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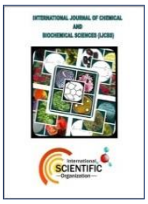

Groundwater Quality Assessment Using Nitrate Pollution Index (NPI), in Doukkala Region Case: An Evaluative Approach

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Abstract

Nitrate is the nearly exclusive nitrogen pollutant in groundwater, while ammonium often contaminates surface waters. Nitric pollution in aquifers is increasing globally, primarily due to agricultural activities, particularly the excessive use of fertilizers. The objective of our study focused on well contamination by calculating the Nitrate Pollution Index in the Doukkala region. Additionally, 22 wells were investigated by measuring nitrate and chloride concentrations, as well as the Cl-/NO3- ratio. The results obtained reveal that the average concentrations of NO3- and Cl- in all wells are 63.14±10.70 ppm and 328.64±74.39 mg/l, respectively. Moreover, 12 out of 22 wells exhibited a significant to very significant level of pollution, while 9 wells showed moderate to low pollution levels, suggesting better water quality. However, only one well was classified as having optimal water quality, showing no signs of nitrate contamination. Faced with this situation, and in order to reduce nitrate pollution and safeguard water quality for future generations, authorities must take immediate measures to prevent future water contamination by identifying and addressing nitrate sources.

Keywords: Nitrate, groundwater, ammonium, pollution, surface water

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1. Introduction

Water encompasses almost 70% of the Earth's surface, 3% of fresh water. On the other hand, this asset is not spread evenly across the world, as is typical with demand [1,2]. The contamination of water is a pressing concern that needs to be dealt with because it affects people's health and economic development. This worries all the stakeholders in the sector on a global scale. This pollution comes from different sources like industrialization, urbanization, and agricultural production [3]. Consequently, the pollution of surface water (such as rivers and oceans) has negative impacts on both human health and ecosystems. In recent years, there has been significant technological progress in the agricultural industry in Morocco. However, this is evidenced by pollution of groundwater by nitrates. The latter has serious negative impacts on human health and the environment, especially at high levels (>50 mg1-I as NO3) [4]. The presence of high levels of nitrate ions in water can have harmful effects on both humans and animals. It can accumulate in plant tissues and be transferred to animals, posing health risks for both animals and humans [5,6]. Nitrate in drinking water is contaminated, and this converts the nitrate in it. The gut's microbes convert nitrate into nitrite, which then interacts with iron hemoglobin in red blood cells [7]. This result in the creation of methemoglobin, causing a condition called methemoglobinemia or blue baby syndrome, where the blood's ability to transport sufficient oxygen to the body's cells is reduced [8]. Especially infants younger than one year old, who are the most vulnerable. at risk of developing methemoglobinemia (Met Hb). A low acidic gastric pH can likely lead to an increase in bacteria, thus reducing nitrate ions to nitrite, which could pose a threat to individuals' lives [9]. Furthermore, human activities, industrial production, and the disposal of domestic wastewater can lead to increased levels of nitrogen in waterways. These are the primary sources of high nitrate concentration in groundwater [10]. The purpose of this research is to assess the drinkability of groundwater in Doukkala-Abda, Morocco using the nitrate pollution index (NPI) method

2. Materials and methods

2.1. Study Area

The Doukkala Coast region is a coastal area situated between the Safi governorate and the El Jadida governorate, located between latitudes 32°15' and 33°15'N, and longitudes 8° and 9°15', covering an area of 7,700 km2, with approximately 150 km of coastline. It is characterized by a system of consolidated elongated dunes running parallel to the coast in a general SSW-NNE direction. These dunes are separated by flat-bottomed depressions, some of which extend into more or less marshy areas.

2.2. Sample Collection

To assess the groundwater contamination level, sampling was carried out in 22 wells located in residential and agricultural areas of the Doukkala Sahil region, following standard procedures. High-quality narrow-necked polypropylene bottles with screw caps, each with a capacity of two liters, were used for sample collection. The bottles were initially rinsed with diluted nitric acid and then three times with demineralized water. Prior to sample collection.

2.3. Measurement of NO_3^- and Cl^- Content

To measure nitrates, we used test strips or colorimetric kits. High nutrient content will be associated with agricultural pollution from fertilizers (nitrogen and phosphorus) or animal waste (nitrogen). For chlorine determination, we employed portable digital testers, allowing for reliable quantitative measurements. The bottles were rinsed three times with the water to be sampled, and then samples were taken.

2.4. Nitrate Pollution Index (NPI)

The NPI is an indicator used to assess the level of water pollution caused by a high concentration of nitrates in the water. Groundwaters are categorized in the table 1.

2.5. Statistical Tool

The data were entered into an Excel spreadsheet, and after filtering, this data was transferred to an SPSS sheet. Qualitative variables are expressed in frequency, while quantitative variables are presented as mean ± standard deviation. Chi-square tests of independence and one-way Analysis of Variance (ANOVA) were applied with a 5% error rate.

3. Results and discussion

3.1. Distribution of Nitrate and Chlorine Content in the Investigated Wells

The table (2) showing the results of the distribution of NO3- and Cl- concentrations in the water from the investigated wells reveals crucial information about the quality of the water being studied. Upon analyzing the data, it is observed that the average nitrate levels are 63.14±10.70 ppm, with values ranging from 2.5 ppm as the minimum concentration to 154 ppm for the maximum recorded. The median of 50.50 ppm also highlights a certain symmetry in the distribution of the data. However, the extent of 93 ppm indicates significant variability, as illustrated by a high coefficient of variation of 79.35%, suggesting a significant dispersion of values (table 2). With regards to the distribution of nitrate levels, the coefficient of skewness of 0.65 indicates a relatively symmetric distribution of the data. On the other hand, the average chlorine content in the analyzed wells is 328.64 ± 74.39 mg/l, highlighting a wide variability with values ranging from 20 to 1300 mg/l. This significant dispersion of chlorine data reinforces the idea of a significant contamination of these waters by this substance. It is worth noting that the main source of nitrate pollution in well water could be related to the amounts of fertilizer used in the region under study. Indeed, intensive farming practices can lead to an increase in nitrate levels in groundwater, posing a threat to the quality of this important resource. At the same time, the chlorine contamination appears to originate primarily from the water source itself, specifically at Hilt. This situation emphasizes the need for ongoing monitoring and targeted interventions to prevent any further deterioration of water quality in the region. In conclusion, the analysis of the NO_3^- and Cl^- levels in the water from the wells investigated reveals significant data regarding the quality of these water resources. The observed variability, especially in terms of nitrate and chlorine levels, raises significant concerns regarding potential contamination of these waters and emphasizes the importance of implementing protection and monitoring measures to ensure their long-term preservation (table 2). The Cl^-/NO_3^- ratio indicates an average of 12.28±4.21, with a minimum of 0.27 and a maximum of 66.67. With a large intra-group dispersion and a spread of 66.40.). The high ratios of $C1^-/NO_3^-$ indicate that the source of chlorides comes from agricultural applications. The loss of nitrogen is caused by uneven fertilizer application due to denitrification and greater removal of nitrogen than chlorides by crops and harvested fertilizers, affecting the use of shallow wells in adjacent lands, different fertilizer styles (table 2). The analysis of variance based on the "collection region" effect revealed a significant difference between the average Cl^- levels in the northern and southern zones. Indeed, the average Cl^- content in the northern zone was 204.55±55.749 mg/l, while it was 452.73±130.615 mg/l in the southern zone. The F-test yielded a value of 3.05 with a p-value less than 0.05, indicating a significant difference between the two regions in terms of Cl^- content. Similarly, regarding the NO_3^-/Cl^- ratio, the Fisher test also showed a significant difference between the average ratios of the two regions. With an F value equal to 3.59 and a p-value less than 0.05, it is established that the two regions exhibit significant differences concerning this ratio. This highlights significant variations in the chemical composition of water between the northern and southern zones, especially regarding the relationship between nitrate and chloride ions (table 3). However, it is interesting to note that the observed difference is not significant for the NO3- parameter itself. Indeed, the F-value for the average NO3- levels was 0.83 with a p-value of 0.37, indicating a lack of significant difference between the two regions in terms of nitrate content. These results emphasize the importance of a detailed analysis of various components of water quality, especially when assessing differences between different geographic regions. They highlight significant variations in water composition in terms of chloride and the ratio between nitrate and chloride, which can have important implications for water quality management and the protection of water resources. This study highlights the importance of considering regional variations in assessing water quality and underscores the need for in-depth analyses to comprehend the factors influencing the chemical composition of water resources. It could also serve as a foundation for implementing water management and preservation measures tailored to each region, based on the specific characteristics of its aquatic environment. However, the average NO_3^- content in wells in the northern zone is 53.318 (min=2.5 ppm; max=135 ppm) compared to an average content of 72.95 ppm in the southern zone. On the other hand, the average Cl- content in wells in the southern zone significantly exceeds that of wells in the northern zone, with values of 452.73 mg/l and 204.55 mg/l, respectively. Regarding the intragroup dispersion of NO_3^- and Cl^- levels, it is notably high, reflected by values exceeding 80%. In conclusion, the water extracted from wells in the southern zone of the studied region has shown to be highly polluted compared to those in the northern region of the same area. Nevertheless, wells 12, 19, and 22 have proven to be the most polluted with very high ratios exceeding 1000 ppm (figure 1).

3.2. Nitrate Pollution Index (NPI)

The NPI, or Nitrate Pollution Index, is a crucial tool used in water quality assessment due to the presence of elevated nitrate levels. Nitrates are chemical compounds containing nitrogen and oxygen, primarily originating from sources such as agriculture, industry, and municipal wastewater. These nitrates can lead to an increase in water pollution, which may have detrimental consequences on human health and the environment. As part of our study, the average NPI was calculated to be 2.17 with a standard deviation of 0.43. Index values range from a minimum of -0.5 to a maximum of 7, with a median of 2. The data distribution follows a normal distribution, as evidenced by the skewness coefficient of 0.99. This distribution provides a clear insight into the level of water pollution in the studied region. Analyzing the data in more detail reveals that out of the 22 wells studied, 12 of them exhibit a significant to very significant level of pollution, indicating a notable contamination by nitrates. In contrast, 9 wells showed moderate to mild pollution levels, suggesting better water quality. Surprisingly, only one well was classified as having optimal water quality, without signs of nitrate contamination (figure 2). This classification of wells based on the degree of pollution highlights the extent of the nitrate pollution problem in the studied region. It is crucial to take immediate measures to prevent future water contamination by identifying and addressing nitrate sources. Stricter regulations for agriculture, industry, and wastewater treatment can contribute to reducing nitrate pollution and safeguarding water quality for future generations (figure 2). In conclusion, the NPI is a valuable tool for assessing water pollution from nitrates and implementing corrective measures accordingly. Regular monitoring of nitrate levels in water is essential, and prompt action is necessary to protect our vital water resource. Through effective management and increased awareness, it is possible to preserve water quality for the well-being of all.

3.3. Global Analysis

The figure (3) presents the results of the simple regression between the Pollution Index (NPI) and the Cl- content. Indeed, a positive correlation associates these two variables ($r=0.679$; $p<0.001$), indicating that the pollution index increases with an increase in chlorine levels. However, the projection of wells in principal component analysis within the space defined by components 1 and 2 shows two distinct groups (figure 4): The first group consists of wells that exhibited high chlorine levels and a relatively significant pollution index (W12 and W22). In contrast to this group, the other wells (10 wells) showed low levels of chlorine and NPI. Group 2 consists of wells that displayed high NO_3^- levels (5 wells) but without an indication of NPI. In opposition to this group, well 19 has a relatively low NO_3^- level. It is important to note that the positive correlation between the pollution index and chlorine content suggests a direct relationship between these two variables. However, the presence of distinct groups in the principal component analysis indicates diversity in the characteristics of the studied wells. This diversity may be attributed to environmental or geological factors specific to each well, as well as complex interactions among various pollutants. Therefore, it would be relevant to deepen the analysis by considering these different variables to better understand the variations observed in pollution levels. In conclusion, the combination of different indicators, such as chlorine content, NO_3^- levels, and the pollution index, allows for a more comprehensive picture of the water quality in the studied wells. This highlights the importance of a multidimensional approach to assess and manage water pollution effectively. The most significant groundwater formations in the Doukkala regions are the shallow aquifers primarily composed of limestone [12]. Furthermore, aquifer lithology, marine intrusions, and agricultural practices have been identified as the main factors influencing water quality in the region. The composition of groundwater rocks can influence the physicochemical properties of water [13, 14]. Additionally, marine intrusions can introduce contaminants into coastal aquifers. Agricultural practices, such as excessive use of fertilizers and pesticides, can lead to groundwater contamination [15]. Monitoring and managing these factors are essential to ensure water quality in the region. However, in some irrigated areas of Doukkala, the excessive use of fertilizers and water poses a high risk of groundwater contamination by agricultural chemicals [16,]. It is therefore crucial to implement sustainable and responsible agricultural practices to prevent this pollution. Strategies such as crop rotation, the use of organic fertilizers, and efficient water management can contribute to reducing adverse impacts on the environment and safeguarding the quality of water resources in the region [17]. In our study, water extracted from wells in both study zones of the region showed elevated levels of nitrate and chlorine. These results are comparable to those found by [18].

Table 1. NPI Classification of Groundwater

Classification of NPI	Type of Pollution
<0	Clean (not polluted)
0-1	Light Pollution
1-2	Moderate Pollution
2-3	Significant Pollution
>3	Very Significant Pollution

The NPI is measured using the following equation [11]: NPI = (Cs - HAF) {HAF}; Where Cs is the nitrate concentration, and HAF is the acceptable human value for nitrate, taken as 20 mg/L.

Table 2. Descriptive Analysis of Nitrate and Chlorine.

Parameters	Nitrate (ppm)	Chlore (mg/l)	Cl^-/NO_3^-
Mean	63,14	328,64	12,28
95% Confidence Interval for the Mean	40,88	173,92	3,5156
	85,40	483,36	21,04
Median	50,50	200,00	3,63
Variance	2520,77	121774,24	390,73
Standard Deviation	50,21	348,96	19,77
Minimum	2,50	20,00	,27
Maximum	154,00	1300,00	66,67
Skewness	0,65	1,50	2,06
Kurtosis	-0,94	2,15	3,06

Table 3. Distribution of NO_3^- and Cl^- between the Two Collection Zones

Par	region	Mean	Estd	Mini	Maxi	CV in %
NO_3^-	N	53,3	10,44	2,5	135,	64,97
	S	72,9	18,78	4,0	154,	85,40
	T	63,1	10,70	2,5	154,	79,52
Cl^-	N	204,5	55,74	20	500	90,39
	S	452,7	130,6	30	1300	95,69
	T	328,6	74,39	20	1300	106,18
NPI	N	4,7	1,338	0,6	14,8	93,63
	S	19,8	7,83	0,2	66,6	131,19
	T	12,2	4,214	0,2	66,6	160,97

N: Northern. S: Southern. T: Total; Par: Parametrs. Estd : Erreur standard:

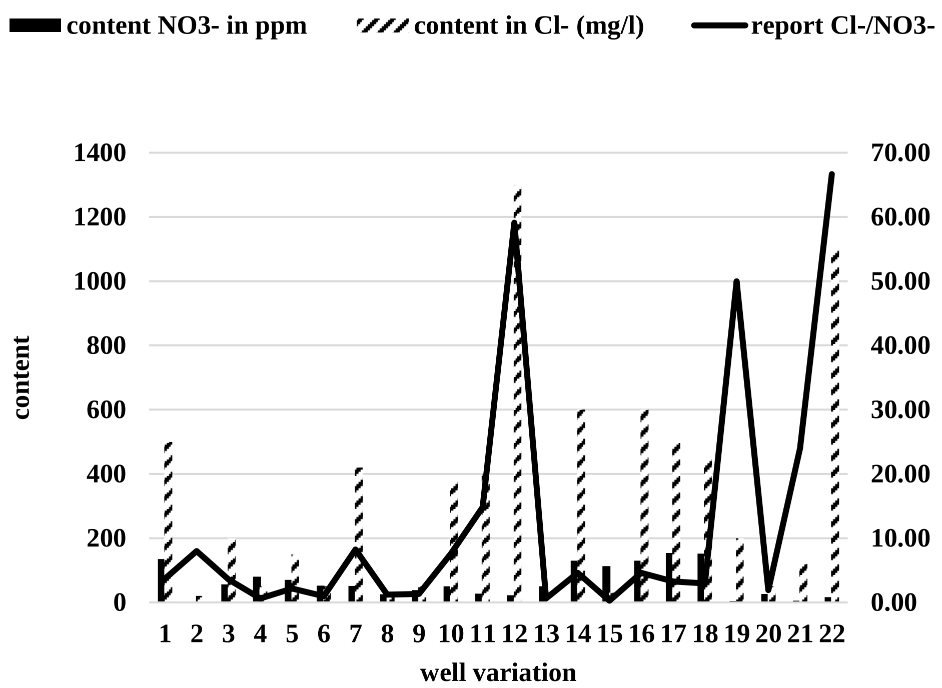

Figure 1. Distribution of NO_3^- and Cl^- concentrations in the investigated wells

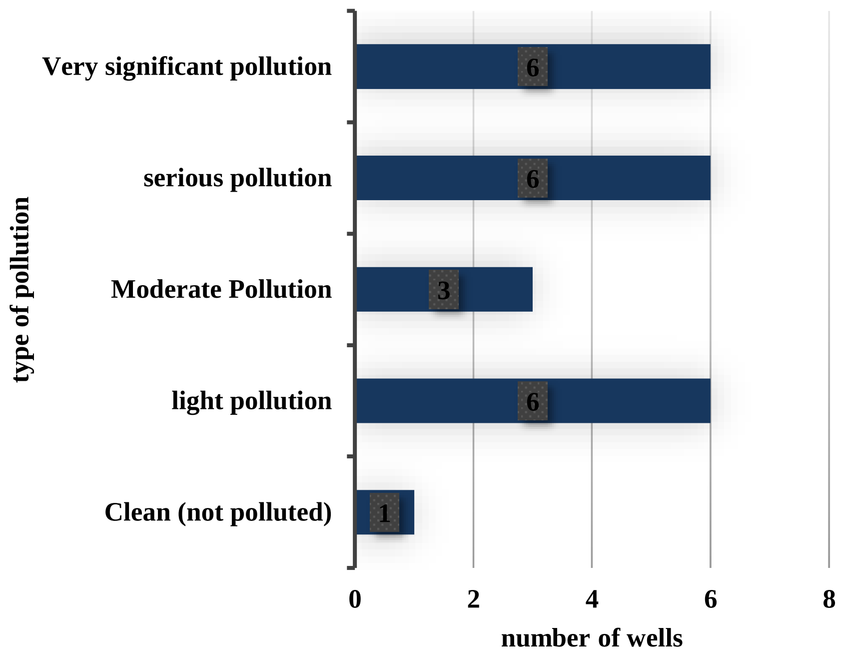

Figure 2. NPI Groundwater Classification

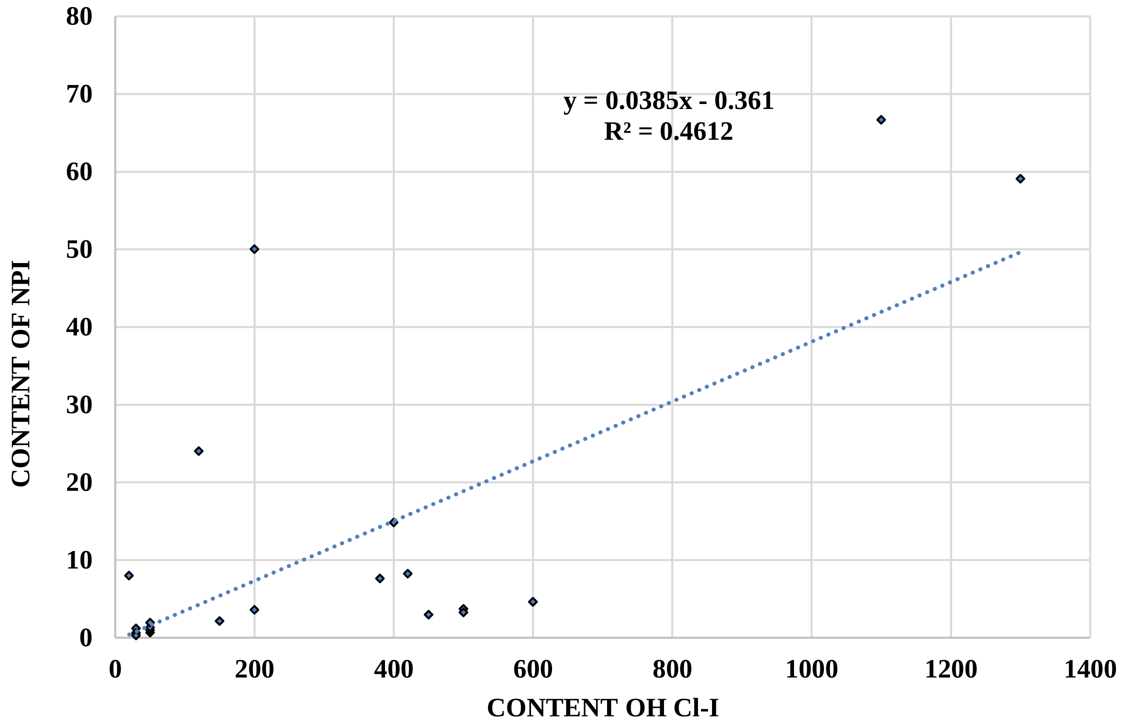

Figure 3. Linear Regression between Chlorine Content and NPI

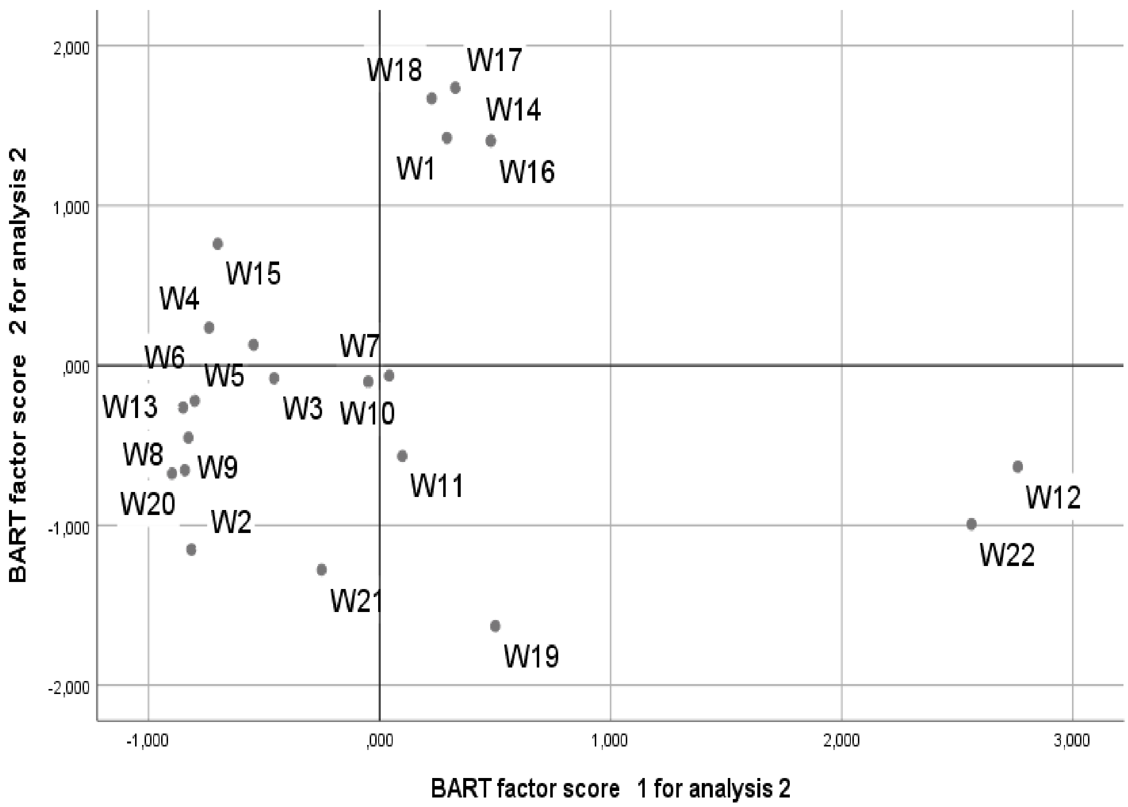

Figure 4. Principal Component Analysis (PCA) Projection of Wells

Studies conducted by [19] have identified agricultural activities, particularly the use of chemical fertilizers and animal farming, as the main sources of groundwater pollution by nitrates. On the other hand, potassium (K) is identified as one of the significant conditioning factors influencing groundwater contamination by nitrates [20]. In Morocco, numerous studies have addressed groundwater contamination by nitrate, such as that conducted by [21,22]. Higher concentrations of NO3- are attributed to sandy aquifers due to fertilizers; it has been observed that most aquifers are characterized by higher concentrations of nitrates released from composting.

4. Conclusions

This study investigated groundwater quality for nitrate in 2018, which varied spatially in a part of the Sahel in Doukkala, Morocco. The strata in this area are primarily composed of fractured rocks and karstic limestone from the Cenomanian period. The results of the sampled water indicated high concentrations of NO_3^- in groundwater, suggesting that fertilizers are the main source of nitrates. Adequate data on water quality, particularly nitrate concentration, need to be established to prevent hazardous health effects related to nitrate NO_3^-. Therefore, it is essential to exercise caution and safeguard groundwater from such issues. Consequently, this study confirms this need and recommends that policymakers take necessary measures to protect the groundwater in the study area. Additionally, raising awareness among farmers about the excessive use of fertilizers and its severe consequences for human health is strongly advised.

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