Assessment of Groundwater Quality Using the Water Quality Index (WQI) and Nitrate Pollution Index (NPI), in the El-Oued Region (South-East Algeria)

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Abstract

Groundwater, serving critical requirements for both drinking and irrigation, is a vital and irreplaceable resource. The objective of this paper is to assess the quality of unconfined aquifers in the El-Oued region located in the northern Sahara of Algeria. The assessment employs two practical analysis models, namely the Water Quality Index (WQI) and the Nitrate Pollution Index (NPI), with a focus on irrigation and domestic water use. In this investigation, an extensive set of 113 samples was gathered from diverse locations to undergo analysis and assessment.

The WQI findings indicate that 38% of the samples exhibit very poor to unsafe water quality, characterized by strong to very strong salinity unfit for all uses. Conversely, 62% of the study area samples demonstrate good water quality with moderate salinity suitable for both domestic and irrigation purposes.

The Nitrate Pollution Index (NPI) was calculated to assess the level of nitrate (NO3) contamination in the El-Oued region water's. According to the NPI results, 24% of the samples indicate high to very high pollution levels unsuitable for any use, while 76% of the study area samples exhibit low to moderate pollution, making them suitable for irrigation purposes. The elevated nitrate pollution in the unconfined aquifer observed in urban areas is attributed to human activities, such as improper waste disposal in open areas and infiltration of sewage.

Keywords: Groundwater, Unconfined aquifer, WQI, NPI, Pollution, El-Oued, Algeria.

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Introduction

Water distribution is one of the concerns of all humanity. For this reason, for decades, states and governments in Africa in general and Algeria in particular have been working to provide their populations with adequate hydraulic infrastructure (Khechana.s.2014). In Eloued, the demographic growth and urbanization of the city have contributed to making the enormous efforts made by the State ineffective. Thus, the quantity of water resources supplied to populations remained insufficient (Bouselsal, B. and Kherici, N. 2014, ZINE, Brahim. 2009). This led to a rise in the water demands of the population, a demand that had not been satisfied despite the numerous boreholes previously installed by the state.

Indeed, the increase in water needs of populations has led to an increase in borehole flow rates, which is the cause of numerous borehole breakdowns.

The study region has therefore been the subject of several quantitative studies. Urban activities, increasingly intensive, to which are added significant demographic growth and deficit rainfall, have contributed to the reduction of aquifer reserves and the degradation of their quality (Bouselsal, B. and Kherici , N. 2014). Among the chemical agents likely to be the cause of pollution of the aquifer are nitrates and various salts.

Various factors, including hydrogeochemical interaction and the residence time of groundwater, influence the chemical quality of groundwater (Stallord and Edmond, 1983; Dethier, 1988; Faure, 1998; Umar et. al., 2006; Giridharan et al., 2008). Presently, a discernible trend of aquifer quality deterioration has been observed, primarily attributed to human actions (Dragon, 2008). On a global scale, nitrates stand out as prevalent contaminants in water table (Rajmohan and Elango, 2005). Potential origins of nitrate in aquifer encompass sewage discharge, fertilizers, municipal wastewater, and urban development (Spalding and Exner, 1993; Wilhelm et al., 1996). The nitrate pollution index (NPI) is employed to detect and assess groundwater contamination by nitrates.

Various techniques are employed to evaluate the water resources quality, with the water quality index (WQI) being one such method. The Water Quality Index (WQI) is a method used to evaluate how various water quality factors collectively affect the overall suitability of water for human consumption. (Vasanthavigar et al., 2010; Zamich et al., 2018; Nadjet Z et al., 2021).

Handling, processing, and interpreting data can become challenging when dealing with a large volume of information. Hence, multivariate data analysis has emerged as a potent tool to effectively process and condense extensive water quality datasets (Zamich et al., 2018).

Utilizing multivariate statistics aids in recognizing spatial and temporal fluctuations in water quality and discerning the origins of contamination be they natural or anthropogenic. This is achieved through the analysis of similarities and dissimilarities among sampled sites (Andrade et al., 2008).

The latest studies carried out on the quality of groundwater in the El-Oued region noted that these waters were facing anthropogenic pollution (Bouselsal, B. and Kherici, N. 2014, ZINE, Brahim. 2009). In addition, studies show that the water resources of study area are facing pollution of anthropogenic origin.

The study that we present is a contribution to the evaluation of the current state of the Eloued water table. It also aims to take an environmental assessment of the use of nitrates in the Eloued region through the evaluation of contamination and its spatial evolution, and to assess the physicochemical quality of groundwater water.

This diagnosis will make it possible to develop management strategies rational and thus contribute to the sustainable development of the research region in order to achieve establishment of a water pollution prevention and rapid alert network underground over the entire free aquifer of El-Oued.

2. Materials and methods:

2.1. Description the study area:

The urban zone of El Oued is centrally located in the municipality El Oued state, Algeria. The urban zone of El Oued lies between 33° 24’ 36” and 33° 19’ 46” North latitudes and 6° 49’ 15” and 6° 53’ 30” east longitudes. The urban zone covers a total area of about 40,5 km2 (Fig. 1). The examined region is predominantly sandy, situated at an average elevation of 80 meters. Geomorphologically, the study area features continental-origin sand dunes formed in the recent Quaternary period. The terrain's elevation ranges from 50 to 110 meters above mean sea level.

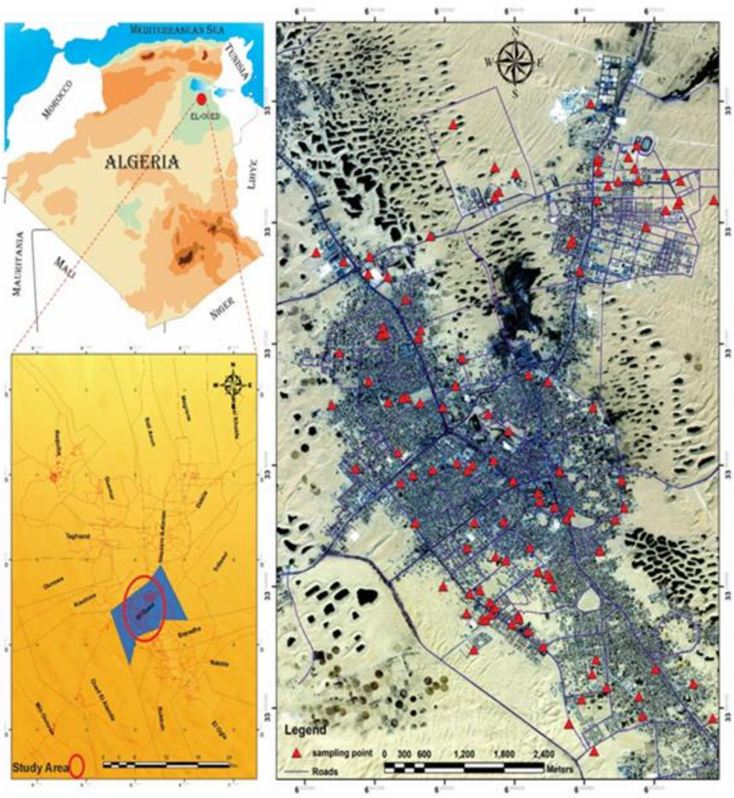


Fig. 1. The urban area (study area) of the municipality of El Oued

A study was carried out in the El-Oued area, the objective of which is to determine the quality of groundwater water, with reference to drinking standards. This work focused on 113 water samples taken randomly throughout the area, during the period spanning between March and May 2023. These samples were subject to various analyzes in the laboratory in order to assess their quality by through the Water Quality Index (Apha et al., 2005), based both on the standards of the World Health Organization (WHO, 2011). (Figure 1).

Analyses focused on eighties (08) physicochemical parameters which are: Temperature, Conductivity (CE), pH, Water hardness (TDS), Nitrites (NO2-), Nitrates (NO3-), ammonium (NH4+) and Phosphate (PO4-3).

2.2. The Water Quality Index (WQI):

The (WQI) serves as a method for categorizing water, relying on the evaluation of water quality parameters against established international standards. Essentially, the WQI condenses extensive water quality data into easily understandable terms (such as excellent, good, poor, etc.), producing a score that characterizes the qualitative condition of the water for domestic use. This method was initially proposed by Horton (Horton., 1965; Brown et al 1970). In recent years, several studies have used this concept to estimate groundwater quality using different calculation methods (Saeedi et al., 2009; Ketata et al., 2012; Vasanthavigar et al). Hence, in this study, the (WQI) was employed to assess the impact of both natural and anthropogenic factors, utilizing various key parameters of groundwater chemistry. The Water Quality Index (WQI) was computed using the methodology introduced by Yidana. (Yidana et al., 2010). In this methodology, a numerical value known as weight (Wight), ranging from 2 to 5, is allocated to each parameter, indicating its level of impact on water quality (Bhat et al., 2018; Aher et al., 2016; Sener et al., 2017, Nadjet Z et al., 2021). The weights assigned to the different physicochemical parameters are presented in Table 1.

Table 1: Weight of physicochemical parameters (Dhanasekarapandian et al., 2016).

Parametre	wi	relative Wight (Wi)	WHO (2011)
pH	4	0,16	6,5-8,5
CE	4	0,16	1500
TDS	4	0,16	500
T°	2	0,08	12-30
NO_3^-	5	0,2	50
NO_2^-	2	0,08	0,1
NH_4^+	2	0,08	4
PO_4^{-3}	2	0,08	5
	∑ wi= 25		

The calculation of the relative weight (Wi) is determined using the following equation:

Wi = wi / ∑ni=1 wi (1)

Wi represents the relative weight, wi signifies the weight assigned to each parameter, and n stands for the total number of parameters. The quality rating scales (qi) for each parameter are computed by dividing the concentration of each parameter by the corresponding WHO standard and then multiplying the result by 100.

qi = (Ci/Si) (2)

qi: quality rating scale.

Ci : the concentration of each parameter in mg/l.

Si : the WHO standard for each parameter in mg/l.

In the computation of the Water Quality Index, the initial step involves determining the Sub-Index (SQI). The Water Quality Index for each sample is then established by summing the Sub-Indexes of individual parameters.

SQi=Wi*qi (3)

WQI= ∑ SIi (4)

The water quality index values listed in Table 2 facilitate the categorization into four distinct quality classes.

Table 2: Water classification according to WQI (Sahu et al., 2008).

Value WQI	WQI catégories
< 1	Very good water quality
1-1,5	Good water quality
1,5-2	Moderate water quality
2-2,5	poor water qualité
> 2,5	Very poor water quality

2.3. Nitrate pollution index (NPI):

The Nitrate Pollution Index (NPI) serves as a crucial indicator in discerning nitrate pollution in water influenced by human activities. Equation (5) provides the formula for calculating the NPI.

NPI= Cs – HAV/HAV (5)

Here, NPI denotes the Nitrate Pollution Index, Cs represents the nitrate concentration in the well (mg/l), and HAV is the health advisory value for nitrate in drinking water (mg/l), set at 20 mg/l (Adelam S. M. A et al., 2006; Obeidad et al., 2012; Saidi et al., 2009).

As outlined by Subba Rao (2018), the NPI classification comprises five distinct categories (Table 3).

Table 3 : Categories of NPI.

NPI value	NPI class
< 0	Unpolluted
0 - 1	Low pollution
1 - 2	Moderate pollution
2 - 3	High pollution
>3	Very high pollution

2.4. Statistical methods:

The (PCA) is a multivariate statistical analysis technique, built from a correlation matrix, allowing a graphical representation of the links between variables n (n >2) and the positions of individuals in relation to vectors of these variables.

Principal Component Analysis (PCA) is additionally utilized to reveal similarities or discrepancies among variables and pinpoint those variables that exhibit the highest correlation with one another. (Zamiche et al., 2018).

To this end, the statistical approach was applied in the present study to determine the impact of each parameter in the model of water quality on WQI of the El-Oued aquifer.

3. Results and discussion:

As outlined by Subba Rao (2018), the NPI classification comprises five distinct categories (Table 3).

Table 3: Fundamental statistical analysis of the physicochemical parameters of groundwater within the research zone (2023).

	Unit	Min	Max	Mean	SD
pH	-	6,96	8,06	7,38	0,46
CE	µs/cm	2678	18076	4748,01	2149,43
TDS	mg/l	1424	28243	**3197,67**	**3404,32**
T°	C°	12,80	29,80	21,23	4,03
NO_3^-	mg/l	0,771	180,4	**52,04**	**32,33**
NO_2^-	mg/l	0	1,22	0,065	0,33
NH_4^+	mg/l	0	2,84	**0,44**	**0,70**
PO_4^{-3}	mg/l	0	4	0,3	0,76
IQW	-	1,09	12,18	2,04	1,41
NPI	-	-0,96	8,02	**1,60**	**1,60**

The waters of the unconfined aquifer of El-Oued region are generally neutral. All of the water sampled appears too mineralized with conductivities generally greater than 1500 µS/cm with a minimum of 2678 µS/cm and a maximum of 18076 µS/cm and an average of 4748±2149.43 µS/cm. The average contents of nitrites, ammonium and phosphate are respectively 0.065±0.33; 0.44±0.7; 0.3±0.76 (Tab.3). It complies with WHO standards; however the majority of water points represent very high nitrate values with a minimum of 0.77 mg/l and a maximum of 180.4 mg/l and an average of 52± 32.33 mg/l. They far exceed the standards recommended by the WHO.

We note that the deviation from the average is considerable for certain elements such as NPI, TDS and nutrients (Tab.3).

By employing Equations (4) and (5), gathering geospatial data on all parameters utilized in water quality and nitrate pollution models facilitates the calculation of the Water Quality Index (WQI) and Nitrate Pollution Index (NPI), indicating the distribution pattern of the water

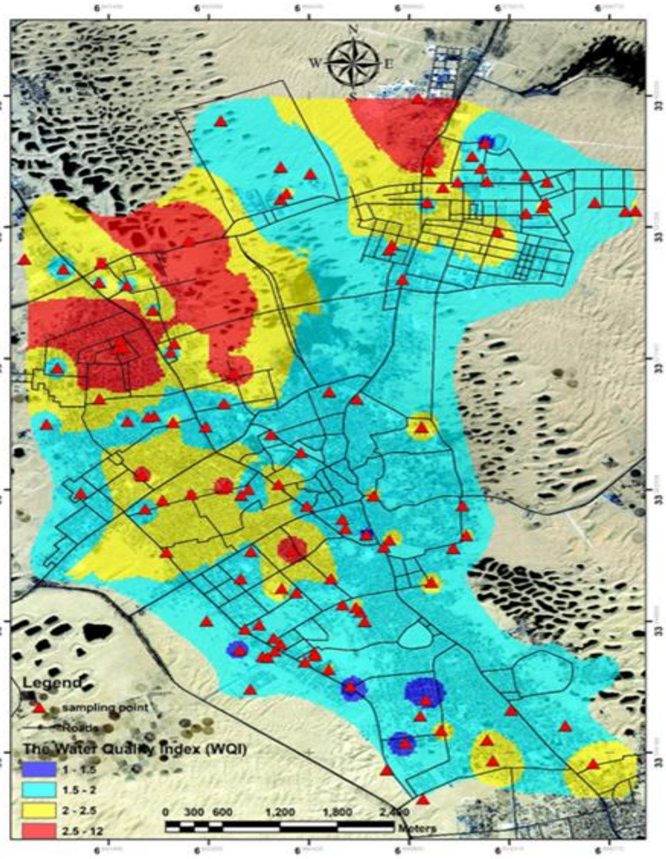
3.2. Water quality index (WQI):

The calculated water quality index (WQI) map shows that the index varies between 1.09 and 12 with an average of 2.04 ± 1.41. According to Table 2, four classes of water quality can be distinguished: good, average, poor and very poor (Fig.2). The calculation of the WQI index showed, according to WHO standards, that 10% of the samples taken are of good quality, 52% are of poor quality with a possibility of use for irrigation and industrial and 38% are of poor to very poor quality and must be restored before using for irrigation (Tab.4).

The WQI was decreasing from east to west, is due to the dissolution of the gypsum-saliferous formations which constitute the substratum of the unconfined aquifer and the dissolution of gypsums, limestones formations.

The impact of high Levels of electrical conductivity (EC) and total dissolved solids (TDS) on the increase in Water Quality Index (WQI) and the degradation of water quality is also evident, given that 90% of these boreholes have EC and TDS levels exceeding WHO standards.

Table 4. The category of the water quality index (WQI) for this study area



Water quality category	% of wells	Number of wells
Good water quality	9,73	11
Moderate water quality	52,21	59
Poor water quality	29,20	33
Very poor water quality	8,84	10

Fig.2. Disruption spatial map of water quality index (WQI)

3.3. Nitrate Pollution Index (NPI):

The Nitrate Pollution Index serves as an indicator to evaluate water contamination resulting from elevated nitrate concentrations. Within this study area, NPI values vary between -0.96 and 8.02, with a mediocre NPI of 1.6. Approximately 12% of well locations exhibit no pollution, while 28% display low pollution, 35% indicate moderate pollution, and 24% of well sample locations demonstrate high to very high pollution levels, attributed to elevated nitrate concentrations (refer to Table 5 and Fig. 3).

Figure 3 illustrates that over 60% of water points are affected by nitrate contamination.

High nitrate concentrations were noted in the North and Center of the study zone. The minimum nitrate value was observed in the southern limit of the free water table. It should be noted that low nitrate levels were found in the South-East zone and at the northern end of the study sector.

Table .5. The category of the nitrate pollution index (NPI) for this study zone

Water quality category	% of wells	Number of wells
Unpolluted	12,38	14
Low pollution	28,31	32
Moderate pollution	35,39	40
High pollution	14,15	16
Very high pollution	9,73	11

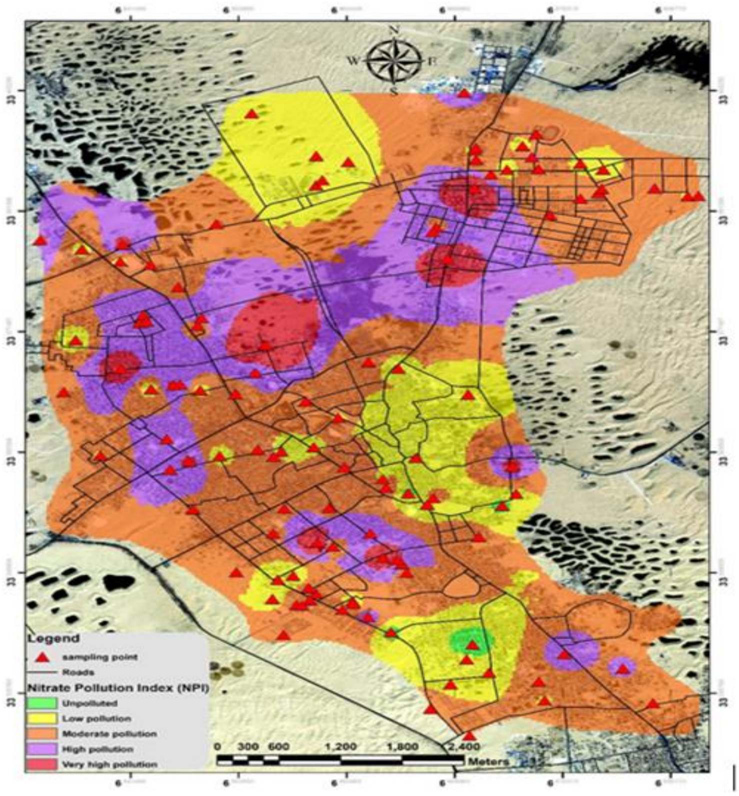


Fig 3. Disruption spatial map of pollution index of nitrate

In the town of Eloued, work reporting excess nitrates in groundwater is becoming more and more frequent. The origin of nitrates in groundwater can be multiple. The high nitrate levels encountered in the waters of the Quaternary aquifer have an urban origin linked to:

The insufficiency of the sanitation network in the study region due to population growth results in additional pressures and the evolution of the urban population, as well as the well-latrine intercommunication through underground flow and fluctuation, from the level of the tablecloth.

The latter is due to the drainage network in poor condition; infiltration of wastewater, leaks from the separate network. This risk can only concern new housing estates which are exceptionally equipped with separate networks. They are uncommon; however these wells are undeveloped.

3.4. Statistical analysis:

The connections between all pairs of variables and the correlation coefficients among these various variables are outlined in the correlation matrix (Table 6). Examination of table 06 relating to the correlation matrix allows us to see some significant correlation between the different elements:

The WQI is strongly correlated with TDS (0.98) and CE (0.92). Other significant correlations between TDS and CE (0.9). WQI is correlated only and moderately with NO3 (0.51) and NO2 (0.54), indicating that they are closely linked together and have an impact on the quality of unconfined aquifer of Eloued.

Very weak correlations are observed between the WQI and PO4 (0.049) and negative correlations are observed between pH and EC, NH_4, NO_2, NO_3, TDS, T° and WQI.

Table 6 Correlation matrix between variables.

	pH	CE	NH4	NO2	NO3	PO4	TDS	T°	WQI
pH	1								
CE	-0,2	1							
NH4	-0,38	0,079	1						
NO2	-0,13	0,42	0,065	1					
NO3	-0,001	0,12	0,019	-0,05	1				
PO4	0,0037	0,022	-0,07	0,059	-0,04	1			
TDS	-0,15	**0,9**	0,07	0,45	0,1	0,045	1		
T°	-0,09	0,12	0,093	0,08	0,15	-0,075	0,06	1	
WQI	-0,17	**0,92**	0,086	**0,54**	**0,51**	0,05	**0,98**	0,11	1

The analysis of the PCA variables in the F1-F2 factorial plan is presented in Figures

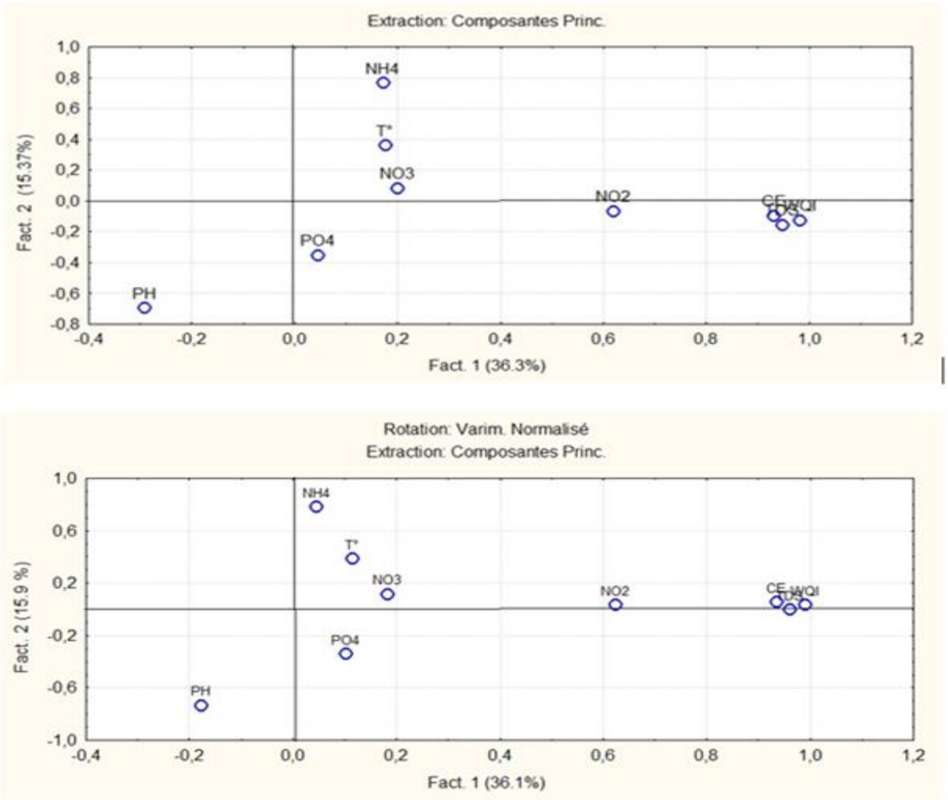


Fig 4. Analysis of variables in the F1-F2 factorial design without and after rotation

This graph emphasizes two primary clusters of the studied parameters within the waters of the unconfined aquifer of Eloued.

The Principal Component1 around the factorial axis F1 accounts for 36.1% of the total variance and which takes into account electrical conductivity, WQI, TDS and NO2. This factor is therefore that of salinity. It reflects natural mineralization by leaching of salts from geological formations. (Fig4).

Principal Component 2 along the F2 factorial axis accounts for 15.9% of the variance and is influenced by NH4, NO3, temperature (T°), and PO4. This component is associated with domestic and agricultural pollution, as shown in Figure 4. The two components represent the main processes that explain the origin, acquisition and the evolution of the chemism of the free Eloued aquifer, supposed to be linked to water-rock interaction and pollution from domestic activities.

The projection of individuals reveals three families of water quality, the first and the second correspond to zones of average mineralization (Tab.7).

Table 7 Characteristics of the PCA applied to the physico-chemical data of the aquifer phreatic of El-Oued (2023)

Variables	Extraction method Principal component analysis without rotation		Extraction method Principal component analysis with rotation varimax with normalization of Kaiser	
	Factor 1	Factor 2	Factor 1	Factor 2
CE	**0,867**	**0,876**	**0,934**	0,056
pH	**0,854**	0,567	-0,17	**-0,732**
NH4	0,029	**0,616**	0,045	**0,783**
NO2	0,384	0,388	**0,622**	0,035
NO3	0,039	0, 46	0,182	**0,515**
PO4	0,020	0,126	0,101	**0,440**
TDS	**0,899**	**0,923**	**0,960**	0,00
T°	0,030	0,162	0,114	**0,585**
WQI	**0,965**	**0,981**	**0,989**	0,034

4. Conclusion:

The degradation of the water resource quality has been substantial, curbing the effective water potential and resulting in notable health and ecological consequences. The present investigation focuses on evaluating groundwater quality, considering both natural and anthropogenic sources of contamination. A total of 113 groundwater samples from diverse locations were included in this study for a comprehensive assessment of their characteristics.

The (WQI) displayed a range of values between 1.09 and 12, averaging at 2.04. About 90% of the aquifer samples examined within this study area were classified as exhibiting poor to very poor water quality, indicating their unsuitability for drinking purposes.

The Nitrate Pollution Index (NPI) displayed values ranging from -0.9 to 8. Approximately 60% of the sites sampled require treatment prior to consumption because of nitrate contamination, attributed to human activities such as improper waste disposal in open areas and sewage infiltration.

This research suggests water desalination as a means to mitigate salinity before utilization, whether for irrigation or domestic purposes. Additionally, we recommend the rehabilitation of the sanitation network to alleviate nitrate pollution in the El-Oued aquifer waters.

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