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Original Research Article

Suitability Assessment of Groundwater Quality in Sidi Allal Tazi Region Using Water Quality Index

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ABSTRACT

Groundwater plays a vital role as a natural resource essential for supporting life. This study aimed to evaluate the suitability of groundwater for drinking purposes in the Sidi Alall Tazi region, Morocco, using water quality indices (WQI). Forty-five water samples were collected from different locations in the study area. The investigation focused on the spatial and temporal variations of physical parameters, such as pH, and electrical conductivity (EC), and chemical parameters, such as sodium (Na^+), magnesium (Mg^{2+}), nitrate (NO_3^-), chloride (Cl^-), potassium (K^+), calcium (Ca^{2+}), and bicarbonate (HCO_3^-). The spatial distribution of Ca^{2+}, EC, and Na^+ revealed poor groundwater quality in some wells located near the Nador Canal and the Esbou River. The spatial distribution of nitrates (NO_3^-) was higher than the permissible limit in most of the study samples due to the excessive use of agricultural fertilizers in the study area. The results of WQI values ranged from 54.4 to 341. Specifically, samples W33 and W35 were found to be unsuitable for drinking purposes, with WQI values of 341.9 and 317.4, respectively, indicating poor water quality attributed to factors such as river intrusion, overexploitation, and harsh weather conditions. It is worth noting that the majority of the parameter values exceeded the recommended limits set by the World Health Organization (WHO) for safe consumption. By analyzing groundwater quality data and mapping the distribution of pollutants, officials can take measures to mitigate and prevent further pollution.

Keywords: Well quality, Water quality index, Major cations, Major anions.

Introduction

Groundwater serves as the primary water source for both drinking and irrigation needs worldwide. Most developed and developing countries rely heavily on groundwater. In Morocco, a large percentage of the population in rural and urban areas depends on groundwater to meet their daily water needs.[1] Given the importance of sources of water, it is necessary to evaluate the quality of groundwater before consumption. In recent years, water pollution resulting from rapid industrialization and urbanization has become a major threat to human organisms and agriculture.[2]

Morocco faces major problems with its water resources, as renewable water resources are estimated at 29 billion cubic meters annually, equivalent to 1,044 cubic meters per capita per year in 1998. However, by 2025, it is projected to decrease to only 786 cubic meters per capita per year. This indicates a significant decline in available water resources per person, highlighting the growing water scarcity challenges in the country.

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Water resources in the Gharb region of Morocco face an increasing threat from pollution due to urban, agricultural, industrial, and artisanal development. The growing demand for water resulting from development activities has put significant pressure on these resources. Additionally, the development has led to the creation of several polluted sites, such as Lake Fouarat, Rivers, and Paper mills. This pollution further exacerbates the challenges faced in ensuring the availability of clean and safe water in the region. Efforts to mitigate pollution and protect water resources are crucial to sustainably manage and preserve the coastal region's water sources.[3–5]

In recent years, the calculation of the water quality index (WQI) has become increasingly popular, being a good tool for evaluating and classifying water quality from different sources, including agriculture and industry. The WQI is a single numerical value that provides a comprehensive overview of the overall quality of water resources based on multiple criteria.[6,7] The water quality index offers an extensive analysis of water quality by utilizing various mathematical models to calculate it. This tool is widely used to assess the suitability of water for drinking purposes in many countries. Given that one of the key challenges is to develop cost-effective pollution control strategies for groundwater, WQI plays a crucial role in addressing this issue.[8,9]

In recent times, geographic information system (GIS) technology has become an efficient tool for storing, evaluating, monitoring, and visualizing spatial data concerning the quality of surface and groundwater.[10] This tool has demonstrated its effectiveness in addressing water resource issues, comprehending the natural environment, and managing water resources. Analyzing and

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evaluating spatial data on water resources using the inverse distance weighted interpolation (IDW) method in GIS techniques, offers a potent, cost-effective, and time-efficient means of transforming comprehensive datasets into various spatial distribution maps and projections. Consequently, it unveils trends, correlations, and sources of pollutants in any given study area.[10,11]

The present study was conducted to evaluate the suitability of groundwater for drinking purposes in the Sidi Allal region utilizing the water quality index (WQI) technique to provide insight into the overall water quality.

Materials and Methods

Study region

Sidi Allal Tazi is a city in Morocco situated in the Gharb-Chrarda-Beni Hssen region. It is located between the coastal zone and Oued Sebou in the northwestern part of the country. The city's geographical coordinates are approximately 34°32'36" N latitude and 6°20'12" W longitude (Figure 1). The study area has a warm and temperate climate. Winter receives more precipitation than summer. The average annual temperature in the city is 20°C. The annual average precipitation in Sidi Allal Tazi is 500 mm. July is the only month with no precipitation at all. December experiences the highest precipitation of the year, averaging 120 mm. January is the coldest month, with an average temperature of 13°C. The hydrogeological structure of the aquifer system in the coastal zone of Kenitra, Morocco, can be described in two distinct layers. The first layer is a sandy grassy surface layer. In the inner dunes, it ranges from 5 to 10 meters in thickness, while in the dune cordon, it ranges from 20 to 30 meters. Within this layer, the water table is relatively shallow in the interior dunes, ranging from 2 to 10 meters in depth. However, in the littoral cord, the water table depth is larger, ranging from 10 to 40 meters. The second layer is much thicker than the first layer, measuring over 50 meters in thickness. It primarily consists of clayey materials. Hydraulic communication between these two layers occurs through a red clay-sandy screen, which has a thickness varying from 10 to 20 meters.[12,13]

Sample collection and chemical analysis

Groundwater samples were collected from 45 wells at various locations and stored in polythene bottles. The bottles were then refrigerated at 4°C to preserve the samples for further analysis. Subsequently, the samples were transported to the laboratory for examination of their physico-chemical parameters within different areas of the study. The analyzed parameters included pH, electrical conductivity (EC), calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), potassium (K^+), ammonium ($NH4^+$), nitrate (NO_3^-), chloride (Cl^-), carbonate (CO_3^{2-}), bicarbonate (HCO_3-), and sulfate (SO_4^{2-}). The analysis of these parameters necessitated the use of specialized chemicals, materials, and equipment. The pH was determined using a pH meter, and electrical conductivity (EC) was assessed with a conductivity meter. Sulfates (SO_4^{2-}) were examined utilizing a spectropolarimeter. Sodium (Na^+) and potassium (K^+) were assessed through a flame spectrophotometer. Calcium (Ca^{2+}) and magnesium ($Mg^{2+)}$ were determined via titration employing the EDTA-2Na complex, along with a buffer solution and specific indicators. For Ca^{2+}, Patton and Reeder's indicator were utilized, while Eriochrome black T was employed for the combined determination of Ca^{2+} and Mg^{2+}. Carbonates (CO_3^{2-}) and bicarbonates (HCO_3^-) were determined by titration using a sulfuric acid solution along with suitable indicators, phenolphthalein for CO_3^{2-} and bromocresol green for HCO_3^-. Chloride (Cl^-) was assessed through titration with silver nitrate, using potassium chromate solution as an indicator. Nitrates (NO_3-) were analyzed using the Kjeldahl method, involving the distillation of mineral nitrogen, followed by fixation as ammonium tetraborate in the presence of boric acid during the distillation process. The collection and analysis of groundwater samples adhered to the standard procedures established by the American Public Health Association (APHA).[14] The measured physicochemical concentrations of the samples were then compared to the guideline values provided by the World Health Organization (WHO, 2011).[15]

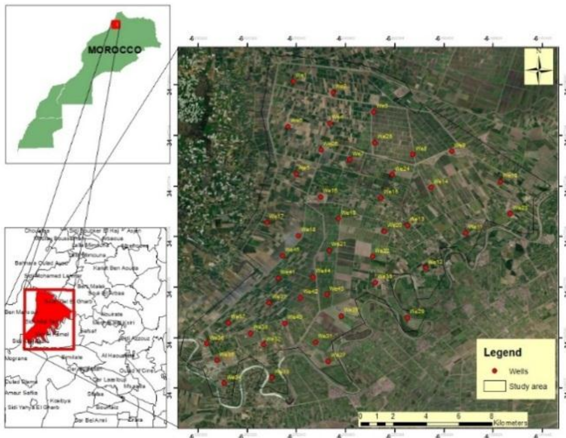

Figure 1: Location of the study area in Sidi Allal Tazi City, Morocco.

Spatial distribution maps

A Garmin eTrex 30 GPS device was used to determine sampling sites. The geographic coordinates of these sites were then imported into ArcGIS version 10.8, to perform spatiotemporal analysis of the samples and generate groundwater quality distribution maps.

Determination of water quality index (WQI)

The WQI proposed by Brown *et al.* (1970) is a valuable tool for assessing the quality of groundwater for drinking purposes.[16] It provides an overall evaluation of contamination levels in the study area. Calculating the WQI involves three steps. First, quality ratings are assigned to selected water quality parameters based on their concentration levels and established standards or guidelines. These ratings are assigned relative weights on a scale between 1 and 5, where 1 indicates low importance and 5 indicates high importance (Table 1).[17,18]

The relative weight (Wi) for each parameter is then calculated using the following formula, equation Eq 1:

$Wi = wi / \sum wi$ ……………Eq 1

Where, wi is the weight assigned to the parameter, and $\sum wi$ is the sum of weights assigned to all parameters.

The next type involves the quality rating and weight of each parameter combined to calculate the sub-index (Si) for that parameter using the following formula, equation Eq 2:

$Si = 100 \times (1 - |Ci - Si| / Si)$ ……………..Eq 2

Where, Ci represents the measured value of the parameter, while Si represents the standard value for the parameter.

The standard value represents the desirable or maximum allowable concentration of the parameter for drinking water and can vary depending on national or international standards.

Finally, the overall WQI is calculated by combining the sub-indices for each parameter using the following equation Eq 3:

$WQI = \sum Wi \times Si$ ……………Eq 3

Where $\sum Wi$ is the sum of relative weights assigned to all parameters, and Si is the sub-index for each parameter.

Results and Discussion

Groundwater quality is determined by assessing the concentrations of various chemical components and comparing them with international standards. The results obtained by physicochemical analyses on the main indicators measured are shown in Table 2. The pH is a measure of the acidity or alkalinity of water. It indicates the concentration of hydrogen ions present and stands for "potential of hydrogen." The pH level serves as a crucial indicator for assessing water quality.[19] In the present study, the pH values of all samples fell within the range of 6.7 to 8, with an average of 7.2±0.3 (Table 1). These pH values conform to the acceptable standards set by the WHO guidelines and Moroccan

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Standards for drinking water (Figure 2). Electrical conductivity refers to the capacity of an aqueous solution to carry an electric current. It is influenced by factors such as the presence of ions and their concentrations and exhibits an inverse relationship with electrical resistivity.[20] The electrical conductivity of the water samples varied from 874 to 7,640 µs/cm, with an average of 2,508 ± 1,704 (Table 1). According to Moroccan standards, roughly 15% of the well water is considered to be of good quality, while the remaining 85% of the wells are very bad quality and not safe for human consumption (Figure 3).

Calcium (Ca^{2+}) occurs naturally in crystalline and sedimentary rocks, and due to its high solubility, it is frequently found in various types of water sources.[21,22] The concentrations of calcium were between 89.2 and 300.8 with an average of 171.86±50.956.8 as presented in Table 1 and Figure 4). According to Moroccan standards, more than half of the study area shows an increase in calcium concentration, and this pollution may be due to natural sources. Magnesium can naturally occur in water due to the dissolution of magnesium-rich rocks and minerals present in the Earth's crust. Examples of such minerals include dolomite (calcium magnesium carbonate) and magnesite (magnesium carbonate).[23,24] The concentrations of magnesium (Mg^{2+}) were found to range from 10.69 to 293.3 mg/L, with an average of 41.07±42.37 mg/L (Table 1). The values found are consistent with the Moroccan standards. According to the analysis, 95% of wells have a level of good quality water, and 5% of wells are bad quality (Figure 5). Sodium (Na^+) is a widely abundant element on earth, commonly occurring in both crystalline and sedimentary rocks, including sands and clays. One well-known rock that contains sodium is halite (NaCl), often referred to as salt. Sodium chloride (NaCl) is highly soluble in water.[25] The sodium ion (Na^+) concentration ranged from 63.7 to 1,274.8 mg/L, with an average of 306.2±325.2 mg/L (Table 1). According to Moroccan standards, approximately 67% of the wells meet the excellent to good quality water criteria, while the remaining 33% are classified as poor to very poor quality (Figure 6). The increase in sodium concentration may be due to several sources, including marine water leakage, sewage, and agricultural waste. Potassium (K^+) primarily originates from crystalline rocks, clays, and fertilizers. Crystalline rocks, including igneous and metamorphic rocks, contain potassium-bearing minerals such as feldspar and mica. Clays, which are sedimentary rocks, also contain significant amounts of potassium.[26] The potassium ion (K^+) concentrations ranged between 3.59 and 13.05 mg/L, with an average of 8.138±2.646 mg/L. As highlighted in Table 2 and Figure 7, most wells are acceptable according to Moroccan standards.

Chloride (Cl^-) is a negatively charged ion that is commonly found in groundwater. It originates from various sources in the environment. As water percolates through the ground, it comes into contact with these geological formations, which contain naturally occurring chloride compounds. Over time, the chloride ions dissolve into the water, increasing its chloride content.[27]

Table 1: Standard value, weight, and relative weight of parameters

Chemical parameters	**Unit**	**WHO standards (2011)**	**Weight (wi)**	**Relative weight**
				WI = ∑ni=1 wi
pH	-	6.5-8.5	4	0.13
Electrical conductivity (EC)	µS/cm	500	4	0.13
Calcium ($Ca^{2+)}$)	mg/l	75	2	0.07
Magnesium ($Mg^{2+)}$)	mg/l	45	1	0.03
Sodium ($Na^{+)}$)	mg/l	200	2	0.07
Potassium ($K^{+)}$)	mg/l	12	2	0.07
Bicarbonate (HCO_3^-)	mg/l	250	3	0.10
Chloride (Cl^-)	mg/l	250	3	0.10
Sulphate ($SO4^{2-}$)	mg/l	250	4	0.13
Nitrate ($NO3^-$)	mg/l	50	5	0.17
			∑ wi = 30	∑ wi =1.00

WHO: World Health Organization

Table 2: Statistics of physico-chemical analyses of groundwater

Variable	**Minimum**	**Maximum**	**Mean**	**StDev**	**Moroccan Standards**
pH	6.7	8	7.2413	0.2517	6.5-9
Electrical conductivity (EC)	874	7640	2508	1704	1500
Calcium ($Ca^{2+)}$)	89.2	300.8	171.86	50.9	<100
Magnesium ($Mg^{2+)}$)	10.69	293.3	41.07	42.37	<100
Sodium ($Na^{+)}$)	63.7	1274.8	306.2	325.2	200
Potassium ($K^{+)}$)	3.59	13.05	8.138	2.646	12
Bicarbonate (HCO_3^-)	200	848.5	403.7	138	250
Chloride (Cl^-)	98	1900.1	524.8	540	250
Sulphate ($SO4^{2-}$)	47.9	661.2	128.9	101.8	250
Nitrate ($NO3^-$)	5.3	229.5	114.6	71.9	50
WQI	54.4	341.9	148.70	68.9	

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The concentrations of Cl^- in water samples ranged between 98 and 1,900 mg/l with an average of 1,524.8±540 (Table 1). Based on Moroccan water standards, 50% of well water is of excellent to good quality and 50% is of poor to very poor quality (Figure 8). Sulfates (SO_4^{2-}) are prevalent in all natural waters, even those considered "unpolluted." The primary source of sulfate compounds in natural waters is the result of the oxidation of sulfide ores. Sulfide minerals, such as pyrite (iron sulfide) or sphalerite (zinc sulfide), can be present in rocks and sediments.

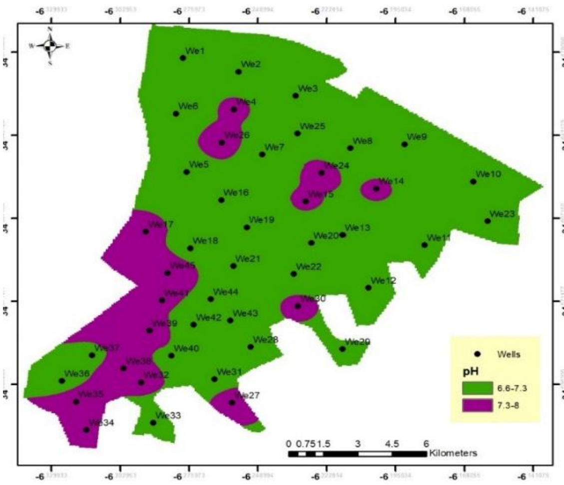

Figure 2: Spatial distribution map of pH.

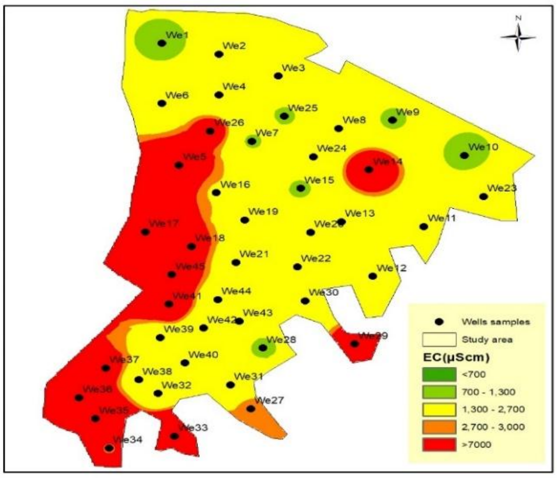

Figure 3: Spatial distribution map of Electrical conductivity.

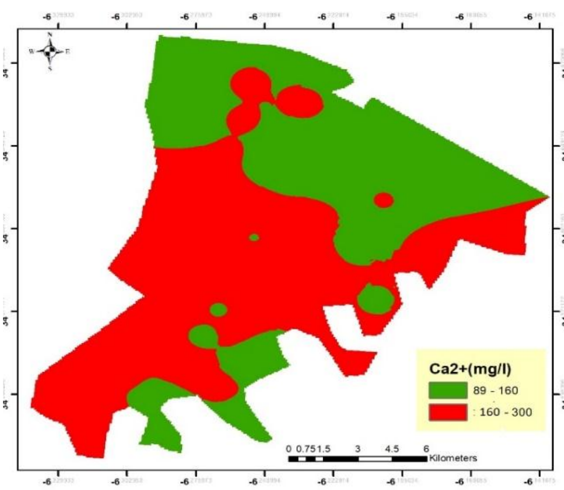

Figure 4: Spatial distribution map of calcium.

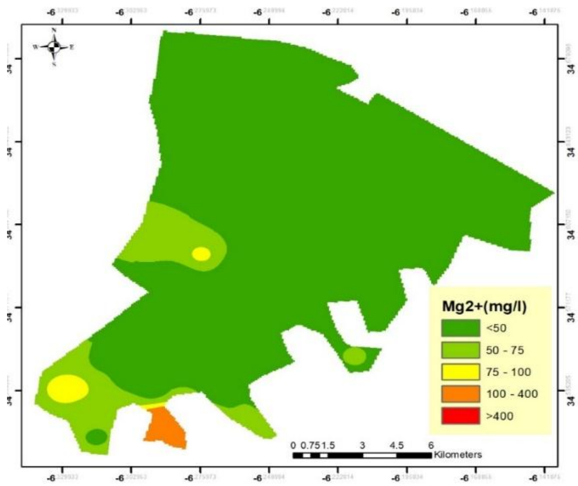

Figure 5: Spatial distribution map of magnesium.

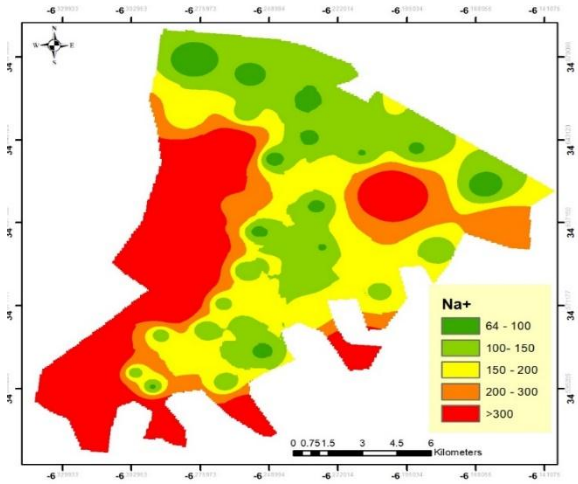

Figure 6: Spatial distribution map of sodium.

When these minerals come into contact with oxygen and water, they undergo a natural chemical reaction called oxidation, resulting in the release of sulfate ions into the surrounding water.[28] The sulfate concentrations (SO_4^{2-}) ranged from 47.9 to 661.2 mg/L, with an average of 128.9±101.8 (Table 1 and Figure 9). Based on the Moroccan standards, it was observed that the majority of the samples meet the criteria for being suitable for drinking. The concentration of bicarbonate in groundwater can vary depending on factors such as the geology of the region, the presence of carbonate rocks, the amount of organic matter, and the rate of water-rock interaction. Bicarbonate is an essential component of the carbonate buffering system, which helps maintain the pH stability of water.[29,30] The concentrations of HCO_3^- in samples of water were between 200 and 848.5 mg/L with a median of 403.7+138 as shown in Table 2 and Figure 10. According to Moroccan standards, about 75% of samples are excellent to good quality, and 15 % of samples are bad to very bad quality. Nitrates (NO_3^-) are commonly found in both groundwater and surface water at minimal concentrations. However, they can reach high levels under certain conditions, primarily due to two main factors: leaching from cultivated land and contamination from human or animal waste.[31–34] The concentrations of NO_3^- in water samples range between 5.3 and 229.5 mg/l with an average of 114.6±71.9 (Table 2 and Figure 11). The distribution map indicates that the highest levels of nitrates are found in areas where agricultural activity is most concentrated, which indicates the excessive use of agricultural fertilizers and their leakage due to irrigation and rain into groundwater, causing its contamination with nitrates.

Correlation matrix analysis assesses the relationship between two variables using a simple correlation coefficient. This coefficient indicates how well one variable can predict the other.[35] Table 3 provides the correlation coefficients for the primary parameter's concentrations.

Table 3: Correlation matrix of 11 physicochemical parameters

	pH	EC	Ca[mg/L]	Mg[mg/L]	Na[mg/L]	K[mg/L]	HCO3[mg/L]	Cl[mg/L]	SO4[mg/L]	NO3[mg/L]
EC	0.14									
Ca[mg/L]	0.18	0.63								
Mg[mg/L]	-0.28	0.68	0.20							
Na[mg/L]	0.16	0.99	0.56	0.67						
K[mg/L]	-0.01	0.28	0.29	0.28	0.23					
HCO3[mg/L]	-0.12	0.49	0.51	0.63	0.42	0.31				
Cl[mg/L]	0.18	0.99	0.61	0.61	0.99	0.24	0.40			
SO4[mg/L]	-0.16	0.64	0.25	0.79	0.66	0.22	0.28	0.58		
NO3[mg/L]	0.05	-0.05	0.21	-0.13	-0.11	0.18	0.08	-0.10	-0.18	
WQI	0.29	0.50	0.51	0.08	0.48	0.13	0.20	0.50	0.15	0.31

Table 4: Classification of groundwater quality index (WQI) of the study area

Wells	WQI	Type of water	Well	WQI	Type of water
We1	75.674308	Good	We24	121.501137	Poor
We2	105.339997	Poor	We25	70.3781609	Good
We3	141.745909	Poor	We26	198.217174	Poor
We4	115.683497	Poor	We27	145.874665	Poor
We5	202.692631	Very poor	We28	64.2929259	Good
We6	69.3263211	Good	We29	100.536041	Poor
We7	106.339231	Poor	We30	99.9455385	Good
We8	153.431298	Poor	We31	137.470049	Poor
We9	64.4472955	Good	We32	128.70555	Poor
We10	54.4197055	Good	We33	341.914354	Unsuitable
We11	79.1573277	Good	We34	182.677564	Poor
We12	134.148428	Poor	We35	317.416423	Unsuitable
We13	88.1290937	Good	We36	184.342685	Poor
We14	157.684012	Poor	We37	109.521828	Poor
We33	97.5299756	Good	We38	153.900469	Poor
We16	187.579365	Poor	We39	129.695116	Poor
We17	295.423714	Very poor	We40	153.786051	Poor
We18	192.717486	Poor	We41	252.041349	Very poor
We19	144.311126	Poor	We42	148.051156	Poor
We20	94.1669857	Good	We43	219.999199	Very poor
We21	131.242642	Poor	We44	93.9097752	Good
We22	137.687506	Poor	We45	227.353423	Very poor
We23	279.030189	Very poor			

The matrix of correlation for the ten physicochemical parameters in the study area reveals the presence of strong correlations ($r > 0.9$) and good correlations ($r = 0.5$ to 0.7) among the various physicochemical parameters.
EC with Na^+ and Cl^- also Na^+ with Cl^- are strong correlations
EC with Ca^{2+} and Mg^{2+} with Mg^{2+}, K^+ and K^+, Mg^{2+} with Na^+, K^+ and Ca^{2+}, Na^+ with K^+ and K^+ with Ca^{2+} are good correlations.
Other correlation parameters exhibit poor correlations.
pH with each parameter is weak correlation and negative correlation with K^+, HCO_3^-, and $SO4^{2-}$
The parameters most effective on WOI are EC, Ca^{2+}, Na^+, Cl^- and $NO3^-$.

The WQI provides a single value that summarizes the quality of water and assesses its suitability for drinking purposes. The WQI rating system classifies water into different groups, including excellent water (<50), good water (=50 to 100), poor water (=100 to 200), very poor water (=200 to 300), and non-potable water (>300).[36] Table 4 displays the computed WQI values for every groundwater sample within the research area. These WQI values ranged between 54 and 317, with an average of 148.70. Based on this classification of WQI, 26,6% was good, 55.6% was poor, 13.4% was very poor, and 4.4% unsuitable for drinking purposes in the study region. It was noted that samples W33 and W35 were not drinkable, as their WQI values were measured at

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341.9 and 317.4, respectively (Figure 12). These high values indicate substandard water quality, primarily due to factors such as leakage of the Esbou River, exploitation of fertilizers, and agricultural waste (Table 4).

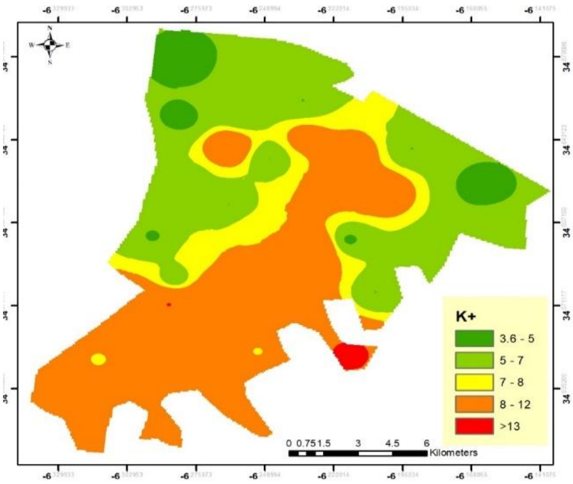

Figure 7: Spatial distribution map of potassium.

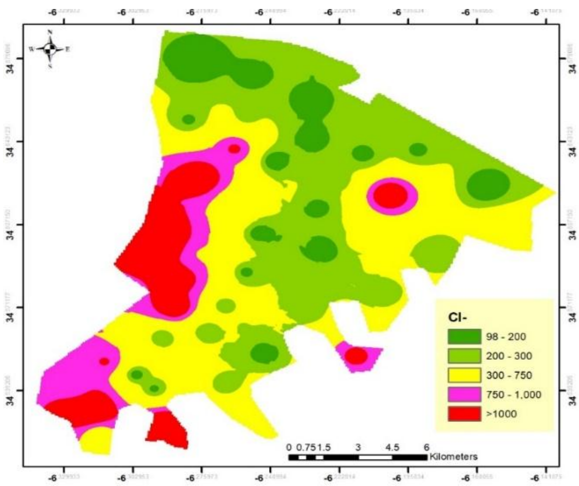

Figure 8: Spatial distribution map of chloride.

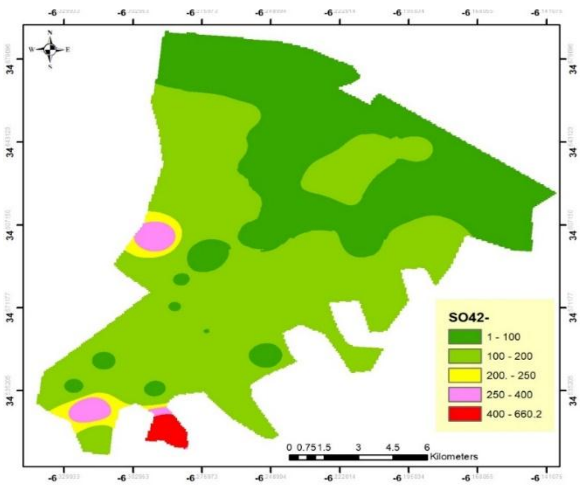

Figure 9: Spatial distribution map of sulfate.

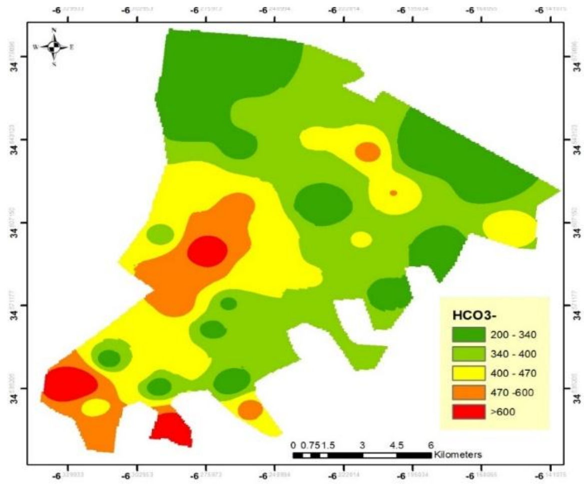

Figure 10: Spatial distribution map of bicarbonate.

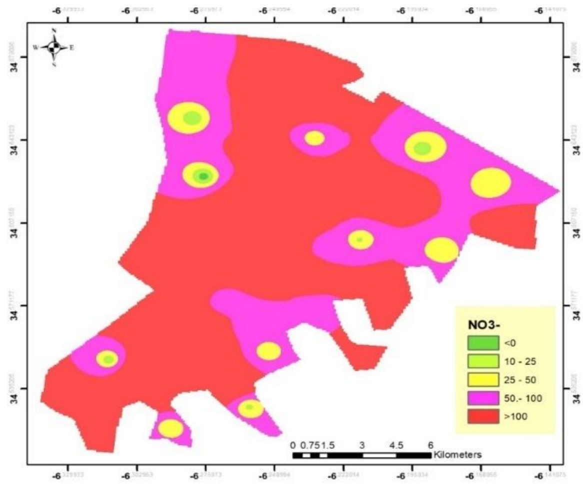

Figure 11: Spatial distribution map of nitrates

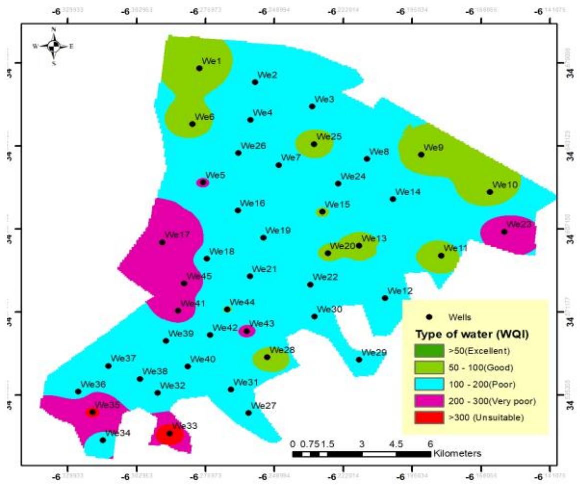

Figure 12: Spatial distribution map of water quality index.

Conclusion

Analysis of groundwater samples revealed that pH levels were within an acceptable range, according to Moroccan groundwater standards. However, a large portion of the samples showed high levels of electrical conductivity. In terms of cations and anions, most of them were found to be within the permissible range, except the concentrations of sodium, calcium, and nitrate. It was observed that nitrates exceeded the permissible limit in the majority of wells, indicating concern about groundwater quality concerning this

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parameter. To assess the overall groundwater quality, the WQI was calculated. The results showed that 26.6% of the groundwater samples were classified as good for drinking purposes. However, a significant portion, 55.6%, was categorized as poor, and 13.4% were classified as very poor. Additionally, 4.4% of the samples were determined to be unsuitable for drinking. Overall, the findings of the study provide valuable insights into the spatial and temporal variations of groundwater quality in the study area and can inform decision-making in the Sidi Allal Tazi region in Morocco.

Conflict of Interest

The authors declare no conflict of interest.

Authors' Declaration

The authors hereby declare that the work presented in this article is original and that any liability for claims relating to the content of this article will be borne by them.

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