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Assessment of Groundwater Quality in the Tafilalet Region of Southeastern Morocco Using Water Quality Index

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ABSTRACT

This study evaluated the suitability of groundwater from primary basins in the Tafilalet area of southeast Morocco for drinking purposes. Water samples were collected from 100 wells, and physicochemical parameters, including temperature, conductivity, pH, hardness, and organic and inorganic ion concentrations, were analyzed. The weighted arithmetic water quality index (WQI) was used as an ecological indicator for quality evaluation in relation to Moroccan drinking water criteria. Ten locations were chosen for monthly inspection based on their proximity to the potential sources of pollution. The study found a considerable improvement in water quality over a 15-year period (2004–2019), with three sites classified as "Good quality" and seven as "Poor Water". The analysis revealed that the pH values of all groundwater samples were within the acceptable range according to the World Health Organization (WHO) standards. The chloride ion concentrations decreased significantly over time, while the nitrate and sulfate concentrations increased. The hydrometric title of groundwater was very high in all study sites, with a significant proportion of alkaline earth metals present. The study suggests that the development of the sewerage network and supply and distribution of drinking water in the region has led to improved water quality. The study demonstrated changes in the physicochemical properties of groundwater in the Tafilalet region of Morocco over a 15-year period, with an overall improvement in water quality.

Keywords: water quality index, groundwater, physicochemical quality, pollution, Tafilalet, Morocco.

INTRODUCTION

Globally, water is an essential resource for human survival, with over 1.5 billion people relying on it as their primary source of drinking water (UNESCO, 2021). Groundwater is the primary source of drinking water (He et al., 2015), and as such, assessing its quality is of paramount importance to human health (Bahir et al., 2019). Efficient management and access to groundwater resources require an understanding of the hydrogeological and hydrogeochemical properties of the aquifer (Hamed et al., 2018). A variety of factors, including precipitation, topography, ion exchange, mineral content, oxidation and reduction, anthropogenic and natural activities, as well as the use of pesticides and composts, can impact groundwater quality (Aly, 2015; Sappa et al., 2015; Besser et al., 2019; Benyoussef et al., 2021a; Benyoussef et al., 2021b).

The arid climate, population pressure, and anthropogenic activities in the region pose a threat to groundwater, which is critical for meeting water requirements. Efficient management of water resources in the area, therefore, necessitates monitoring and quality assessment to protect groundwater. According to Kachroud et al. (2019), maintaining water quality is a critical objective in the conservation and management of natural resources. Moreover, as Rosemond et al. (2009) noted, evaluating water quality is deemed a necessary step for safeguarding water resources and identifying the best way to allocate them for diverse purposes. The traditional method of assessing sample importance to health is by comparing the concentration values of monitoring data to water quality reference values (Tunc Dede et al., 2013). However, recent years have seen the employment of specific tools to quantify water state and chemistry (Horton, 1965). Thus, one of the most useful methods for assessing groundwater quality and obtaining a comprehensive picture of water quality is the Water Quality Index (WQI) (Brown et al., 1970).

This mathematical methodology transforms water characteristic data into a straightforward procedure that describes water quality quantitatively, distinguishing between extremely clean and polluted water at a specific site and time (Singh et al., 2013; Tyagi et al., 2013; Wang et al., 2015; Tiwari et al., 2015).

The objective of this study was to assess, using the water quality index method, the suitability of groundwater in the Tafilalet region and its adjacent areas for human consumption. This is achieved by evaluating the changes in the physicochemical properties of groundwater in the study area through monthly monitoring of the water samples collected from 10 wells during 2019, the quality of which was compared to the quality of groundwater studied in 2004 by analyzing the water from hundreds of wells in the same area (Ait Boughrous et al., 2007).

MATERIALS AND METHODS

Study area

The Tafilalet region is situated in the southeastern part of the Atlas Mountains in Morocco, precisely between the south-Atlantic latitudes 29°30'N and 32°30' N (Figure 1), covering approximately 8.44% of the total land area of the country, or around 60,000 km^2 (HCP, 2021).

The population of Tafilalet is predominantly rural, with approximately 70,000 residents currently living in the area. Ten sampling stations were selected for a physicochemical study of the water in Tafilalet.

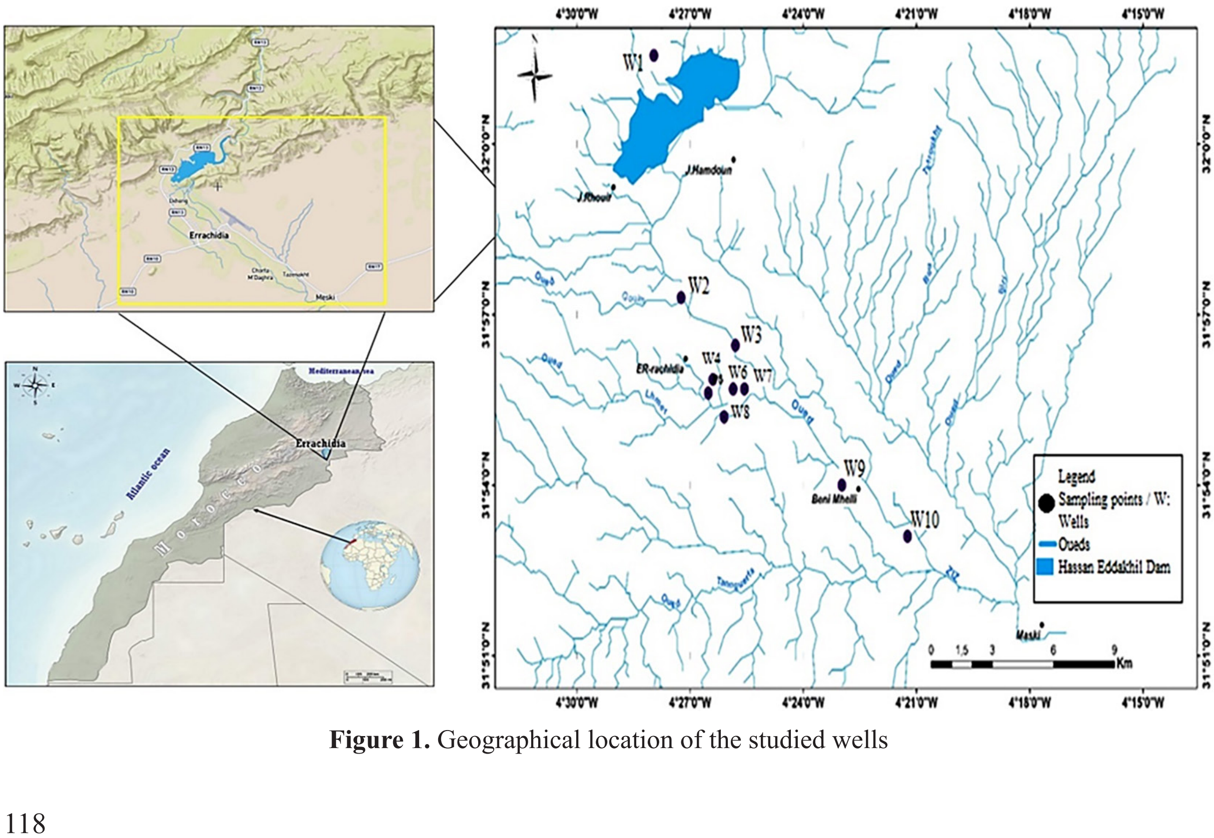

Figure 1. Geographical location of the studied wells

These stations are positioned along the Oued Ziz river (Fig. 1), following the direction of the water table flow from upstream of the city of Errachidia (W1) to downstream, located on the right bank of the Oued Ziz (W4).

The chosen study sites are situated in different areas of the city: some near the city centre agglomerations (W2 to W8), including the sewage spreading area, and others outside of this area (W1, W9 and W10), to the northwest and southeast of the agglomeration, respectively.

Methodology

In this study, a survey was conducted in the Tafilalt zone of the south-eastern region of Morocco in 2019, to evaluate the quality of groundwater through 10 selected wells. This study builds upon the previous research conducted in 2004, which monitored the quality of groundwater through hundreds of wells (Ait Boughrous, 2007).

By comparing the results of these two studies, this research aimed to assess any changes in the physicochemical properties of groundwater over time and to evaluate the suitability of the groundwater for drinking purposes.

To achieve this purpose, in-situ measurements of physicochemical properties such as temperature (T), Hydrogen potential (pH), dissolved oxygen (DO), total alkalinity (TAC), and electrical conductivity (EC) were conducted using WTW portable meters. Additionally, laboratory samples were analyzed to determine the concentrations of ions such as sodium (Na^+), sulfate (SO_4^{2-}), and chloride (Cl^-), as well as organic pollution indicators including nitrate (NO_3^-), nitrite (NO_2^-), ammonium ions (NH_4^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), and water-hardness (TH) using AFNOR criteria and the techniques recommended by Rodier et al. (2009) (Table 3).

The collected data was then used to calculate the Water Quality Index (WQI) using the weighted arithmetic mean method (Brown et al., 1970), as modified by Backman et al. (1998), and based on the standards established by the World Health Organization (WHO, 2011a).

It is important to note that this rigorous experimental approach was necessary to accurately assess the suitability of groundwater in the study area for human consumption, and to identify the potential sources of contamination. Moreover, to allow the best evaluation of the groundwater suitability for drinking purposes, the selection of the WQI parameters is based on analysed data significance and their availability.

To estimate the WQI, a four-step process was followed:

1) eight water quality characteristics were selected, and each was assigned a weight (W_i) based on its importance to the overall water quality (Table 1);
2) due to the frequent impact NO_3^- and total dissolved solids (TDS) on groundwater quality, the highest weight of five was assigned to these parameters;
3) pH, EC, and SO_4^{2-} were assigned weights of four, while chloride Cl^- and bicarbonate (HCO_3^-) were given weights of three. Ca^{2+} and Na^{2+} were assigned weights of two based on their importance to the general nature of water for utilization;
4) Mg^{2+}, which has little impact on groundwater quality, was given the lowest weight of one.

Weight unit assignment for each parameter

There are several ways to calculate relative weights, including expert opinions, Inverted Standard Value, statistical methods like Analytic Hierarchy (AHP) (Sutadian et al., 2017), weight standards (Sapkal and Valunjkar, 2013), and modern modelling techniques such as the Soft Computing Technique (Alizadeh et al., 2018) which uses the iterative back-propagation algorithm with a hidden layer ANN model. The process of determining weight for each parameter in the final indicator is based on its relative significance and impact, and the range of weights is typically between 0 and 5. This is important, because different pollution indicators have varying effects on water quality. In this study, each parameter was at first assigned a unit weight (W_i) based on its potential impact on human health if present in drinking water, with a minimum weight of one and a maximum weight of five (the most significant effect on drinking water quality). Then, by dividing the unique weight of each parameter by the total of all unique weights of the parameters, the relative weight of each parameter (W_i) is determined using the formula below:

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \quad (1)$$

where: W_i – represents the relative weight;
w_i – denotes the unit weight of the Ii[th] parameter;
n – stands for the number of chosen parameters (in this study, n = 7).

- Calculation of the rating scale for each parameter

The rating scale standardizes the various units and aspects of water quality criteria. The rating scale for each parameter (Q_i) is calculated by dividing its concentration by the maximum value, according to Moroccan regulations, and the result is then multiplied by 100 using the formula below:

$$Q_i = \frac{(C_i - I_i)}{(S_i - I_i)} \times 100 \quad (2)$$

where: Q_i – the parameter rating scale;
C_i – the concentration of each chemical parameter in mg/L at a specific sampling point;
I_i – the ideal value of parameter i in pure water (i.e., the ideal value for a pH of seven and a zero value for all other parameters);
S_i – the recommended average value by WHO (2011a) for each chemical parameter in mg/L.

- Developing sub-indices

The relative weight (W_i) and rating scale (Q_i) of each parameter are multiplied to determine the value of the water quality sub-index (S_i), like shown below:

$$SI_i = W_i \times Q_i \quad (3)$$

where: SI_i – the sub-index value of i^{th} parameter.

Aggregation of sub-indices

It is used in this study to calculate the index of water quality (WQI). According to the following equation, the WQI is the total of all sub-indices of the selected parameters:

$$WQI = \sum_{t=1}^{n} SI_i \quad (4)$$

The WQI values were used to assess groundwater quality classes. Table 2 illustrates how these cultivars are classified into five categories (Sahu and Sikdar, 2008).

Calculation of effective weights

The effective weight (EW_i) of each water quality parameter on the WQI values was determined to accomplish the second aim. As depicted in the following equation (Sener et al., 2017), the EW_i for each parameter was calculated by dividing its sub-index value (SI_i) by the WQI value at a provided sampling site and the result was multiplied by 100.

$$EW_i = \frac{SI_i}{WQI} \times 100 \quad (5)$$

where: EW_i – denotes the effective weight value of the i^{th} parameter.

Statistical analysis

Prior to analysis, normality of distribution of quantitative data was assessed using Kolmogorov-Smirnov tests (N < 50). Data are presented as arithmetic mean ± standard deviation and coefficient of variation. Comparison of arithmetic means was performed using paired Student's t-test.

Table 1. Water quality classification based on the WQI

WQI range	Type of water
< 50	Excellent
50–100	Good
100–200	Poor
200–300	Very poor water
> 300	Water non suitable for drinking

RESULTS AND DISCUSSION

General qualitative characteristics

The study investigated the concentrations of various inorganic anions in natural water in the Tafilalet region, Morocco (2004 and 2019).

Table 2. The weight and relative weight of each parameter used to calculate the WQI (WHO, 2011a)

Physicochemical parameters	Unit wright	Relatives weight	WHO standard
pH	4	0.174	6.5–8.5
EC (µS/cm)	4	0.174	1500
NO_3^- (mg/L)	5	0.217	50
SO_4^{2-} (mg/L)	4	0.174	250
Ca^{2+} (mg/L)	2	0.087	75
Mg^{2+} (mg/L)	1	0.043	50
Cl^- (mg/L)	3	0.130	250

The study presents a comparison of the physicochemical properties of water samples taken from ten different locations (W1–W10). Furthermore, concentrations, the minimum and maximum values, standard deviation, Coefficient of Variance, and Student's t-test for each physicochemical parameter are presented in Table 3.

The temperature (T)

The temperature (T) of the all-surveyed wells water varies between 18.5 °C and 30 °C, with no significant variation over the 15 years of study (Student's t-test, $p > 0.05$). Indeed, the mean temperature of the water samples in 2019 (24.1 °C) was higher than in 2004 (20.5 °C) with a statistically significant difference ($p = 0.003613$). The maximum temperature recorded in 2019 was 30 °C, which was higher than in 2004 (22.5 °C).

The hydrogen potential (pH)

The pH values obtained for the groundwater range from 7.1 to 8, indicating slightly alkaline water in all the sampled sites.

The pH is an essential parameter, since it affects various chemical reactions and solubility calculations in groundwater. All pH values are within the acceptable range according to the World Health Organization (WHO) standards (6.5 to 8.5).

The mean pH of the water samples in 2019 (7.4) was slightly lower than in 2004 (7.6), but the difference was not statistically significant ($p = 0.5144$). The minimum and maximum pH values were within a similar range in both years.

Chloride ion (Cl^-)

The chloride ion (Cl^-) concentrations were found to be within the range of 227.2 to 1267.5 mg/L in 2004 and 67.45 to 245 mg/L in 2019, with the WHO-prescribed standard value for chloride concentration being 250 mg/L. In 2004, most samples exceeded the maximum limit, except for sampling points W3 and W6, with concentrations of 198.8 mg/L and 227.2 mg/L, respectively. However, in 2019, all chloride values were below the standard admissible limit.

The *Student's t-test* indicated an improvement in chloride values by 67.57% during the 15-year study, suggesting development of the sewerage network and supply and distribution of drinking water in the region.

High chloride levels in water can lead to unpleasant salty taste, metal corrosion in pipes, and raised metal concentrations in drinking water (WHO, 2011a). Groundwater contamination is therefore associated with excess chloride levels (Loizidou and Kapetanios, 1993).

The mean concentration of Cl^- increased from 525.6 mg/L in 2004 to 170.5 mg/L in 2019, a 67.6% decrease. The coefficient of variance is high, indicating high variability in the data. There is no statistically significant difference in mean concentrations between the two years at a significance level of 0.05 ($p = 0.5118$).

Nitrates (NO_3^-) and nitrites (NO_2^-)

Nitrate concentrations were found to range from 6.8 to 53.0 mg/L in 2004, with only one concentration exceeding the WHO standard limit of 50 mg/L, and this was found in well W4 located within the slaughterhouse of the city Errachidia. However, nitrate concentrations decreased in all the sites studied and were below the standard limit in 2019.

The mean nitrate concentration of the water samples in 2019 (18.3 mg/L) was lower than in 2004 (23 mg/L) with a statistically significant difference ($p = 0.04894$). However, there was no significant difference in the mean nitrite concentration between the two years. The minimum and maximum NO_3^- and NO_2^- values were within a similar range in both years.

Sulfate (SO_4^{2-})

The sulfate ion (SO_4^{2-}) is one of the most common anions found in freshwater resources. Its concentrations ranged from 68.5 mg/L to 269.9 mg/L in the study sites, with most of the values being within the WHO-prescribed standard limit of 250 mg/L, except sites W5, W7, and W9 in 2004, with values of 269.86 mg/L, 254.05 mg/L, and 255.11 mg/L, respectively. However, in 2019, several sulfate concentrations exceeded the authorized limit, except for sites W1, W2, W3, and W10, with values of 138.3 mg/L, 182.4 mg/L, 183.8 mg/L, 208.6 mg/L, respectively. High sulfate concentrations can cause a laxative effect, discomfort and dehydration (WHO, 2011a). Statistically, the mean concentration of SO_4^{2-} increased from 189 mg/L in 2004 to 369.8 mg/L in 2019, a 95.6% increase.

The coefficient of variance is moderate, indicating moderate variability in the data. The difference in mean concentrations between the two years is statistically significant at a significance level of 0.05 (p = 0.0001223).

Hydrometric title (TH)

The hydrometric title of groundwater or Hardness (TH), which mainly refers to the presence of alkaline earth metals, such as calcium and magnesium ions, was found to be very high in the study sites. Calcium concentrations ranged from 89.6 mg/L to 208 mg/L, and magnesium concentrations ranged from 250 mg/L to 736 mg/L in 2019, while in the previous study, these values ranged from 8.9 mg/L to 153.1 mg/L and 329.9 mg/L to 1751.1 mg/L, respectively (Ait Bourghous et al., 2007). All values of Ca^{2+} and Mg^{2+} ion concentration exceeded the WHO standard limit (75 mg/L for Ca^{2+} and 50 mg/L for Mg^{2+}), except for site W10, which had a calcium concentration of 8.93 mg/L. The majority of groundwater in the study sites was found to be very hard, which can affect the suitability of drinking water (WHO, 2011a) as well as lead to scale deposition in water supply systems and heated water hardware (WHO, 2011b). However, according to the Student's t-test, there is no remarkable difference in the TH values obtained between the two periods of study.

The mean concentration of Ca^{2+} increased from 108.1 mg/L in 2004 to 147.3 mg/L in 2019, a 36.2% increase. The coefficient of variance is high, indicating high variability in the data. However, the difference in mean concentrations between the two years is statistically significant at a significance level of 0.05 (p = 0.02074). As for the mean concentration of Mg^{2+}, it increased from 608.1 mg/L in 2004 to 512.5 mg/L in 2019, a 15.7% decrease. The coefficient of variance is high, indicating high variability in the data. There is no statistically significant difference in mean concentrations between the two years at a significance level of 0.05 (p = 0.06791).

Electrical conductivity (EC)

The mean EC of the water samples in 2019 (1.7 μS/cm) was lower than in 2004 (1.9 μS/cm), but the difference was not statistically significant (p = 0.4608). The minimum and maximum CE values were within a similar range in both years.

Dissolved oxygen (DO)

The mean dissolved oxygen concentration of the water samples in 2019 (5.4 mg/L) was slightly lower than in 2004 (5.8 mg/L), but the difference was not statistically significant (p = 0.5817). The minimum and maximum O_2 values were within a similar range in both years.

Ammonium (NH_4^+)

The mean concentration of ammonia ions decreased from 0.3 mg/L in 2004 to 0.1 mg/L in 2019, a 66.7% decrease. The coefficient of variance is very high, indicating high variability in the data. However, the difference in mean concentrations between the two years is not statistically significant at a significance level of 0.05 (p = 0.1068).

TAC

The mean concentration of TAC increased from 312.2 mg/L in 2004 to 542.5 mg/L in 2019, a 73.7% increase. The coefficient of variance is moderate, indicating moderate variability in the data. The difference in mean concentrations between the two years is statistically significant at a significance level of 0.05 (p = 0.00874). In conclusion, the study provides valuable information on the concentrations of various inorganic anions in natural water in the Tafilalet region. The results suggest an improvement in chloride values, while nitrate concentrations decreased, and sulfate concentrations exceeded the authorized limit in several sites in 2019. High concentrations of calcium and magnesium ions were also found, which could affect the suitability of drinking water and water supply systems. The findings of this study can be useful in implementing the strategies to improve the quality of drinking water in the region.

Assessment of groundwater quality using WQI

Table 4 presents the Water Quality Index (WQI) and corresponding water quality classification for ten groundwater sampling sites in 2004 and 2019. The WQI values range from 77.17 to 250.93, and the water quality classification varies from Good to Very Poor. In 2004, six out of ten sites were classified as Poor, while in 2019, seven out of ten sites were classified as Poor. The WQI values for W1, W3, W4, W5, W6, W7, W8, W9, and W10 sites decreased from 2004 to 2019, while the WQI values for W2 increased.

The arithmetic mean WQI for 2004 and 2019 is 133.7 and 141.2, respectively. The standard

Table 3. Comparison of the average values of the results of physicochemical analysis of the waters of Errachidia and its surroundings between the two study years 2004 and 2019

Parameters	T	T	pH	pH	CE	CE	O_2	O_2	NO_3^-	NO_3^-	NO_2^-	NO_2^-
	2004	2019	2004	2019	2004	2019	2004	2019	2004	2019	2004	2019
Unit	°C		-		µS/cm		mg/L					
W1	22	22	7.52	7.37	0.99	0.9	7.3	6.92	9.2	10	0.71	0.03
W2	20.7	21	7.52	7.3	1.63	1.32	6.15	5.32	6.76	5	1.34	0
W3	19.9	22	7.51	7.2	1.62	1.28	6.5	5.29	32.39	10	1.86	0
W4	21.5	25	7.97	7.66	1.7	1.74	4.9	4.93	52.96	20	3.47	0.02
W5	22.5	28	7.97	7.4	1.87	1.92	6.7	8.41	41.55	25	4.59	0
W6	21.3	24	7.65	7.66	1.36	2.22	6.45	5.32	6.79	30	1.39	0.05
W7	20	30	7.85	7.47	2.88	1.93	6.6	4.4	8.73	28	2.73	0.03
W8	19	25	7.34	7.27	2.23	1.99	5.35	8.41	37.13	30	2.05	0.02
W9	19.4	23	7.63	7.4	1.84	1.95	5.85	1.91	11.26	5	1.89	0.8
W10	18.5	21.4	7.12	7.2	2.47	1.92	2.4	2.77	23.45	20	0.75	0.03
Size	10	10	10	10	10	10	10	10	10	10	10	10
Mean	20.5	24.1	7.6	7.4	1.9	1.7	5.8	5.4	23	18.3	2.1	0.1
Standard deviation	1.26	2.8	0.26	0.16	0.52	0.39	1.32	2.02	16.09	9.54	1.16	0.23
Min	18.5	21	7.1	7.2	1	0.9	2.4	1.9	6.8	5	0.7	0
Max	22.5	30	8	7.7	2.9	2.2	7.3	8.4	53	30	4.6	0.8
Range	4	9	0.9	0.5	1.9	1.3	4.9	6.5	46.2	25	3.9	0.8
Coefficient of variance	6.18%	11.61%	3.37%	2.13%	27.91%	22.77%	22.60%	37.61%	69.88%	52.13%	55.73%	239.30%
Comparison of arithmetic means (paired Student's t-test)	$p = 0.003613$		$p = 0.04894$		$p = 0.5144$		$p = 0.5817$		$p = 0.4608$		$p = 0.0005598$	
Evolution 15 years	17.87%		-2.83%		No difference						*-95.28%*	
Parameters	NH_4^+	NH_4^+	SO_4^{2-}	SO_4^{2-}	TAC	TAC	Ca^{2+}	Ca^{2+}	Mg^{2+}	Mg^{2+}	Cl^-	Cl^-
	2004	2019	2004	2019	2004	2019	2004	2019	2004	2019	2004	2019
Unit	mg/L											
W1	0.85	0	107.76	138.3	265.45	430	63.04	89.6	576.96	250.4	857.27	67.45
W2	0.52	0	120.85	182.4	274.63	580	72.14	101.6	329.86	322.4	504.1	148.39
W3	0.03	0	237.95	183.8	235.04	590	123.45	108	434.55	346	227.2	130.29
W4	0.06	0	159.38	294.1	414.8	600	120.24	124	384.1	466	383.4	191
W5	0.05	0	269.86	473.3	200.08	540	142.68	187.2	537.32	644.8	340.8	185
W6	0.1	0	208.07	494	397.72	610	121.04	190.4	436.96	683.6	198.8	245
W7	0.09	0	254.05	463.7	190.4	575	124	174.4	596	613.6	752.6	196
W8	0.08	0	208.82	495.4	473.36	495	152.3	178	497.7	682	312.4	242.11
W9	0.12	0.6	255.11	764.6	383.52	300	153.11	208	536.89	736	411.8	136.32
W10	1.26	0	68.47	208.6	287.24	705	8.93	112	1751.07	380	1267.5	163.3
Size	10	10	10	10	10	10	10	10	10	10	10	10
Mean	0.3	0.1	189	369.8	312.2	542.5	108.1	147.3	608.1	512.5	525.6	170.5
Standard deviation	0.4	0.18	67.04	190.16	92.99	106.17	43.75	41.91	389.46	169.69	319.52	50.9
Min	0	0	68.5	138.3	190.4	300	8.9	89.6	329.9	250.4	198.8	67.5
Max	1.3	0.6	269.9	764.6	473.4	705	153.1	208	1751.1	736	1267.5	245
Range	1.2	0.6	201.4	626.3	283	405	144.2	118.4	1421.2	485.6	1068.7	177.6
Coefficient of variance	127.68%	300.00%	35.46%	51.42%	29.78%	19.57%	40.47%	28.45%	64.04%	33.11%	60.79%	29.85%
Comparison of arithmetic means (paired Student's t-test)	$p = 0.1068$		$p = 0.02074$		$p = 0.0001223$		$p = 0.06791$		$p = 0.5118$		$p = 0.00874$	
Evolution 15 years	No difference		*95.64%*		73.75%		No difference				-67.56%	

Table 4. Water quality index calculation results for groundwater consumption for the two study years 2004 and 2019

Parameter	WQI / Water quality 2004		WQI / Water quality 2019	
W1	131.15	Poor	77.17	Good
W2	92.15	Good	94.63	Good
W3	112.02	Poor	98.04	Good
W4	119.96	Poor	131.93	Poor
W5	136.39	Poor	170.58	Poor
W6	97.58	Good	185.21	Poor
W7	145.17	Poor	167.87	Poor
W8	124.95	Poor	180.01	Poor
W9	126.45	Poor	190.31	Poor
W10	250.93	Very poor	116.7	Poor
Samples size	10		10	
Arithmetic mean	133.7		141.2	
Standard deviation	42.08		40.31	
Min	92.2		77.2	
Max	250.9		190.3	
Range	158.7		113.1	
Coefficient of variance	31.47%		28.55%	
Comparison of arithmetic means (paired Student's t-test)	p = 0.7013			

deviation for 2004 and 2019 is 42.08 and 40.31, respectively, whereas the coefficient of variance is 31.47% and 28.55%, respectively. The paired Student's t-test showed no significant difference between the arithmetic means of WQI for 2004 and 2019 (p = 0.7013). In 2019, the WQI values ranged from 77.17 to 190.31, indicating an improvement in the quality of groundwater, with water quality ranging from "Good" to "Poor." Despite the 5.6% increase, the Welch test showed no significant difference in water quality. However, there was heterogeneity of variation between the previous study years and the year 2019. Of the 10 sampling sites, three were classified as "Good," and seven were classified as "Poor" water.

The water quality in the study area is generally poor, with a decrease in the WQI values from 2004 to 2019, indicating degradation in the groundwater quality. The decline in water quality may be due to various anthropogenic activities, including untreated wastewater and fertilizer use. However, the paired Student's t-test showed no significant difference between the arithmetic means of WQI for 2004 and 2019, suggesting that water quality did not significantly change over the study period. Further monitoring and management of groundwater resources are recommended to ensure adequate water quality and safeguard public health.

CONCLUSIONS

In conclusion, the study evaluated the quality of groundwater in the Tafilalet area through the WQI, which considers eleven physicochemical parameters weighted by Moroccan standards. The results showed an improvement in water quality compared to previous years, but over 70% of the groundwater resources were still classified as of Poor water quality, indicating inadequate management. The study identified anthropogenic pollution as the primary cause of groundwater contamination, with downstream wells being affected by nitrates likely originating from untreated wastewater and fertilizer use, as well as upstream wells having high levels of electrical conductivity and chlorides. The study emphasized the need for proper management and monitoring of groundwater resources to prevent further deterioration of water quality as well as protect public health and the environment. Further research is necessary to identify specific sources of contamination and implement effective measures to address them. Hence, effective management of groundwater resources in the Tafilalet area is crucial to maintain their quality and protect public health.

On the basis of the study findings, there are three perspectives and recommendations for well managing groundwater resources in the region.

First, sustainable management practices and policies should be implemented to prevent further degradation of water resources. Second, the sources of pollution must be identified, and effective measures should be taken to prevent contamination. Third, regular monitoring of water quality is necessary to maintain the quality of groundwater resources and detect any potential issues early on. By adopting these recommendations, the Tafilalet area can improve its groundwater management practices and ensure the provision of safe drinking water to the public.

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