 2011)
	China		(Chen, Zhu et al. 2015)
	Morocco		(Mourhir, Rachidi et al. 2014)
	Brazil		(Lermontov, Yokoyama et al. 2009)

index method with specific weightings of importance adapted to the environmental characteristics of the study area. The results obtained are compared to results obtained by applying other widely used methods. The reliability of the selected importance weights is confirmed by the agreement of the results obtained by all methods. According to the WQI, more than half of the samples studied are considered unfit for human consumption. The analysis of the spatial distribution of the WQI results shows that few areas provide the water fit for human consumption. These areas are generally distributed far from the sea or at high altitudes and are far from urban areas. The Wilcox diagram and the Richard's diagram are considered together. The samples studied are considered unfit for human consumption. Just three samples of waters are excellent, indicating that these waters are not drinkable. The highest concentration of ions was observed on the northeast side, which indicates an incursion of saline water near the coastal zone. For the southern side, the highest concentration may indicate irrigation return. The trilinear diagram shows that most of the groundwater samples fall in the field of Na-Cl and Ca-Mg-SO4 facies. Therefore, salinity and human activity are the main factors influencing the groundwater quality in the Bakoya massif. In light of the consequences of this review, most of the groundwater in the Bakoya Massif is viewed as unacceptable for human utilization, and the continued use of this water over the long term may affect the health of the population. It may increase the salinity and alkalinity problems in the soils. To better understand the degradation of the quality of these waters and to identify the origins of salinization, geochemical and hydrogeological studies must be conducted to complete the knowledge of the functioning of the aquifer. The social attachment to natural water resources and the poor infrastructure of the drinking water distribution network prevent the population from suspecting the quality of the groundwater in the Bakoya Massif and induce an extensive use of this water to cover all their needs, even if largely uncontrolled. The methods and results presented in this study make it possible to determine the quality of the water with simple indices adapted to a specific context, helpful in directing water management services towards potentially exploitable sources of adequate quality in terms of consumption. A continuous water quality monitoring program is mandatory.

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