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APPLICATION OF ENTROPY WEIGHTED WATER QUALITY INDEX (EWQI) AND GIS FOR GROUNDWATER QUALITY ZONING IN OUARGLA, ALGERIA

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Abstract
Polluted groundwater poses a significant threat to human health by compromising water quality. This study investigates the quality and drinking water suitability of groundwater in the Ouargla aquifers, Algeria. This study focused on evaluating the groundwater quality and its suitability for drinking, in Ouargla, Algeria. For this purpose, seventy-two shallow groundwater samples were sampled during 2024. Physical and chemical parameters of groundwater such as electrical conductivity, pH, temperature, Ca^{2+}, Na^{+}, K^{+}, Mg^{2+}, HCO_3^{-}, $SO4^{2-}$, Cl^{-}, and NO_3^{-} were determined.
The calculation results of entropy weighted water quality index (EWQI) showed that about 66.66% of groundwater samples are unfit for drinking purposes.
The results indicate that applying the EWQI is useful for helping the public and decision-makers identify and evaluate groundwater quality in Ouargla, solve groundwater pollution problems, and ensure healthy drinking water in this basin and other similar regions worldwide.

Keywords: EWQI; Quality of drinking water; WHO standards, GIS; Ouargla.

Introduction

Worldwide, groundwater serves as a critical resource for irrigation, industrial processes, and human consumption, particularly in regions with limited or polluted surface water sources. A nominal supply of clean and safe drinking water is required for the sustenance of life (Godebo et al., 2011; Rango et al., 2012; Rina et al., 2012; Hua et al., 2020; Subba Rao et al., 2022).

Natural processes, including rock weathering, ion exchange, evaporation, and runoff, control groundwater composition. The quality of recharged water, precipitation, surface water, and subsurface geochemical processes influenced the groundwater quality. Understanding the long-term evolution of groundwater chemistry is essential to comprehending current hydro-chemical processes and their underlying controls (Ravindra et al., 2022; Wang S. et al., 2022). However, changes in recharge sources, hydrological conditions, human activities, and inadequate environmental regulations in industries such as mining, power generation, and manufacturing can lead to fluctuations in groundwater quality over time (Broers and van der Grift, 2004; Chatterjee et al., 2010; Reza and Singh 2010). Human health is closely related to the quality of groundwater, and it is threatened by the poor quality of groundwater (Amiri et al., 2014). The deterioration of the groundwater quality not only affects local residents' physical health but also restricts socio-economic sustainable development locally and regionally (Milovanovic2007). Once groundwater becomes polluted, it is extremely difficult to clean up and restore its quality. Therefore, it is absolutely essential to regularly monitor groundwater quality and develop effective strategies to protect it (Vasanthavigar et al. 2010).

Numerous methods, including fuzzy mathematics, membership degree, factor analysis, gray modeling, and analytic hierarchy processes, exist to evaluate water quality. However, these methods aren't able to clearly express the water pollutant categories, and we cannot explain whether the parameters involved in the evaluation meet the requirements of functional areas (Varnosfaderany et al., 2009 ; Pei-Yue et al., 2010). Groundwater chemistry has been utilized to outlook water quality for various purposes (Amiri et al., 2014).

As a traditional comprehensive index, the water quality index (WQI) is an important technique for demarcating groundwater quality and its suitability for drinking purposes. This method is widely used to reflect the overall groundwater quality by efficiently integrating numerous physiochemical characteristics into a single value (Nasiri et al., 2007; Simo˜es et al., 2008; Jawad Alobaidy et al., 2010; Ishaku 2011; Rubio-Arias et al., 2012; Amiri et al., 2014; Li et al., 2021; Rao et al., 2022; S. Wang et al., 2023).

However, during the WQI calculating process, expert-based weighting can introduce subjectivity, potentially leading to the loss of important water quality information. Correspondingly, the weighted water quality index method (EWQI) may remedy the above deficiency by combining subjective and objective assignment methods, which has been used successfully in numerous cases to assess water quality (Amiri et al., 2014; Marghade et al., 2021; Mukherjee and Singh, 2022).

In this paper, improved EWQI was applied to the groundwater quality assessment in Ouargla, southeast of Algeria, to provide a general view of groundwater quality status in this region for drinking purpose. It is chosen as a typical desert region where the only source of drinking and irrigation water is groundwater. In the past few decades, there has been a tremendous increase in the demand for fresh water due to the rapid growth of population and the accelerated pace of industrialization, a huge amount of groundwater resources are excessively pumped for agricultural irrigation, population growth, and economic development. Groundwater overexploitation has triggered dramatic changes in the groundwater budgets, hydraulic connections, and geochemical evolution, which may indirectly affect drinking water safety due to the progressive accumulation of groundwater salinity. In addition, other environmental concerns (e.g., industrial and domestic sewage discharge) also deteriorated and complicated the groundwater quality in this basin (Guendouz et al., 2003; Charikh, 2015; Slimani, 2016; Slimani et al., 2017; Charikh et al., 2022; Slimani et al., 2023; Slimani et al., 2024). Therefore, assessing the groundwater quality and related human health risks is of great significance to the residents' health in such vulnerable regions.

World Health Organization standards (WHO) have been used to evaluate the water quality changes in Ouargla.

Materials and methods

- **Study area**

In the northeastern desert of Algeria, "Lower Sahara" (Figure 1) is located the study region, 31° 54' to 32° 10'N and 5° 15' to 5° 27'E, with an average altitude of 134 m. It is installed in a large basin that constitutes the end of the hydrographic aorta of the Mya wadi, called the Ouargla basin. It is a vast depression with an area of approximately 750 km^2(Charikh et al., 2022; Slimani et al., 2023,).

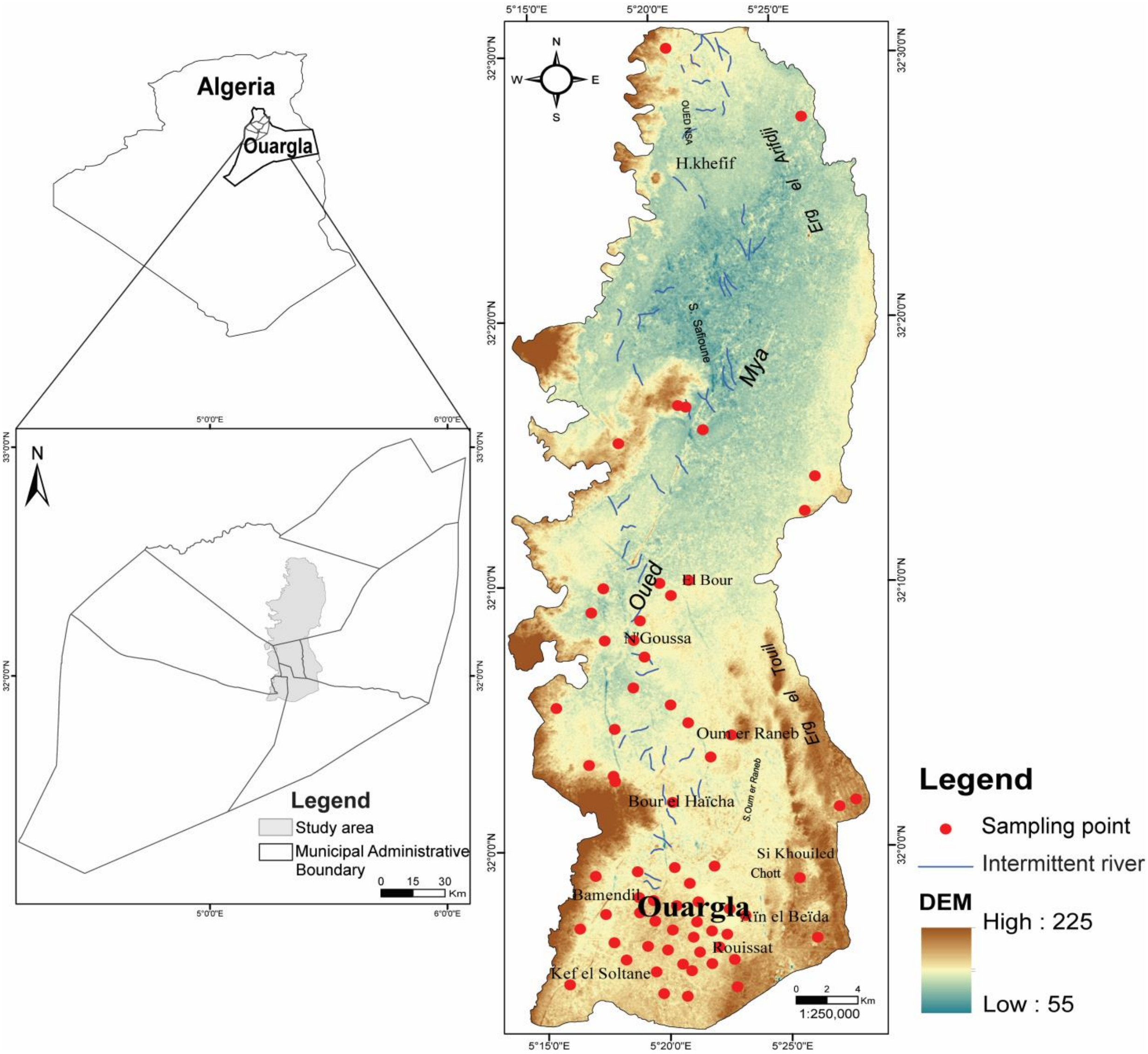

Figure 1: Geographical location map of the study area and groundwater sampling site.

The region's climate is characterized by Mediterranean Saharan conditions. Precipitation is highly variable, averaging 44 mm annually, with a range of 0-90.9 mm. While the Sahara is typically arid, rainfall increases noticeably from November to January. Temperatures fluctuate between 16°C in winter (January-February) and 30°C in summer (July-August). Strong winds, particularly sandstorms, contribute to aridity. Relative humidity is lowest in July (26%) and highest in December (62%). Annual evaporation averages 222.78 mm, ranging from 83 mm in January to 393 mm in July. Annual evapotranspiration peaks at 218.2 mm in July, averaging 1114.6 mm yearly (Slimani et al., 2024).

The Ouargla region, as well as the entire Lower Sahara, is made up of sedimentary formations. According to Slimani et al. (2024), in the Ouargla region, on the flint limestones and marls of the Upper Senonian or Middle Eocene, a continental formation, the "Intercalary Continental" was deposited, formed mainly of sands that were deposited and consolidated in a warm semi-arid climate in the Pontian Miocene or Lower Pliocene. This formation includes, from bottom to top:

- A yellow clay or sandy red clay bank 1 to 20 m thick;
- A detrital set of 12 to 35 m of coarse white or yellow sands, containing the so-called Mio-Pliocene artesian aquifer;
- An impermeable level of 15 to 20 m of lacustrine limestone and marl, generally very hard, the base of which is formed by a more or less sandy clay bank;
- From 10 to 25 m of generally pink or red sand, with intercalations of pink sandstone banks, difficult to distinguish from the quaternary sands that surmount them. (Cornet, 1964; Aumassip et al., 1972; Charikh, 2015 ; Slimani, 2016; Charikh et al.,2022 ; Slimani et al., 2023).

According to Charikh (2015) and Slimani et al. (2024), in the valley subsoil, there are three large aquifer sets, which from bottom to top are:

- The Intercalary Continental (CI) aquifer set, also called the Albian aquifer, is strongly artesian and located at a depth of 1100 to 1200 m.
- The Terminal Complexe (CT) aquifer set comprises three different aquifers, which from top to bottom are the Mio-Pliocene, the Senonian, and the Turonian.
- The water table, whose level is often close to the surface, generally between 1 and 2 m, but it can exceed 18 m south of Ouargla or under the reliefs.

- **Methodology**

In this study, groundwater from 72 regional monitoring wells was sampled and analyzed during 2023 (sampling points presented in Figure 1). Different sources, such as agricultural and potable deep wells, rural dug wells, industrial and recreational facilities, and drilled wells in the vicinity of pollution sources of urban and rural sewage discharge points, were sampled.

The groundwater samples were collected using pumps installed in these wells, and groundwater was purged for at least 2–3 min to drain out stagnant groundwater until the in situ measurement parameters were stable. Before the final collection, high-density and pre-cleaned polyethylene bottles (500 ml) were pre-rinsed three times with the target ground water. Then, the groundwater samples were sent as soon as possible to the Laboratory of Biogeochemistry of Desert Environments, Kasdi Marbah University, Ouargla, Algeria, for experimental testing.

The standards for drinking purposes as recommended by WHO have been considered for the calculation of EWQI. In this study, 11 qualitative parameters, including calcium (Ca^{2+}), sodium (Na^{+}), potassium (K^{+}), magnesium (Mg^{2+}), bicarbonate (HCO_3^{-}), sulfate (SO_4^{2-}), chloride (Cl^{-}), nitrate (NO_3^{-}), electrical conductivity (EC), pH, and temperature (T), are used to evaluate the groundwater quality for drinking.

In this study, EWQI has been implemented to understand water quality variations of Ouargla. Using the EWQI method might have eliminated the human subjectivity of the data within the weight quantitative calculation of an evaluation index (J. Liu et al., 2021; Gao et al., 2022). The following steps are used to calculate the EWQI (Subba Rao, 2021).

Step1. Establish the initial water quality matrix

The initial data eigenvalue matrix X is computed according to Eq. (1). The numbers of groundwater samples are represented as m and the evaluation index is n, respectively.

$$x = \begin{bmatrix} x_{11}\, x_{12} & \cdots & x_{1n} \\ x_{21}\, x_{22} & \cdots & x_{2n} \\ \vdots & \ddots & \vdots \\ x_{m1}\, x_{m2} & \cdots & x_{mn} \end{bmatrix} \qquad \text{Eq. (1)}$$

Step2. Data standardization

$$y_{ij} = \frac{x_{ij} - (x_{ij})_{min}}{(x_{ij})_{max} - (x_{ij})_{min}} \qquad \text{Eq. (2)}$$

In Eq. (2), $(x_{ij})_{min}$ and $(x_{ij})_{max}$ represent the minimum and maximum values of x_{ij}. The normalized matrix Y is expressed as follows:

$$y = \begin{bmatrix} y_{11}\, y_{12} & \cdots & y_{1n} \\ y_{21}\, y_{22} & \cdots & y_{2n} \\ \vdots & \ddots & \vdots \\ y_{m1}\, y_{m2} & \cdots & y_{mn} \end{bmatrix} \qquad \text{Eq. (3)}$$

Step3. Determination of weights

Calculate information entropy “e_j” and entropy weight “w_i” using Eqs. (4)–(6). The index *j* value for sample *i* is shown as P_{ij}.

$$e_j = -\frac{1}{Inm}\sum_{i=1}^{m} P_{ij} In P_{ij} \quad \text{Eq. (4)}$$

$$P_{ij} = \frac{y_{ij}}{\sum_{i=1}^{m} y_{ij}} \quad \text{Eq. (5)}$$

$$w_i = \frac{1- e_j}{\sum_{i=1}^{n}(1- e_j)} \quad \text{Eq. (6)}$$

Step4. Determination of the quantitative standards of grading

The q_i is calculated by the following formula:

$$q_i = \frac{C_i}{S_j} \times 100 \quad \text{Eq. (7)}$$

Where C_i is the concentration of each chemical parameter in each water sample in mg/l, and S_j is the limit for drinking groundwater of each parameter in mg/l according to quality standards for groundwater of WHO. The above equation ensures that if *j* parameter is totally absent in the water, the q_i is 0, and when the amount of this parameter is just equal to its permissible value, the q_i is 100.

Step5. Calculation of entropy weighted water quality index (EWQI)

$$EWQI = \sum_{j=1}^{n} w_j q_i \quad \text{Eq.(8)}$$

Step6. Water quality classification according to EWQI

According to EWQI, groundwater is classified into five ranks, ranging from ‘‘excellent water’’ to ‘‘extremely poor water’’ (Jian-Hua et al., 2011). The classification standards are listed in Table 1.

Table 1: Classification of groundwater quality according to EWQI (Jian-Hua et al., 2011)

EWQI	Rank Water	quality
<50	1	Excellent
50 –100	2	Good
100 – 150	3	Medium
150 – 200	4	Poor
>200	5	Extremely poor

To construct the water quality map, three steps were followed: Collecting data, Data processing (digitization), and Map creation: using the GIS Arc-GIS 10.0 software.

Results and Discussion

Before calculation of EWQI for each sample, statistical properties of parameters are analyzed. The hydro-chemical data of groundwater (72samples) in Ouargla with WHO standards of drinking water are statistically presented in Table 2. The EC values varied from 2 to 7.52 mS/cm, with an average is 3.25 mS/cm, suggesting a large variation in groundwater salinity. The average pH value was 7.64 and ranged from 7 to 8.38, indicating a slightly alkaline nature in the groundwater aquifer. The prevalent cations in groundwater were in the order of Na^+ > Ca^{2+} > Mg^{2+} > K^+. The concentration of Na^+ ranged from 106 to 845.33 mg/L, with an average of 366.76 mg/L, making it the most dominant cation in groundwater. The Ca^{2+} concentration diverged from 71.14 to 389.96 mg/L, with an average of 211.48 mg/L. The Mg^{2+} concentration fluctuated from 40.1 to 299.92 mg/L, with a mean of 124.85 mg/L. The K^+ presented a variation in concentration from 3.52 to 134.11 mg/L, with an average of 35.42 mg/L. While the major anions were SO_4^{2-} (260.32–1489.93 mg/L, mean 756.99 mg/L), Cl^- (335–1496.8 mg/L, mean 685.92 mg/L), HCO_3^- (58.58–283.73 mg/L, mean 133.55 mg/L) and NO_3^- (0–40.74 mg/L, mean 13.02 mg/L). It is worth noting that 100% of groundwater samples showed nitrate concentrations less than the recommended limit of WHO (50 mg/L). Concerning anions, the order of mean anion contents was found to be SO_4^{2-} > Cl^- >HCO_3^- > NO_3^-.the groundwater temperature fluctuated from 18 to 28 °C, with a mean average 23.74 °C.

Table 2: Statistics summary of hydrochemical parameters and WHO standards of drinking water

Parameter	Min	Max	Mean	SD	WHO guideline
EC (mS/cm)	2	7.52	3.25	1.03	1.5
T (°C)	18	28	23.74	1.73	25
pH	7	8.38	7.64	0.30	8.5
HCO_3^- (mg/L)	58.58	283.73	133.55	44.59	200
Cl^- (mg/L)	335	1496.8	685.92	232.50	250
SO_4^{2-} (mg/L)	260.32	1489.93	756.99	266.92	250
$NO3^-$ (mg/L)	0	40.74	13.02	11.98	50
Na^+ (mg/L)	106	845.33	366.76	131.63	200
K^+ (mg/L)	3.52	134.11	35.42	27.41	20
Mg^{2+} (mg/L)	40.1	299.92	124.85	49.00	50
Ca^{2+} (mg/L)	72.14	389.96	211.48	66.29	100

According to Table 2, the mean of Ca^{2+}, Na^+, Mg^{2+}, K^+, SO_4^{2-}, Cl^-, and EC is more than desirable values for drinking water based on WHO standards. Thus, as an initial conclusion, the contribution of Ca^{2+}, Na^+, Mg^{2+}, K^+, SO_4^{2-}, and Cl^- in increasing EC and in changes of groundwater quality is more than other ions and it is to some extent expected that the water quality is away from threshold ranks (i.e. ‘‘excellent’’ and ‘‘extremely poor’’) and most of the samples are classified in three categories of 2, 3 and 4. The effect of geological structures in increasing concentrations of ions, which mainly have a natural origin, as a considerable matter in statistical results is visible.

The influence of individual and combined parameters on groundwater quality changes was thoroughly examined using factor analysis. This multivariate statistical technique reduces a large number of variables into a smaller set of uncorrelated factors, maximizing information retention. By replacing original variables with these factors, we can simplify complex datasets (Ashley and Lloyd 1978; Suk and Lee 1999; Liu et al. 2008; Amiri et al., 2014; Wang S. et al., 2023).

After the statistic analysis, the EWQI and quality rank of each water sample for drinking were calculated. In this case, after first step that was calculation of entropy value and entropy weight of each parameter, the WQI value was calculated according to rating scale of water quality. Finally, after multiplying WQI value and entropy weight of each parameter, the summation of these values is presented as EWQI for each sample (Eq. 8). The parameters with minimum entropy value and maximum entropy weight have the greatest impact on water quality (Jian-

Hua et al. 2011; Amiri et al., 2014). In Table 3, the calculation results of entropy and entropy weight for each parameter are presented.

Table 3: Information entropy value and entropy weight of parameters

Parameter	Entropy value	Entropy weight
EC	0.995	0.001
T	0.299	0.099
pH	0.387	0.087
HCO_3^-	0.187	0.115
Cl^-	0.290	0.100
SO_4^{2-}	0.319	0.096
$NO3^-$	0.293	0.100
Na^+	0.299	0.099
K^+	0.301	0.099
Mg^{2+}	0.265	0.104
Ca^{2+}	0.277	0.102

Results show that all parameters have the same influence on groundwater quality with equal entropy weight.

EWQI determination using entropy weights and quality ranking of groundwater samples based on WHO drinking water standards was the main aim of this study. The calculated EWQI and quality ranking for each water sample are presented in Table 4.

Table 4: EWQI value and quality rank of samples based on WHO standards

No. of sample	EWQI	Rank	No. of sample	EWQI	Rank	No. of sample	EWQI	Rank
1	109.84	3	25	136.57	3	49	219.50	5
2	79.74	2	26	161.62	4	50	279.71	5
3	82.63	2	27	172.58	4	51	177.34	4
4	94.14	2	28	198.38	4	52	90.32	2
5	145.09	3	29	203.14	5	53	129.78	3
6	157.78	4	30	160.01	4	54	89.84	2
7	112.76	3	31	188.73	4	55	98.42	2
8	136.03	3	32	197.68	4	56	84.59	2
9	144.00	3	33	174.41	4	57	130.66	3
10	127.74	3	34	234.47	5	58	158.22	4
11	135.20	3	35	213.57	5	59	94.58	2
12	165.67	4	36	226.39	5	60	140.08	3
13	137.74	3	37	204.11	5	61	124.82	3
14	155.63	4	38	230.31	5	62	151.69	4
15	156.38	4	39	187.10	4	63	160.67	4
16	161.39	4	40	222.82	5	64	183.35	4
17	173.99	4	41	183.75	4	65	161.81	4
18	155.13	4	42	189.73	4	66	123.42	3
19	182.10	4	43	259.47	5	67	168.07	4
20	167.32	4	44	195.60	5	68	158.61	4
21	152.21	4	45	187.78	4	69	109.85	3
22	175.43	4	46	204.05	5	70	160.35	4
23	173.33	4	47	204.60	5	71	152.29	4
24	178.62	4	48	273.76	5	72	124.46	3

Ranking of samples showed that most of the samples are placed in the ‘‘poor’’ quality (rank 4). Thirty-four groundwater samples (47.22%) are classified in ‘‘poor’’ quality categories based on WHO standards. In addition, eight samples are located in ‘‘good’’ quality rank (rank 2), 16 samples in ‘‘medium’’ quality rank (rank 3), 14 samples in ‘‘extremely poor’’ quality rank (rank 5), and finally no samples in "excellent’’ quality rank (rank 1), based on WHO standards for drinking water, respectively. The brief numerical report of these analyses is presented in Table 5.

Table 5: Summary statistics of groundwater ranking

Rank	Number of samples	% (≈)
1	0	0
2	8	11.11
3	16	22.22
4	34	47.22
5	14	19.44

Interpolation is a vital tool in mapping, particularly when dealing with limited data. By analyzing existing data points and identifying underlying patterns, interpolation enables cartographers to estimate values at unsampled locations. This technique is invaluable for creating continuous surfaces that represent various phenomena, such as temperature, rainfall, or pollution levels. Interpolation allows for a more comprehensive understanding of spatial distribution, aiding in decision-making, resource management, and environmental analysis. By filling gaps in data and revealing trends, interpolation enhances the accuracy and usefulness of maps.

In the context of EWQI mapping, interpolation can be used to fill data gaps. If certain areas lack sufficient data, interpolation can help estimate EWQI values based on data from nearby regions.

To predict the spatial distributions of EWQI in Ouargla, interpolation is used to create a more comprehensive and detailed map by extending known patterns and trends beyond the scope of observed data.

The spatial repartition of various ranks determined based on EWQI and according to WHO standards for drinking water is showed in the water quality map (Figure 2). The water quality is classified into four categories: Good, Medium, Poor, and Extremely Poor, using the EWQI.

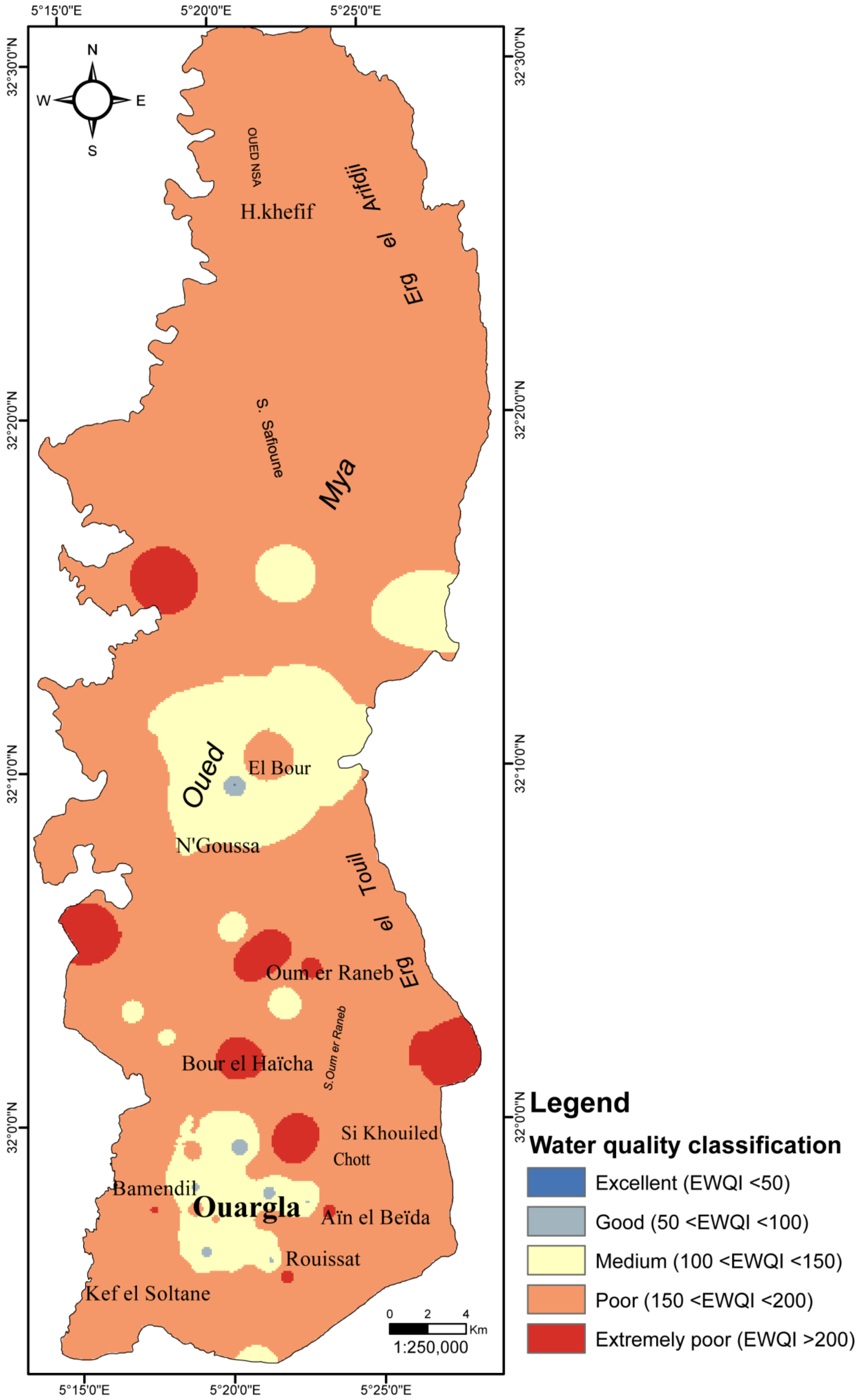

Figure 2: water quality map according to EWQI.

The map shows a clear spatial variation in water quality. There are areas with good water quality, particularly in the northern part of the region. However, a significant portion of the region, especially in the central and southern parts, exhibits poor to extremely poor water quality (orange, yellow, and red). This suggests potential issues with pollution, salinity, or other factors affecting water quality. For example, areas with high salinity or pollution from natural sources may have poorer water quality. This map indicates that these areas should be paid more attention to groundwater protection in the future.

This map reveals that most sampling sites are situated in urban, rural, residential, and industrial zones. The increase in nitrate, sulfate, and chloride concentrations in groundwater is primarily attributed to:

- Agricultural activities: Infiltration of chemical fertilizers used in farming.
- Geological processes: Geological formations, soil types, climate conditions and Dissolution of gypsum minerals.
- Human activities: such as agriculture, industry, and urbanization can degrade water quality through pollution, over-extraction, and improper waste disposal.

Conclusion

The GIS-based water quality index calculation technique is used in this study as a tool to evaluate and visually partition the rank of groundwater quality, helping managers understand the aquifer quality in this study area. Then, proposes solutions for sustainable management of water resources in the region. The EWQI result shows that all parameters have the same influence on groundwater quality in the study area. Groundwater quality in the area is divided into four main categories. In which the water quality reached “good water quality," accounting for over 11.11% of wells. However, 47.22% of wells have "poor water quality" out of 72 wells in the study area. Correspondingly, the EWQI map shows that good quality groundwater is rarely present in Ouargla.

The cationic composition of Ouargla groundwater was characterized by a predominance of sodium ions, with calcium, magnesium, and potassium ions present in decreasing order. Anionic composition was dominated by sulfate ions, followed by chloride, bicarbonate, and nitrate ions.

The EWQI result shows that all parameters have the same influence on groundwater quality in the study area. Groundwater quality in the area is divided into four main categories. In which the water quality reached “good water quality," accounting for over 11.11% of wells. However, 47.22% of wells have "poor water quality" out of 72 wells in the study area. Correspondingly, the EWQI map shows that good quality groundwater is rarely present in Ouargla.

The application of entropy weighting in WQI calculation eliminates the need for subjective expert judgment in assigning parameter weights. The calculated EWQI demonstrates the effectiveness of this method in objectively assessing groundwater quality, with results consistent with field investigations. EWQI is a valuable tool for both the public and policymakers to evaluate groundwater quality in Ouargla, Algeria.

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