

# Application of the water quality index (IQEs) to assess the quality of groundwater in the Ghiss-Nekkour aquifer, Al-Hoceima, Northern Morocco

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**ABSTRACT:** The determination of water quality with simple, accurate and easily understood expressions by managers and decision-makers has become a crucial situation in the environmental context, in order to help stakeholders make appropriate decisions. The aim of this study is to assess the quality of groundwater in the Ghiss-Nekkour aquifer, located in north-eastern Morocco, using the Water Quality Index (WQI). The method is based on the analysis of 11 different physico-chemical parameters (pH, EC, Ca<sup>2+</sup>, Na<sup>+</sup>, Mg<sup>2+</sup>, K<sup>+</sup>, HCO<sub>3</sub><sup>-</sup>, SO<sub>4</sub><sup>-2</sup>, Cl<sup>-</sup>, NO<sub>3</sub><sup>-</sup>, NO<sub>2</sub><sup>-</sup>) of this groundwater. By applying this WQI, the water was classified into four categories (Water: good quality, poor, very poor, unsuitable for consumption). The study showed that the water from most wells is unsuitable for domestic consumption and requires treatment.

**Keywords:** Water quality index, physicochemical, Ghiss-Nekkour aquifer, groundwater quality.

## 1 INTRODUCTION

Water has always been a subject of concern, and a number of works have been carried out to extract groundwater and control and store surface water. Groundwater, by its very nature, is involved in numerous geological and geochemical processes and is associated with various ecological services and functions. Many populations are dependent on groundwater for drinking water, food security and sustainable livelihoods, which means that they should be integrated into the economic, social and environmental dimensions of water resources.

The focus on enhancing the water sector has been a critical aspect of Morocco's strategy, acknowledging its pivotal role in fostering economic and social progress. However, this sector is grappling with significant challenges, primarily in rural areas. These challenges are the diminishing availability of water resources due to increasing consumption needs, with predictions indicating a potential for severe shortages by 2025, and the worsening condition of these resources caused by pollution [1].

The Ghiss-Nekkour alluvial aquifer, located in the north-eastern area of the Loukkos water basin, is vital for its strategic contribution to the water supply. It serves as a crucial source of potable water for Al Hoceima and its neighboring urban areas, in addition to supporting the irrigation needs of agriculture across the region. Nonetheless, this aquifer faces the threat of overexploitation, being the region's principal water source. Investigations

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into the aquifer's water quality reveal significant ion concentrations, attributed to the region's geological makeup, the use of mineralized irrigation water, and pollution from human activities [1]. In recent decades, global warming has contributed directly or indirectly to the deterioration in the quality of the groundwater in this aquifer, in a number of ways: it has caused marine intrusion due to the reduction in average rainfall and the overexploitation of this aquifer. The reduction in groundwater recharge has led to a concentration of solutes such as chloride, nitrate and arsenic in soils and shallow aquifers, due to increased evaporation and lower dilution [2]. A study carried out in 2017 on four wells belonging to the study area after the installation of the IMZOUREN wastewater treatment plant revealed the presence of abnormal nitrate levels in certain wells, thus constituting effective pollution that could harm consumer health [3]. This situation underscores the importance of regular and thorough monitoring of the groundwater's status, including the analysis of its chemical, physical, and biological characteristics to ensure its quality

The assurance of clean, quality water is indispensable for fulfilling both human and ecological water requirements, underscoring its significance within the broader framework of environmental management and sustainable development. To accurately gauge groundwater quality, various metrics are employed, offering a comprehensive view of its status [4]. One such metric, the Water Quality Index (WQI), consolidates extensive water quality data into a single figure, providing a snapshot of the overall water quality (Abbasi and al., 2012). It is a practical method that takes into account critical environmental variables, which represent the pollution conditions of a body of water at a given location. As well as being an independent study aimed at determining water quality, it can be seen as a continuation of the surveillance and monitoring of changes in the quality of groundwater in this body of water.

This study aims to evaluate the Ghiss-Nekkour aquifer's groundwater quality using the WQI, grounded on an analysis of physico-chemical parameters. This evaluation seeks to depict a detailed understanding of the water's suitability for household consumption, particularly as drinking water.

## **2 MATERIALS AND METHODS**

### **2.1 Study area**

The Ghiss-Nekkour plain, located about 12 km southeast of Al-Hoceima in northern Morocco (Fig.1), opens northwards towards the Mediterranean Sea, covering roughly 100 km<sup>2</sup>. It is positioned between longitudes 3°72'W and 3°95'W and latitudes 35°09'N and 35°24'N, primarily in the Nekkour area, with the Ghiss region to the northwest. The plain features the Ghiss-Nekkour coastal aquifer below, fed by tributaries from the Ghiss and Nekkour rivers [3]. Geographically, the Ghiss-Nekkour plain is enclosed by the Mediterranean Sea to the north, Trougout douar to the east, Ajdir town and the douars of Ait Youssef ou Ali and Imrabtene to the west, and to the south and southwest, it's bordered by the Bouayach and Tessaft douars, along with the Mohammed Ben Abdelkarim Al Khattabi dam [5].

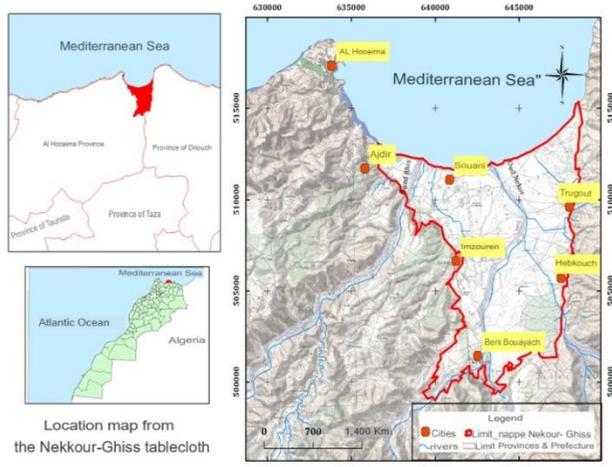


Figure 1: Geological location of the Ghiss-Nekkour plain

## 2.2 Geological setting

The Ghiss-Nekkour plain, characterized by Middle Quaternary alluvium and silts atop Paleozoic Ktama shale, lies within the Outer Rif. Its Quaternary layers, up to 450 m thick near Imzourene, reflect a geological history tied to the North African margin's transformation since the late Oligocene-Miocene. Enclosed by shale and sandstone, except for carbonate formations in the northwest and volcanic materials in the northeast, the plain presents a diverse geological structure [6].

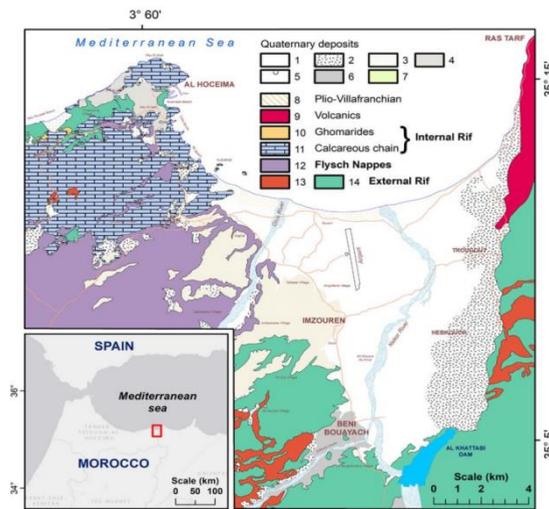


Figure 2: Geological map of the Ghiss-Nekkour plain [6].

The Ghiss-Nekkour aquifer, a plio-quaternary system, comprises a complex network of alluvial deposits with varied facies changes both vertically and laterally, harboring a predominantly free water table that becomes confined in certain areas. From the bottom upwards, it includes the Plio-Villafranchian layer with conglomerates, sandstones, and silts in the west; the ancient Quaternary with a base of conglomerates on the lower Ghiss plateau; the Middle Quaternary featuring Tensiftien-Amirien gravel terraces in the south

and west; and the Recent Quaternary, covering most of the plain with grey silts and evolving into silty coastal deposits and low terraces towards the plain's south and east [7].

### 2.3 Sampling and analysis procedures

Proper sample collection and storage are crucial for reliable physicochemical analysis results, affecting sampling methods and preservation. Ideally, samples should be analyzed promptly and stored in cool, dark conditions in glass or polyethylene containers. Water samples must be collected in clean, pre-rinsed containers, sealed without air bubbles. Some tests, like residual chlorine and pH, need immediate analysis due to sensitivity to storage and transport changes [8].

To assess the quality of the groundwater in the Ghiss-Nekkour aquifer in this study, 25 samples were collected from wells in order to acquire representative data on the quality of this water. These wells were distributed over the entire study area from upstream to downstream, in order to obtain an overall picture of the aquifer. The water samples were taken in spring 2023.

The calculation of the groundwater quality index for the Ghiss-Nekkour aquifer is based on the following 11 parameters: hydrogen potential (pH), electrical conductivity (EC), cations (Ca<sup>2+</sup>, Na<sup>+</sup>, Mg<sup>2+</sup>, K<sup>+</sup>) and anions (HCO<sub>3</sub><sup>-</sup>, SO<sub>4</sub><sup>-2</sup>, Cl<sup>-</sup>, NO<sub>3</sub><sup>-</sup>, NO<sub>2</sub><sup>-</sup>). pH and electrical conductivity were measured in the field using portable instruments, while chemical parameters were analysed using Rodier's techniques in the laboratory, and according to the methods listed in Table 1 [9].

Table 1 : Main chemical parameters measured: methods, equipment and units.

Parameters	Materials and Methods		Unit
	Materials	Methods	
Bicarbonates (HCO <sub>3</sub> )	Dosing equipment	Alkalimetric strength and full alkalimetric strength with hydrochloric acid (0.1N)	mg/l
Chlorides (Cl)		Mohr method	
Calcium (Ca)		EDTA volumetric method	
Magnesium (Mg)			
Potassium (K)	Flame spectrophotometer	Determination of potassium and sodium by flame emission spectrophotometry	
Sodium (Na)			
Sulphate (SO <sub>4</sub> )	Spectrophotometer (UV) (Rayleigh UV-9200)	Nephelometric method	
Nitrate (NO <sub>3</sub> )		Molecular absorption spectrometry method	
Nitrite (NO <sub>2</sub> )			

### 2.4 Calculation of the water quality index

In order to assess the quality of the groundwater in the Ghiss-Nekkour aquifer, we will calculate the water quality index, which classifies the quality of the water according to the degree of purity using the most commonly measured water quality parameters.

The water quality index is calculated in the following stages [9]:

- The first stage involves assigning weights ranging from 1 to 5 to the selected parameters. The weight given to each parameter depends on its relative importance

in influencing the overall quality of drinking water and its impact on human health.

- In the second stage, the relative weight ( $W_i$ ) of each parameter is calculated using the following equation:

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

where  $W_i$  is relative weight,  $w_i$  is weight of each parameter and  $n$  is number of parameters.

- The third step is to calculate the quality assessment scale ( $q_i$ ) for each parameter according to the following equation:

$$q_i = \left(\frac{C_i}{S_i}\right) \times 100 \quad (2)$$

with  $q_i$  as the quality score,  $C_i$  is the worth of every boundary in each example (focuses in mg/l, EC in  $\mu\text{S/cm}$ ) and  $S_i$  as the maximum permissible value according to Moroccan standards (NM 03.7.001)

- In the fourth step, the sub-index of the  $i$ th parameter  $S_{Ii}$  is calculated using the following equation:

$$S_{Ii} = w_i \times q_i \quad (3)$$

Where  $W_i$  is relative weight and  $S_{Ii}$  is the subindex of  $i$ th parameter

- Finally, in the fifth step, the water quality index is calculated by adding the  $S_{Ii}$  values of all the parameters according to the following equation:

$$WQI = \sum_{i=1}^n S_{Ii} \quad (4)$$

The calculated WQI values are classified into five categories according to their scores (table 1), as shown in the following table [9]:

Table 2: Quality index threshold defined in the WQI.

Water quality	Groundwater quality index values
<50	Excellent water
50 – 100	Good water
100 – 200	Poor water
200 – 300	Very poor water
>300	Unsuitable for drinking

### 3 RESULTS AND DISCUSSION

#### 3.1 Physico-chemical parameters of Ghiss-Nekkour groundwater

Table 3: Statistical characteristics of the physico-chemical parameters of the groundwater.

Wells	E.C	pH	HCO <sub>3</sub>	Cl <sup>-</sup>	Ca <sup>2+</sup>	Mg <sup>2+</sup>	K <sup>+</sup>	Na <sup>+</sup>	SO <sub>4</sub> <sup>2-</sup>	NO <sub>3</sub> <sup>-</sup>	NO <sub>2</sub> <sup>-</sup>
	uS/cm		mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
1	3200	7,87	533,75	710,00	156,31	93,41	14,3	456,0	384,04	23,49	0
2	4550	7,76	610,00	852,00	140,28	98,23	19,0	547,0	355,32	47,24	0
3	2410	7,62	305,00	426,00	196,39	95,76	11,6	279,0	398,94	18,03	0
4	3300	7,68	305,00	639,00	304,61	124,44	12,8	408,0	680,85	15,64	0
5	5710	7,82	564,25	1050,80	420,84	61,90	21,4	687,8	1107,45	1,78	0
6	3930	7,54	427,00	724,20	272,54	153,27	16,0	474,2	820,21	33,93	0,0184

7	3710	7,89	457,50	681,60	288,58	95,65	15,3	449,6	637,23	15,83	0
8	3170	7,81	457,50	553,80	214,83	99,10	10,6	352,8	860,64	3,84	0,0092
9	3810	7,68	488,00	695,80	280,56	86,06	10,9	447,8	840,43	3,52	0,0441
10	3610	7,73	411,75	653,20	260,52	114,89	11,4	419,2	877,66	17,48	0
11	3480	7,71	381,25	624,80	288,58	71,65	13,0	411,8	730,85	16,54	0,0147
12	5270	7,62	411,75	965,60	308,62	220,43	15,0	621,6	847,87	2,26	0
13	5030	7,55	503,25	923,00	266,93	175,84	17,4	594,0	1005,32	1,58	0,2004
14	3770	7,72	686,25	724,20	184,37	124,58	16,5	473,2	604,26	0,00	0
15	3900	7,45	716,75	781,00	240,48	105,31	16,8	500,0	587,23	2,00	0
16	12720	8,13	396,50	3961,80	384,77	340,34	25,2	2572,8	1617,02	1,87	0
17	9730	7,77	564,25	2627,00	236,47	342,92	23,4	1700,0	1678,72	2,26	0
18	4130	7,80	427,00	837,80	244,49	165,31	14,8	549,8	787,23	48,63	0
19	3080	8,07	442,25	568,00	104,21	71,88	14,5	374,0	619,15	10,47	0
20	4530	8,00	518,50	1107,60	164,33	175,00	14,7	707,6	597,87	37,09	0,0542
21	4650	7,91	533,75	1107,60	112,22	173,15	14,9	718,6	659,57	56,22	0,1113
22	3760	7,83	472,75	766,80	189,98	128,41	12,4	491,8	865,96	28,59	0
23	5150	7,30	3004,25	937,20	36,07	16,76	22,9	612,2	871,28	1,52	25,5563
24	2740	8,22	335,50	553,80	112,22	100,67	9,2	353,8	769,15	34,67	0,0120
25	1825	7,82	549,00	227,20	180,36	66,98	7,9	154,2	684,04	14,70	0

The electrical conductivity values of the groundwater in the study area range from 1825  $\mu\text{S}/\text{cm}$  to 12720  $\mu\text{S}/\text{cm}$  (table 3). The lowest values were measured in wells 3 and 25, and the highest in well 16, with an uncertainty of 350  $\mu\text{S}/\text{cm}$ . Since the Moroccan potability standard is set at 2700  $\mu\text{S}/\text{cm}$ , the water from all the wells exceeds the standard, except for wells 3 and 25, which have values that comply with the standard. The increase in electrical conductivity reflects the high salinity of the water, which is due to the leaching of the reservoir rock in which the water lay, and probably also to climatic conditions.

In all the waters sampled, the water in the study region complies with Moroccan drinking water standards set at  $6.5 < \text{pH} < 8.5$ . The pH values measured are not very heterogeneous and are close to neutral. They range from 7.45 to 8.3, with an average of 7.81 and an uncertainty of 0.1. The lowest values were observed in the water from wells 6 and 15, and the highest in the water from well 23.

The bicarbonate ion results from the dissolution of carbonates by water containing  $\text{CO}_2$  carbon dioxide. Analysis of the groundwater shows that it is characterised by a bicarbonate concentration varying between 305 mg/l in the water from wells 3 and 4 (the poorest) and 3004.25 mg/l in the water from well 23 (the richest), with an average of 580.11 mg/l. These results show that the bicarbonate concentration exceeded the Moroccan standard, which is set at 300 mg/l.

The sodium ion is present in all waters due to its increased solubility. Our analysis showed that sodium levels in the water in the study area (table 4) varied between 154 mg/l and 2572.8 mg/l, with an average of 641.8 mg/l. The concentration of this ion in the samples studied exceeds the Moroccan standard, which is set at 200 mg/l in all wells except well 25. The rise in sodium concentration can be due to the alteration of rock and soil, seawater intrusions, treated water and irrigation systems. The high sodium concentrations in the water of the Ghiss-Nekkour aquifer have the same origin as that of chlorides. In fact, sodium generally accompanies chlorine pollution. Although sodium is necessary for maintaining the body's water balance and for muscle and nerve function, high sodium consumption can damage the kidneys and increase the risk of hypertension.

The potassium ion is found in igneous rocks and in nature in the form of double chloride in many ores and in some industrial waste and fertiliser plants, which can release large quantities of potassium into the water. According to Moroccan potability standards, the potassium content of water intended for human consumption must not exceed a maximum permissible concentration of 12 mg/l. In our study area, potassium concentrations vary from 7.9 mg/l in well 25 to 25.2 mg/l in well 16, with an average of 15.3 mg/l. Analysis of this groundwater shows that it exceeds the maximum permissible value at most wells. The water in wells 3, 8, 9, 10, 24 and 25 complies with standards.

Calcium is the major component of water hardness; it is generally the dominant element in drinking water and its content varies according to the nature of the ground through which it flows. An increase in calcium concentration in a water sample may be due to the dissolution of gypsum or anhydrite [8]. Calcium concentrations in the water samples studied ranged from 36.072 mg/l in well 23 to 420.84 mg/l in well 5, with an average of 223.6 mg/l. From our study, we can see that the water from wells 1, 2, 3, 14, 19, 20, 21, 22, 23, 24 and 25 meets Moroccan standards for drinking water, which is set at 200 mg/l as the maximum admissible value for calcium content. Water from the other wells exceeds these standards.

Magnesium content depends on the composition of the sedimentary rocks encountered (dolomitic limestones, Jurassic or Middle Triassic dolomites) [8]. In the samples studied, magnesium ranged from 16.76 mg/l to 342.92 mg/l, with an average of 132.07 mg/l. The lowest magnesium content was found in well 23, and the highest in well 17. According to Moroccan water potability standards, the magnesium concentration must not exceed 150 mg/l, and consequently only 8 wells in our study area do not comply with these standards, namely wells 6, 12, 13, 16, 17, 18, 20 and 21.

Chlorides are present in all water, and their concentrations in water vary according to the nature of the ground through which it flows. Chloride ions come from clay lenses present in the basin, and may also be partly of human origin [10]. Analysis of water samples taken from wells in the study area revealed chloride levels ranging from 427.2 mg/l in well 25 to 3961.8 mg/l in well 16, with an average of 948 mg/l. Points P2, P5, P12, P13, P15, P16, P17, P18, P20, P21, P22 and P23 contained chloride levels that exceeded Moroccan standards, which set the maximum permissible chloride content at 750 mg/l in drinking water. Exceeding the maximum permissible chloride values will affect the taste of the water and high chlorine concentrations can cause eczema and erythema.

In nature, sulphates in water can have several origins: atmospheric, geochemical or also result from the activity of certain bacteria which oxidise toxic hydrogen sulphide ( $H_2S$ ) into sulphate [11]. Analyses of water samples taken from wells on the Ghiss-Nekkour plain revealed sulphate levels ranging from 355.32 mg/l at Well 2 to 1678.72 mg/l at Wells 16 and 17, with an average of 795.53 mg/l. Moroccan water potability standards set a maximum permissible sulphate content of 400 mg/l in drinking water, so wells P1, P2 and P3 comply with these standards, while the others exceeded the maximum permissible value.

Nitrates are naturally present in groundwater at low concentrations. However, high levels indicate contamination of groundwater by nitrogenous inputs from human activities (excess agricultural fertilisers from cultivated soils, wastewater run-off, etc.) [8]. Nitrate levels in the water studied ranged from 0 mg/l to 56.22 mg/l. Well 14 had the lowest nitrate level, while P21 had the highest. The average nitrate value for the samples analysed was 17.57 mg/l. According to this study, only the water from well 21 exceeded Moroccan potability standards set at 50 mg/l.

Nitrite ions are easily oxidised to nitrate and only very rarely occur in large concentrations in natural waters. In our analysis, the nitrite concentration in well water varied between 0 mg/l and 0.2 mg/l in all wells, except for point 23 where we found 25.55 mg/l with an average of 1.06 mg/l. The maximum admissible value for drinking water according to Moroccan standards must not exceed a concentration of 0.5 mg/l, so according to the results obtained all the water complies with Moroccan standards except for the water from well 25. This increase in concentration at this point may be due to contamination from fertilisers used in farming or contamination from wastewater.

### 3.2 Assessing water quality using the WQI

The relative weight of the samples collected (Table 4) is calculated from the data as follows:

Table 4: The weight (wi) and relative weight (Wi) of each chemical parameter to calculate the QWI with the Moroccan standard (NM 03.7.001) for drinking water [12, 13].

parameters	Moroccan standards (Si)	Weight (wi)	Relative weight (Wi)
<b>PH</b>	6,5 < pH <8,5	4	0,102
<b>E.C</b>	2700	5	0,128
<b>Na<sup>+</sup></b>	200	3	0,076
<b>K<sup>+</sup></b>	12	2	0,051
<b>Ca<sup>2+</sup></b>	200	2	0,051
<b>Cl<sup>-</sup></b>	750	5	0,128
<b>Mg<sup>2+</sup></b>	150	2	0,051
<b>SO<sup>2-</sup><sub>4</sub></b>	400	4	0,102
<b>HCO<sup>-</sup><sub>3</sub></b>	300	2	0,051
<b>N0<sup>-</sup><sub>3</sub></b>	50	5	0,128
<b>N0<sup>-</sup><sub>2</sub></b>	0,5	5	0,128

Table 5: table showing the quality of each water sample

Wells	WQI	Water quality
1	93,43	Good water
2	113,96	Poor water
3	72,82	Good water
4	96,487	Good water
5	141,99	Poor water
6	115,55	Poor water
7	102,22	Poor water
8	92,80	Good water
9	103,86	Poor water
10	103,95	Poor water
11	98,34	Good water
12	126,38	Poor water
13	132,34	Poor water
14	101,73	Poor water
15	105,47	Poor water
16	317,28	Unsuitable for drinking
17	246,74	Very poor water

18	123,30	Poor water
19	86,73	Good water
20	129,47	Poor water
21	137,22	Poor water
22	112,16	Poor water
23	812,74	Unsuitable for drinking
24	91,75	Good water
25	69,79	Good water

Assessment of the quality of the groundwater in the Ghiss-Nekkour aquifer using the water quality index enables it to be classified into several categories. The index values calculated vary between 69.79 and 812.74.

Table 4 above shows that the water in the Ghiss-Nekkour aquifer is of good quality in wells 1, 3, 4, 8, 11, 19, 24 and 25.

The water in well 17 is very poor quality, while wells 16 and 23 are unfit for consumption. In all the other wells, the water is considered to be of poor quality according to the quality index values calculated.

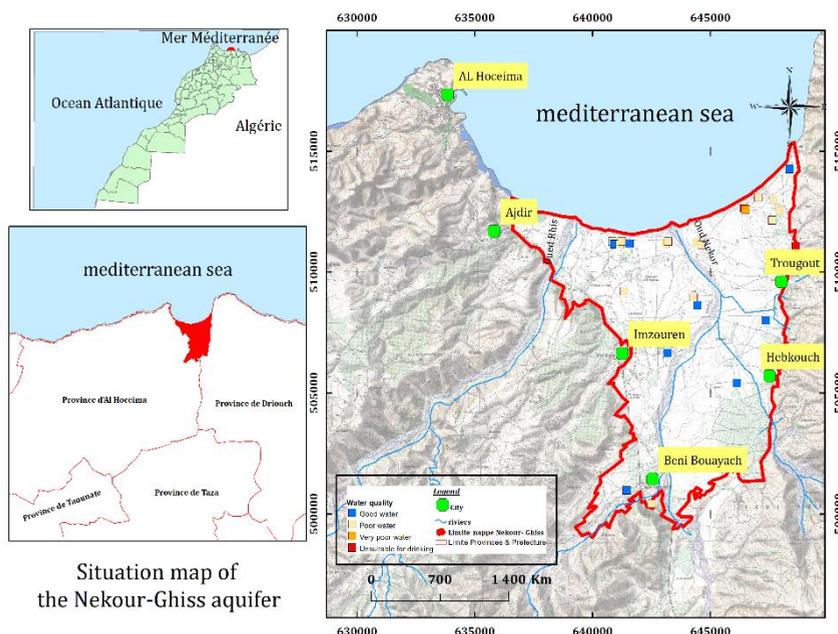


Figure 3: figure showing the distribution of groundwater quality in each well

Figure 3 shows that the distribution of points containing different qualities of groundwater is random, indicating that the sources of pollution of these waters are diverse.

#### 4 CONCLUSION

Our study focused on assessing the quality of groundwater from the Ghiss-Nekkour aquifer, which is located in the geographical area of the city of Al Hoceima in Morocco. This study assessed these water samples for human consumption by calculating the water quality

index, which gives a single value representative of water quality. The use of this approach remains crucial in order to simplify information for the public and stakeholders involved in water management.

The calculation of the WQI in this study showed a very significant spatial differentiation of water quality, ranging from water unfit for consumption to good quality water. The results obtained show that the water from most wells is unsuitable for domestic consumption, and as a result, a programme to develop, treat and sanitise most of these water wells is essential to prevent the population in the study area from contracting water-borne diseases.

In all cases, further studies should be undertaken to identify more dangerous pollution parameters, such as pesticides, other bacteriological parameters and other heavy metals. Taken together, these results underline the urgency of the problem and the need to take measures to limit its effects. This study will provide an in-depth assessment of water resources in the Ghiss-Nekkour plain and could serve as a decision-making tool.

## REFERENCES

- [1] : A. Salhi, S. Benabdelouahab, Etude hydrogéologique de la nappe alluviale de Ghiss-Nekor (Maroc), ResearchGate, (January 2017)
- [2]: Organisation des Nations Unies, Rapport mondial des Nations Unies sur la mise en valeur des ressources en eau 2022 : Eaux souterraines : rendre visible l'invisible. UNESCO, Paris  
[unesdoc.unesco.org/ark:/48223/pf0000380743\\_fre/PDF/380723fre.pdf.multi.nameddest=380743](https://unesdoc.unesco.org/ark:/48223/pf0000380743_fre/PDF/380723fre.pdf.multi.nameddest=380743)
- [3]: F. Dimane, K. Haboubi, I. Hanafi, A. El Himri, Impact Des Facteurs De Pollution Sur La Qualité Des Eaux De La Zone Aval De La Vallée De L'oued Nekor (Al-Hoceima, Maroc), ResearchGate, (January 2017) DOI:[10.19044/esj.2016.v13n3p43](https://doi.org/10.19044/esj.2016.v13n3p43)
- [4] : A. Talhaoui, A. El Hmadi, H. Jaddi. H. Ousmana, I. Manssouri, Calcul De L'indice De Qualité De L'eau (IQE) Pour L'évaluation De La Qualité Physico-Chimique Des Eaux Superficielles De L'Oued Moulouya (NE, Maroc), ResearchGate, (January 2020). DOI : [10.19044/esj.2020.v16n2p64](https://doi.org/10.19044/esj.2020.v16n2p64)
- [5] : A. salhi, Géophysique, Hydrogéologie, Cartographie de la vulnérabilité et risque de pollution de l'aquifère de Ghiss-Nekor, Thesis, Abdelmalek Essaâdi (2008). DOI : [10.13140/RG.2.2.34803.78887/2](https://doi.org/10.13140/RG.2.2.34803.78887/2)
- [6]: D. Chafouq, A. El Mandour, M. El Gettafi, M. Himi, I. Chouikri, A. Casas, Hydrochemical and isotopic characterization of groundwater in the Ghiss-Nekor plain (Northern Morocco), Journal of African Earth Sciences (2017). <https://doi.org/10.1016/j.jafrearsci.2017.11.007>
- [7]: B. Benzougagh, A. Dridri, L. Boudad, D. Sdkaoui, B. Baamar, Contribution of Gis and remote sensing for the evaluation of the physical characteristics of Inaouene watershed (northeast morocco) and their uses in the field of natural hazard management. Am. J. innov. res. appl. sci. (2019), 8(4): 120-130.
- [8]: J. Rodier, L. Bernard, M. Nicole, Water analysis, natural water, wastewater, seawater, 9th edn (Dunod, Paris, 2009), ISBN 987-2-10-054179-9

- [9]: Ş. Şener, E. Şener, A. Davraz, Evaluation of water quality using water quality index (WQI) method and GIS in Aksu River (SW-Turkey), *science of total environment*, (April 2017). <https://doi.org/10.1016/j.scitotenv.2017.01.102>
- [10] : C. Degbey, Facteurs associés à la problématique de la qualité de l'eau de boisson et la santé des populations dans la commune d'Abomey-calavi au Benin, Université Libre de Bruxelles (ULB), Thesis, (2011).
- [11]: C.E. Deliste, J.W. Schmidt, The effects of sulphur on water and aquatic life in Canada. In the: Sulphur and its inorganic derivatives in the Canadian environment, NRCC No. 1, (1977)
- [12]: C. Benaissa, B. Bouhmadi, A. Rossi, Y. El Hammoudani, F. Dimane, Assessment of Water Quality Using Water Quality Index (WQI): Case Study of Bakoya Aquifer, Al Hoceima, Northern Morocco, *Ecological Engineering & Environmental Technology* 2024, 25(1), 22–45. <https://doi.org/10.12912/27197050/173567>
- [13]: NM03.7.001. Moroccan standard relating to the quality of human drinking water. By joint order of the Minister of Equipment and Transport, the Minister of Health, the Minister of Regional Planning, Water and the Environment and the Minister of Industry, Trade and Telecommunications (2020).