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Risk of Groundwater Contamination by Domestic Wastewater in Rural Areas of the Province of Al Hoceima, Northern Morocco

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ABSTRACT

Groundwater is crucial for meeting the water needs of rural communities, serving both domestic and agricultural purposes. However, its quality in our study area remains unclear. Therefore, the primary objective of the current study is to evaluate the groundwater quality and ascertain the level of contamination risk associated with the use of septic tanks in rural communities within the Al Hoceima province. This will be achieved by conducting a comprehensive analysis of physicochemical parameters and employing effective indices, including the Water Quality Index (WQI), Nitrate Pollution Index (NPI), and Chronic Health Risk (CHR). In February 2023, we collected samples from 33 wells, spanning densely and sparsely populated regions, to account for potential variations in water quality. The analyzed parameters included pH, total dissolved solids (TDS), electrical conductivity (EC), ammonium (NH_4^+), nitrates (NO_3^-), nitrites (NO_2^-), sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), chloride (Cl^-), sulfate (SO_4^{2-}), bicarbonate (HCO_3^-), phosphate (PO_4^{3-}), and silica (SiO_2). Our findings revealed slightly alkaline groundwater with TDS levels ranging from 1508.63 mg/l to 8289.8 mg/l, with an average of 3223.19 mg/l. The cation dominance sequence observed was $Na^+ > Ca^{2+} > Mg^{2+} > K^+ > NH_4^+$, while for anions, it followed as $SO_4^{2-} > Cl^- > HCO_3^- > NO_3^- > PO_4^{3-} > NO_2^-$. The Water Quality Index (WQI) indicated contamination in 54.55% of the wells, with notably higher NPI values in densely populated regions. This suggests anthropogenic nitrate contamination, likely originating from septic tanks. The assessment of Chronic Health Risk (CHR) revealed non-carcinogenic health risks in 27.27% of samples for children and 15.15% for adults. Given these findings, it is imperative for Moroccan authorities, despite the efforts of the Loukkos Hydraulic Basin Agency (LHBA), to implement strategic measures to protect groundwater quality in densely populated rural regions.

Keywords: groundwater quality, septic tank, Nitrate Pollution Index, Chronic Health Risk index, rural communities, Al Hoceima.

INTRODUCTION

Water, as an essential life-sustaining resource for all living organisms, demands heightened scrutiny, particularly considering the significant risks it encounters due to human activities. The decrease in rainfall and the increase in temperatures resulted in a lack of water in the study area. therefore, several rural communities depend on groundwater as a source of drinking water (Taher et al., 2023a). Groundwater has been the favored source of drinking water owing to its superior safeguarding against pollution when compared to surface water. However, groundwater contamination has emerged as a significant environmental concern, necessitating the assessment of the hydrochemical quality of groundwater that is meant for consumption (Ramalingam et al., 2022). One of the most distressing problems is the consumption of nutrients from poor-quality groundwater, which exposes the population to potential health risks (El Khodrani et al., 2016).

Groundwater holds immense significance for the advancement of Morocco's water sector (Azzirgue et al., 2022), Ensuring the safeguarding and conservation of these vital water resources poses a substantial challenge, particularly within rural regions. (Ez-zaouy et al., 2022). The link between untreated domestic wastewater and the pollution of surface water and groundwater is a contributing factor to a range of diseases that impact populations globally (Bouderbala, 2019; Mchiouer et al., 2022). In 2020, the World Health Organization (WHO) stated that over 1.7 billion people, accounting for more than 21% of the global population, continue to lack essential sanitation services, including private toilets or latrines.

Septic tanks are frequently used in rural areas as a conventional approach to wastewater treatment. Therefore, the unregulated infiltration of wastewater from septic tanks can contaminate groundwater, thus causing various health risks (Houéménou et al., 2020). Hence, it becomes imperative to conduct thorough research and gain a comprehensive understanding of the repercussions stemming from the infiltration of effluents from septic tanks on groundwater quality, particularly in regions characterized by high population density. Numerous research efforts have therefore been devoted to this question because of its remarkable importance (Close, 1989; Lu et al., 2008; Mallick et al., 2021). The neighboring rural centers of the Giss-Nekor plain use individual septic tanks, due to the absence of sewerage networks, which can lead to the contamination of groundwater resources intended for consumption.

In the Al Hoceima region, the treated drinking water from the wastewater treatment plant is known for its unappealing chlorine taste, prompting residents to seek alternative sources like wells and spring water for their consumption needs (Benaissa et al., 2023). However, it is worth noting that groundwater has the potential to transport contaminants both vertically to the phreatic table level and horizontally through the aquifer, as Salhi observed in 2008. Numerous studies conducted in this area consistently highlight a significant decline in groundwater quality. Notable among these studies are the works of, Benyoussef et al. (2021), and Mchiouer et al. (2022a), which employed Principal Component Analysis (PCA) and bacteriological analyses. Additionally, Benaissa et al. (2023), utilized the Water Quality Index (WQI) in their investigations. Chafouq et al. (2018), and Nouayti et al. (2022), employed multiple isotopic tracers in their research. El Yousfi et al. (2023), utilized the GIS-based DRASTIC Model, while Bourjila et al. (2023), their study focused on the evaluation of quality degradation by seawater intrusion between 2015 and 2022 using hydrochemical methods and GIS-based analysis. These studies collectively emphasize the concerning state of groundwater quality in the study area. However, these studies neglect the use of some indices that have demonstrated their importance in numerous studies on water quality carried out by various researchers around the world, specifically, the Nitrate Pollution Index (NPI) and the Chronic Health Risk (CHR), alternatively known as the Hazard Quotient (HQ). Integrating these indices could offer a more holistic insight into groundwater quality and its associated potential risks.

The NPI was employed in several studies conducted by El Mountassir et al. (2022), and Sehlaoui et al. (2022). Similarly, CHR was utilized in a single study conducted by Barakat et al. (2020). However, it is noteworthy that within the study area, there is a significant lack of utilization of these indices for assessing groundwater quality. In this context, our study aims to evaluate the groundwater quality and ascertain the level of contamination risk associated with the use of septic tanks in rural communities within the Al Hoceima province through the utilization of physicochemical parameters and effective indices, including the Water Quality Index (WQI), Nitrate Pollution Index (NPI), and Chronic Health Risk (CHR).

MATERIALS AND METHODS

Study area

The study area (Fig. 1) is situated within the Rif Mountain belt, in the northeastern part of Morocco, specifically 10 km southeastern Al Hoceima city. It spans between the longitudes 3°54'-3°48'W and latitudes 35°12'-35°8'N. Encompassing a total area of approximately 38 km², this region is intersected by two rivers, namely Ghiss and Nekor. The highest elevation within this area reaches 565 meters above sea level, while the

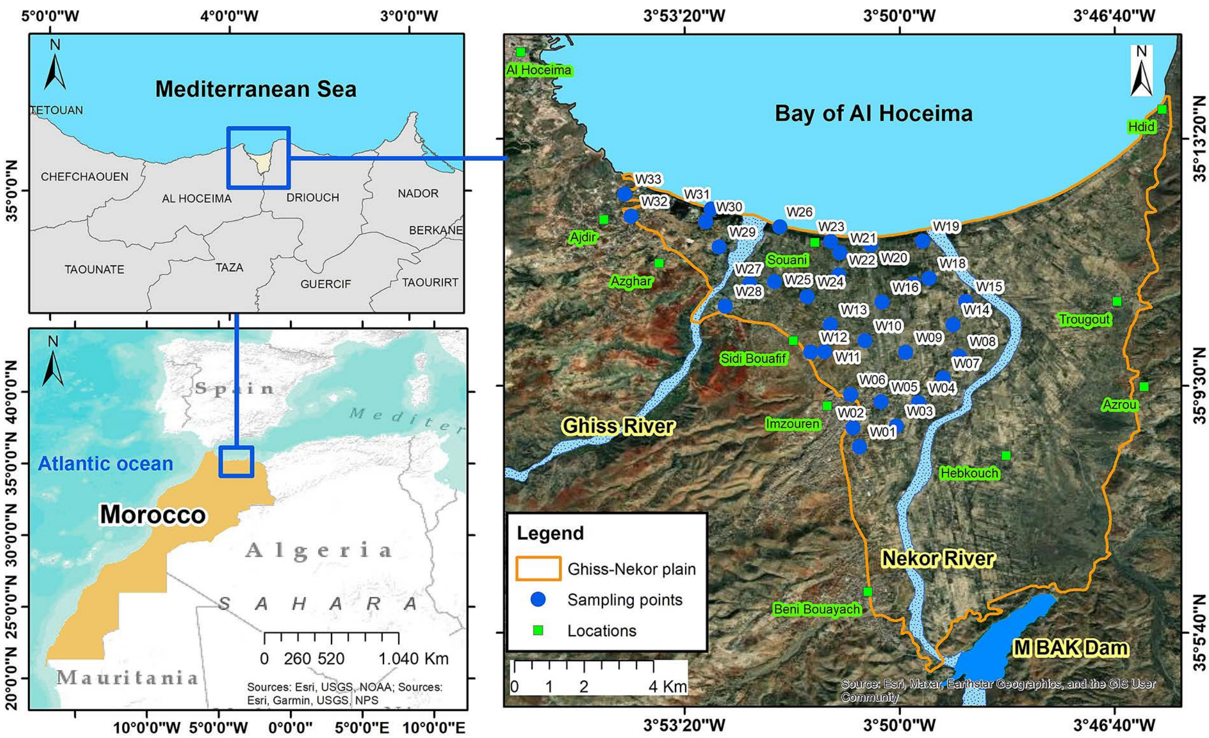

Figure 1. Locations of sampling sites in the study area

lowest point lies at an altitude of 3 meters. The study area experienced irregular annual rainfall over 51 years, fluctuating between 152 mm in 1968 and 624 mm in 2009. Precipitations have tended to decrease in recent years, as shown in Figure 2. Coinciding with this trend, temperatures have increased (Fig. 3), creating conditions conducive to severe drought.

Geologically, the study area resides in the northeastern section of the Rif, characterized by a triangular graben basin with an average altitude of 20 meters, as highlighted by Taher and Mourabit (2019). This basin is bordered by two active faults: Imzouren (NNW-SSE) on the Western side and Trougout (N-S) on the Eastern side (Poujol et al., 2014). The study area appears to represent a basin primarily filled with continental sedimentary deposits, primarily transported by the Nekor and Ghiss rivers. This basin has seemingly experienced subsidence since at least the Pliocene era, as indicated by the substantial thickness of the Plio-Quaternary deposits, as suggested by Poujol (2014). In more recent times, the Quaternary period has dominated the basin's geological composition, evident through the presence of conglomerates, sandstones, and plateau silts carried by the Ghiss and Nekor rivers (Salhi, 2008).

According to the 2014 General Population and Housing Census, the province of Al Hoceima had a total population of 399654 residents, of which 262285 people resided in rural areas, making up 65.62% of the total population. Specifically,

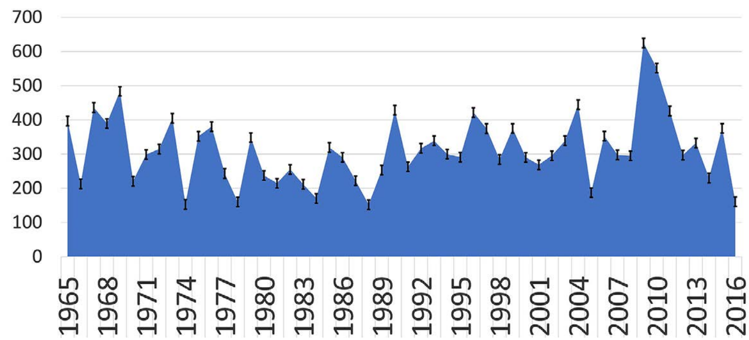

Figure 2. Histogram of annual precipitations in the Al Hoceima station (1964–2016)

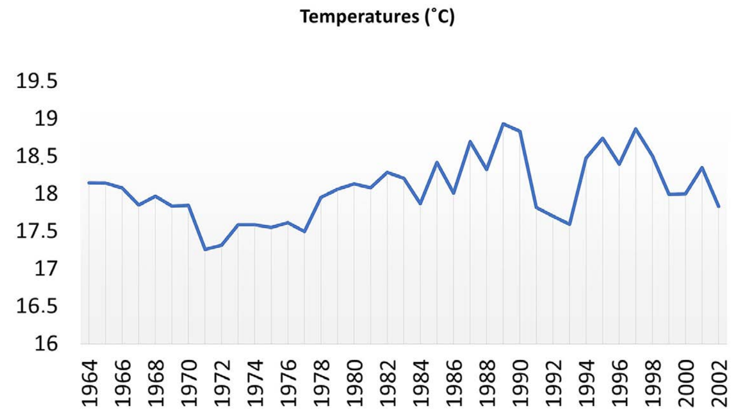

Figure 3. Histogram of annual temperatures in the Al Hoceima station (1964–2002)

within the rural municipality of Ait Youssef Ou Ali, which includes our study area, there was a significant population increase of 1.78% observed between the years 2004 (10619 inhabitants) and 2014 (12673 inhabitants). According to the projections of the High Commissioner for Planning (HCP, 2022), this demographic trend should continue to reach 21373 inhabitants by 2030. The coastal aquifer of Ghiss-Nekor stands out as the most prolific groundwater reservoir within the Al Hoceima province, as highlighted by Chafouq et al. (2018). Its significance emanates from the extensive deposits of coarse sands, gravels, and occasional mixtures of silts and clays found in the Ghiss-Nekor alluvial plain, which stretches adjacent to the coastline. This unique composition gives rise to the distinctive monolayer characteristic of the Ghiss-Nekor aquifer. Owing to its inherent heterogeneity, certain zones of the aquifer are confined, while others remain unconfined, as discussed by Bourjila in 2023. The study area is characterized by a dynamic agricultural activity, highlighting cereal cultivation, goat breeding, and the cultivation of fig trees and oleanders, as highlighted by Benichou et al. (2017). Regarding industrial development, the region is experiencing limited growth, with only a handful of metallurgical and agri-food establishments, as well as a dense concentration of oil mills. Located in a rural community, the inhabitants of the research area often rely on private wells to obtain drinking water and use septic tanks for sewage disposal. However, this practice contributes significantly to the pollution of groundwater, thus impacting the quality of drinking water, knowing that the depth of the groundwater table in the studied area remains shallow, not exceeding a few meters near the coast (Souani Plain) (Chafouq et al., 2018).

Collection and physicochemical examination of groundwater

In February 2023, a total of 33 groundwater samples were gathered from wells located within the designated study area. The exact locations of these wells can be visualized in Fig. 1. Throughout the sampling period, a meticulous procedure was followed: the sampling bottles underwent thorough rinsing, repeated two or three times, using the specific groundwater slated for sampling. The collection, storage, and transportation of these samples adhered to the guidelines outlined in the publication "Water Analysis (9th Edition)" (Rodier et al., 2009). The selected wells were categorized into two distinct groups. The first group comprised wells sited in regions with elevated population density. In contrast, the second group consisted of wells positioned in areas characterized by a lower population density but marked by significant agricultural operations. These wells were primarily designated for supplying domestic water and supporting irrigation needs.

Fifteen physicochemical parameters were measured in this study which are: hydrogen potential (pH), temperature (T°C), electrical conductivity (EC), and concentrations of the main cations and anions: sodium (Na^+), potassium (K^+), magnesium (Mg^{2+}), calcium (Ca^{2+}), ammonium (NH_4^+), bicarbonates (HCO_3^-), nitrates (NO_3^-), nitrites (NO_2^-), chlorides (Cl^-), sulfates (SO_4^{2-}), orthophosphate (PO_4^{3-}), and silica (SiO_2). The T °C, pH, and EC were measured using a PCE-PHD 1 Multimeter (PCE instruments), the Na^+ and K^+ with the Flame Photometer (Model: ELICO CL 378) (accuracy ± 0.5 ppm), the Ca^{2+}, Mg^{2+} using Titration with EDTA, the Cl- with the titration with silver nitrate (0.1 N), HCO_3^- using the titration with hydrochloric acid (0.1 N), and for the elements NO_3^-, NO_2^-, NH_4^+, PO_4^{3-}, SO_4^{2-} and SiO_2, the colorimetric determination method using a UV-VIS spectrophotometer (LANGE HACH DR-6000) was used (accuracy ± 1 nm).

Drinking water quality assessment

Water Quality Index (WQI)

The WQI has been widely used around the world in research efforts focused on water quality assessment and frequently used worldwide in studies related to water quality assessment, in China by Pei-Yue et al. (2010), and Zhang et al. (2020), in Nigeria by Unigwe et al. (2022), in India by Banerji and Mitra (2019), Ram et al. (2021), Kumar et al. (2022), Panneerselvam et al. (2023a), in Turkey by Karakuş and Yıldız (2020), in Algeria by Rezig et al. (2023), in Morocco by Barakat et al. (2018a), Azzirgue et al. (2022), Bahir et al. (2022), and El Mountassir and Bahir (2023). In the study area, three studies applied the Water Quality Index (WQI) to evaluate groundwater quality. These researches were conducted by Benaissa et al. (2023), Benaissa et al. (2022b), and El Yousfi et al. (2023b).

The quality of groundwater was determined using the equations of WQI with the Moroccan standards (NM 03.7.001) for drinking water, 14 critical parameters (pH, EC, TDS, Na^+, K^+, Mg^{2+}, Ca^{2+}, Cl^-, SO_4^{2-}, HCO_3^-, NO_3^-, NO_2^-, NH_4^+ and PO_4^{3-}) were selected to calculate the WQI (El Mountassir and Bahir, 2023; Panneerselvam et al., 2020; Zhang et al., 2020). To calculate the Water Quality Index, the first step is to give a weight of importance (wi) to the 14 parameters. This relative weight depends on the relative importance of the influence on water quality and human health, it varies from 1 to 5 as indicated in Table 1. A weight limit of 5 has been allocated for NO_3^-, NO_2^-, NH_4^+, PO_4^{3-} and TDS, weight of 4 for EC, weight of 3 for pH, Na^+, Cl^- and SO_4^{2-}, weight of 2 for Mg^{2+}, Ca^{2+} and HCO_3^-, and weight of 1 for K^+. The equation 1 was employed to calculate the relative weight (Rwi) for each parameter (Karakuş and Yıldız, 2020) :

$$Rwi = \frac{\text{wi}}{\sum_{i=1}^{n} * wi} \quad (1)$$

where: *wi* – represents the weight assigned to each parameter, *n* – signifies the total number of parameters. The subsequent phase involves assessing the quality rating scale (qi) for each parameter, following the criteria outlined in Moroccan standards (NM 03.7.001), and multiplying the result by 100 according to the following Equation 2: (Bawoke en Anteneh, 2020) :

$$qi = \frac{Ci}{Si} * 100 \quad (2)$$

where: *Ci* – denotes the concentration of physicochemical parameters in each water sample

Table 1. Calculating QWI for drinking water with Moroccan Standard NM 03.7.001: weights (*wi*) and relative weights (*Rwi*) of chemical parameters

Parameters	Units	NM 03.7.001 (Si)	Weight (*Wi*)	*Rwi=Wi/∑Wi*
pH	-	8.5	3	0.063
EC	µS/cm	2700	4	0.083
TDS	mg/l	1000	5	0.104
Na		200	3	0.063
K		12	1	0.021
Mg		150	2	0.042
Ca		200	2	0.042
Cl		750	3	0.063
SO_4		400	3	0.063
HCO_3		120	2	0.042
NO_3		50	5	0.104
NO_2		0.5	5	0.104
NH_4		0.5	5	0.104
PO_4		0.5	5	0.104
			∑Wi= 48	∑Rwi= 1

measured in mg/l, *Si* – represents the corresponding Moroccan drinking water guideline for each chemical parameter, also measured in mg/l. The third step involves calculating the *WQI* using Equation 3:

$$WQI = \sum_{n=1}^{n} Rwi * qi \quad (3)$$

The WQI values have been grouped into five categories, as shown in Table 2 (Yidana en Yidana, 2010).

Nitrate Pollution Index

The presence of nitrates (NO_3^-) in groundwater is regarded as one of the most significant issues contributing to the degradation of groundwater quality (Stadler et al., 2012). The Nitrate Pollution Index (NPI) is a valuable tool for assessing the level of groundwater pollution resulting from increased concentrations of NO_3^- (Panneerselvam et al., 2020). It measures the extent of pollution related to the presence of high concentrations of nitrates in groundwater (Das et al., 2023; Xiao et al., 2022). The NPI is an effective index for determining the level of nitrate pollution in groundwater. It can be calculated using the equation 4:

$$NPI = \frac{Cn - Hav}{Hav} \quad (4)$$

where: *Cn* – represents the observed concentration of nitrate in the sample, while *Hav* signifies the acceptable nitrate threshold for human consumption, set at 20 mg/l (Panneerselvam et al., 2023b, 2020).

Chronic Health Risk Index (CHR)

Given the substantial health risks associated with the consumption of groundwater contaminated with nitrates (NO_3^-), as evidenced by studies conducted by Adimalla and Li (2019) and Li et al. (2014), we utilized the Chronic Health Risk Index (CHR), also referred to as the Hazard Quotient index (HQ), to evaluate the non-carcinogenic health risks linked to the ingestion of NO_3^- contaminated groundwater. This assessment is specifically focused on both children and adults, as supported by research conducted by Adimalla and Li (2019), Rao et al. (2021), and Zhang et al. (2020). In the context of this study, the assessment of chronic health risks is focused on the concentration of nitrate in groundwater. These risks manifest themselves in two discernible categories: carcinogenic and non-carcinogenic hazards, as detailed by Panneerselvam et al. (2020). The study focused on the evaluation of two distinct age cohorts, namely children and adults, residing in the study area, considering the increased concentration of nitrates in groundwater. To do this, the injection exposure of children and adults to groundwater was calculated using the formula described by Das et al. (2023) (Equation 5):

$$AD = \frac{IC * IR * ED * EF}{BW * ET} \quad (5)$$

where: *AD* – stands for the average daily exposure dose (measured in mg/kg/day), *IC* – represents the ionic concentration in groundwater (measured in mg/l), *IR* – denotes the ingestion rate, *ED* – signifies the exposure duration, *EF* – stands for the exposure frequency, *BW* – represents the average body weight, and *ET* – signifies the average exposure time. The reference values of the parameters used for the calculation are presented in the Table 3.

Toxicity's impact originates from the interplay between the exposure dose and the ionic concentration surpassing acceptable thresholds. This toxicity is rooted in the connection between exposure dose and ionic concentration that goes beyond permissible limits, leading to what is known as chronic health risk. The calculation of CHR involves the Equation 6:

$$CHR = \frac{AD}{R} \quad (6)$$

where: *R* – represents the secure dose for chronic oral exposure, standing at 1.60 mg/kg/day for NO_3^-.

Table 2. Proposed water quality classification according to WQI (Yidana en Yidana, 2010)

WQI (Range)	Type of water
<50	Superior water
50–100	High-quality wate
100–200	Low-quality water
200–300	Very low-quality water
> 300	Not suitable for consumption

Data processing

The acquired data underwent a comprehensive analysis using a range of methodologies, including descriptive statistics, the application of the Water Quality Index, assessment through the

Table 3. Standards value for health risk assessment (Das et al., 2023)

Parameters	Units	Children	Adults
IR	(L/day)	1	2
ED	(Years)	12	30
EF	(Days/years)	365	365
BW	(kg)	20	60
ET	(days)	4380	10950

Nitrate Pollution Index, evaluation of the Chronic Health Risk Index, and the creation of spatial distribution maps for hydrochemical parameters utilizing GIS software. The IBM SPSS STATISTICS software (version 25) was used to produce the descriptive statistics. To spatially plot the hydrochemical parameter, we used the ArcGIS 10.8 software. To create the various graphical plots and calculation indices, we used Origin Pro 2021 and Microsoft Excel 365.

Geospatial mapping

The spatial distribution of the computed indices was conducted employing the inverse distance weighting (IDW) interpolation technique within the spatial analysis tool of ArcGIS 10.8 software. IDW operates as a deterministic methodology, estimating values by averaging across established points while assigning greater weight to adjacent locations. Moreover, the application of the IDW method has demonstrated swiftness, user-friendliness, and a capacity to yield precise and impactful outcomes, as evidenced by Bourjila et al. (2021), and Taher et al. (2023b).

RESULTS AND DISCUSSION

General hydrochemistry of groundwater

The utilization of septic tanks in rural and periurban areas significantly contributes to groundwater pollution. The shallow nature of the groundwater table in the study area amplifies the risk of contamination, stemming from the discharge of household wastewater. As documented in various literature sources, untreated domestic wastewater carries elevated levels of dissolved solids, encompassing sodium, chloride, nitrogen, and orthophosphate, among others, as indicated by Lu et al. (2008), Reay (2004), and Withers et al. (2011). The outcomes stemming from the analysis of the groundwater's physicochemical attributes have been methodically compiled within Table 4. It is important to emphasize that the selection of groundwater samples was

Table 4. Statistical analysis of groundwater samples in the study area

	Unit	Mean	Median	Mode	Minimum	Maximum	Std. dev	Skewness
pH	-	7.44	7.39	7.28	6.70	8.08	0.37	0.01
TDS	mg/l	3223.19	2710.03	1508.63	1508.63	8289.80	1553.26	2.04
EC		4095.45	3460.00	2520.00	2080.00	10650.00	1859.60	2.10
Na^{2+}		507.97	437.40	233.00	233.00	1710.00	314.02	2.47
K^{+}		10.83	8.90	3.90	2.30	31.70	7.92	1.11
Mg^{2+}		149.01	129.30	106.56	57.60	367.68	62.93	1.59
Ca^{2+}		254.41	251.70	243.67	59.32	415.21	68.89	-0.16
Cl^{-}		817.25	631.90	432.53	354.53	3027.69	591.58	2.72
SO_4^{2-}		978.11	930.11	410.00	410.00	1592.25	284.46	0.36
HCO_3^{-}		358.98	341.60	286.70	152.50	512.40	86.89	-0.17
NO_3^{-}		25.34	18.09	0.00	0.00	89.63	22.52	1.52
NO_2^{-}		0.04	0.00	0.00	0.00	1.37	0.24	5.74
NH_4^{+}		0.02	0.00	0.00	0.00	0.14	0.03	2.56
PO_4^{3-}		0.04	0.02	0.00	0.00	0.61	0.10	5.35
SiO_2		11.47	13.29	13.29	5.38	20.66	4.27	-0.06

undertaken to assess the influence of the substantial population density within the Al Hoceima region on groundwater quality.

The pH measurements encompass a range from 6.7 (observed in well 25) to 8.08 (observed in well 29), all of which fall within the recommended thresholds set forth by the World Health Organization (WHO) guidelines in 2011. The average pH value recorded stands at 7.44. It's noteworthy that a significant proportion, specifically 87.8%, of the aquifer water within the study area registers a pH above 7, indicating a slightly alkaline characteristic of the groundwater. Electrical Conductivity (EC) stands as a dependable indicator for evaluating water mineralization levels holistically. Within the study area, EC values span from 2.080 to 10.650 µS/cm, culminating in an average of 4095.45 µS/cm. This average exceeds the established EC limit for drinking water, which is 1500 µS/cm by the WHO in 2008, and 2700 µS/cm per Moroccan standards (NM 03.7.001.2006). All samples exhibit values surpassing the WHO's recommended levels, with 84.85% of samples surpassing the maximum permissible limits within Morocco (as depicted in Fig. 4a). The elevated EC readings imply an accumulation of salts in the groundwater, with this heightened salinity potentially attributed to human activities, as pointed out by Youmbi et al. in 2013. Hence, the EC can be categorized as follows: type I (low enrichment

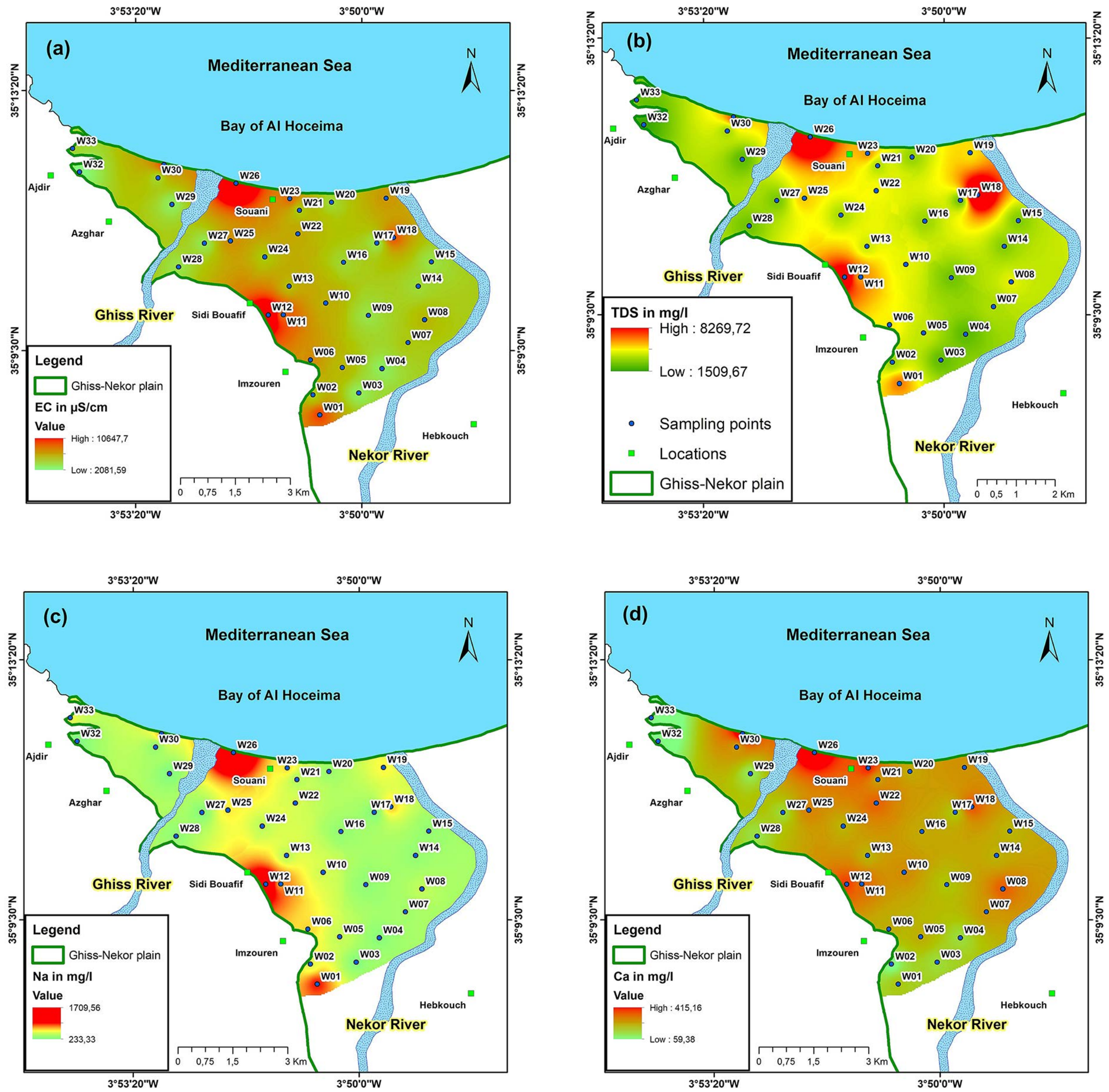

Figure 4. Spatial distribution of hydrochemical parameters: (a) EC, (b) TDS, (c) Na^+, (d) Ca^{2+}, (e) Mg^{2+}, (f) K^+, (g) NH_4^+, (h) SO_4^{2-}, (i) Cl^-, (j) HCO_3^-, (k) NO_3^-, (l) NO_2^-, (m) PO_4^{3-}

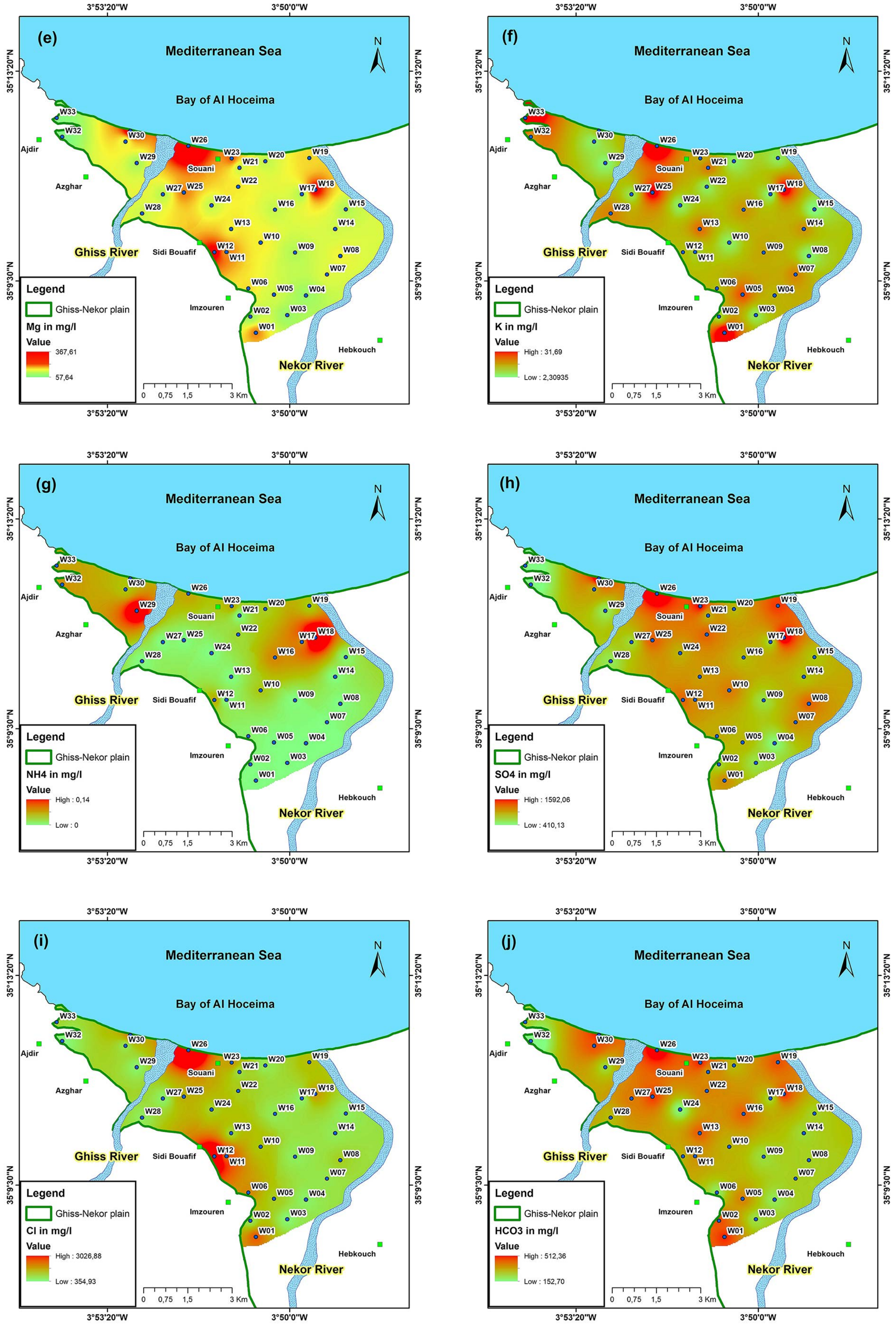

Figure 4. Cont. Spatial distribution of hydrochemical parameters: (e) Mg^{2+}, (f) K^{+}, (g) NH_4^{+}, (h) SO_4^{2-}, (i) Cl^{-}, (j) HCO_3^{-}, (k) NO_3^{-}, (l) NO_2^{-}, (m) PO_4^{3-}

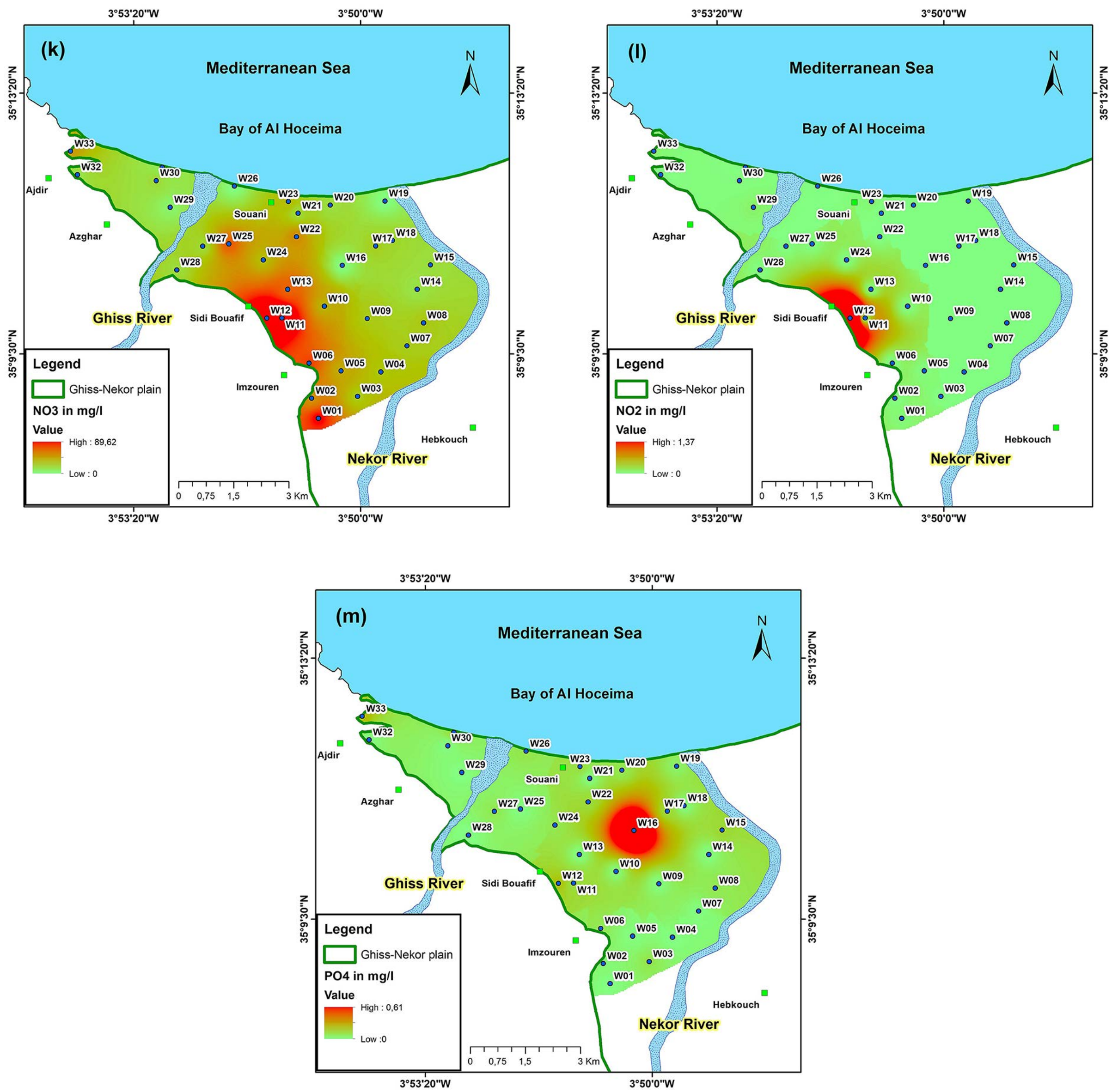

Figure 4. Cont. Spatial distribution of hydrochemical parameters: (k) NO_3^-, (l) NO_2^-, (m) PO_4^{3-}

of salts) when EC<1500 µS/cm; type II (medium enrichment of salts) for moderate salt enrichment when 1500 µS/cm < EC < 3000 µS/cm; and type III (high enrichment of salts) when EC>3000 µS/cm. According to this EC classification, 72.73% of the total groundwater samples are type III; 27.27% are type II, and no samples are classified as type I (Table 5) (Subba Rao et al., 2012).

The calculation of total dissolved solids (TDS) employs the formula: TDS = Σ cations + Σ anions (Bourjila et al., 2023). Analysis of groundwater samples revealed TDS values ranging from 1508.63 mg/l to 8289.8 mg/l, with an average of 3223.19 mg/l (Table 4). Notably, all samples analyzed surpassed both WHO and Moroccan standards (1000 mg/l). Specifically, the wells exhibiting the highest TDS concentrations are as follows: W12 (6270.64 mg/l), situated in the vicinity of a densely populated zone (between Imzouren and Sidi Bouafif), hinting at potential contamination from widely used septic tanks in this area; W26 (7653.06 mg/l), positioned near the coastline, suggesting contamination due to seawater intrusion (Benaissa et al., 2023; Bourjila et al., 2023; Chafouq et al., 2018); and W18 (8289.8 mg/l) within a region characterized by intensive agricultural activity (Fig. 4b and Fig. 5), possibly indicating contamination due to the heavy utilization of fertilizers in the rural agricultural setting. The concentrations of various cations exhibit the following ranges: Na^+ (233 to 1710 mg/l), Ca^{2+} (59.32 to 415.21 mg/l), Mg^{2+} (2.3 to 31.7 mg/l), K^+ (0 to 0.137 mg/l), and NH_4^+ (0 to 0.137 mg/l).

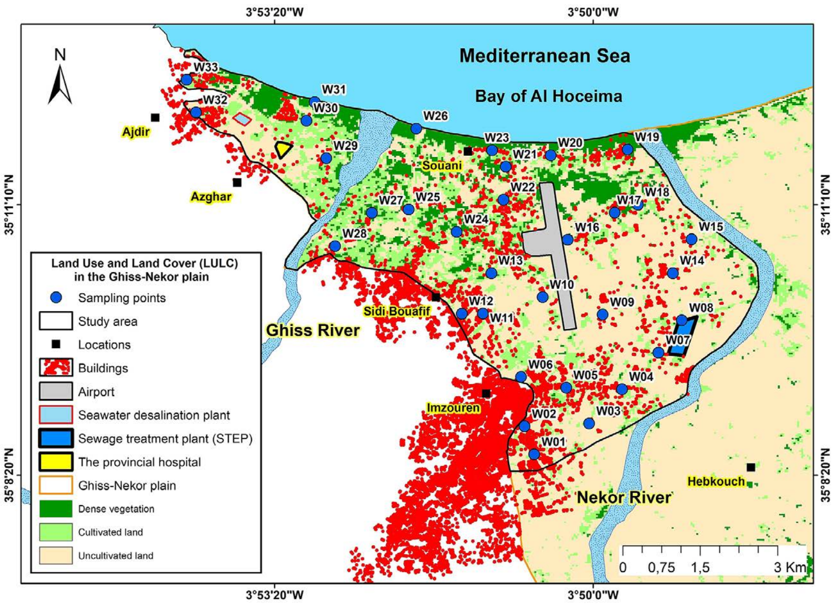

Figure 5. Land use and land cover (LULC) map of the study area

Table 5. Classes of drinking groundwater based on EC (Enrichment of salts) (Subba Rao et al., 2012)

EC (µS/cm)	Water classes	Number of samples	% of samples
1<1500	Type I (low)	0	0%
1500-3000	Type II (medium)	9	27.27%
>3000	Type III (high)	24	72.73%

Among the anions, the values for SO_4^{2-} range from 410 to 1592.25 mg/l, Cl^- from 54.53 to 3027.69 mg/l, HCO_3^- from 152.5 to 512.4 mg/l, NO_3^- from 0 to 89.62 mg/l, NO_2^- from 0 to 1.37 mg/l, and PO_4^{3-} from 0 to 0.61 mg/l (Fig. 4c–m). The sequence of cation abundance was determined as follows: $Na^+ > Ca^{2+} > Mg^{2+} > K^+ > NH_4^+$, with proportions of 55.08%, 27.59%, 16.16%, 1.17% and 0.002%, respectively. While the anion order was found to be $SO_4^{2-} > Cl^- > HCO_3^- > NO_3^- > PO_4^{3-} > NO_2^-$, with percentages ranging from 44.87%, 37.49%, 16.47%, 1.16%, 0.002%, and 0.002%, respectively. The same order of abundance was obtained by previous studies in the same study region, such as Bourjila et al. (2021), and Ghalit et al. (2017).

Na^+ is also prevalent in various foods and human activities. Within the study area, Na+ concentrations consistently surpass the recommended limit of 200 mg/l as stipulated by both WHO and Moroccan standards. Calcium (Ca^{2+}), owing to its abundance in minerals and rocks and its solubility, is naturally present in groundwater. Nevertheless, all groundwater samples examined within the study area exceed the permissible WHO limit of 75 mg/l, apart from a lone sample (W33), as indicated in Table 4. Potassium (K^+) emerges as the least concentrated ion, with 39% of samples exceeding both WHO and Moroccan standards (12 mg/l). The presence of K^+ arises from processes such as the alteration of potassium clay and the dissolution of chemical fertilizers used in agricultural practices, like NPK (Nitrogen N, Phosphorus P, and Potassium K), as well as potential contributions from domestic and industrial discharges.

Ammonium (NH_4^+) contents across all samples fall in line with both WHO and Moroccan drinking water standards, registering values of 0.2 and 0.5 mg/l, respectively. Sulfate (SO_4^{2-}) levels in all analyzed groundwater samples surpass both WHO (250 mg/l) and Moroccan (400 mg/l) standards. The notably elevated sulfate values in the study area suggest a multifaceted origin, potentially stemming from the dissolution of gypsum present in the marl substrate, the use of fertilizers in agriculture, evaporation, or untreated wastewater discharge from conventional septic tanks.

The range of bicarbonate (HCO_3^-) concentration spans from a maximum of 512.4 mg/l to a minimum of 152.5 mg/l, with an average of

358.97 mg/l. Significantly, all samples surpass both WHO and Moroccan standards (set at 120 mg/l). Nitrate (NO_3^-) concentrations exhibit variability from 0 to 89 mg/l, culminating in an average of 34.16 mg/l. Groundwater nitrate contamination within the study area can be attributed to either wastewater discharge, as observed by Chen et al. (2017), and Das et al. (2023), or the application of chemical fertilizers, as indicated by Unigwe et al. in 2022. It's crucial to note that consuming water tainted with nitrates can lead to severe illnesses, as pointed out by Barakat et al. (2020), and Rao et al. (2021). Elevated NO_3^- presence in the bloodstream impedes proper oxygen binding by hemoglobin, a key contributor to "blue infant disease," also known as "methemoglobinemia" (Majumdar, 2003). Nitrite is classified as a potential carcinogen by the International Agency for Research on Cancer (IARC), an organization established in 1965 under the auspices of the World Health Organization (WHO) of the United Nations. Within the study area, a mere 28 out of 33 wells, corresponding to 84.84 %, display zero nitrite values. Only one sample (W12) registers a value of 1.37 mg/l, surpassing the Moroccan standard of 0.2 mg/l. This well, situated near Imzouren, reaches a depth of 38 meters, and is situated in a region lacking sewerage networks for its habitations. This scenario alludes to potential contamination originating from septic tanks utilized by these residences.

Assessment of water quality

Water Quality Index

The Water Quality Index was calculated for 33 samples following Moroccan standards. Out

Table 6. Drinking water quality classification using Moroccan standards (NM 03.7.001)

WQI (Range)	Type of water	N of samples	% of samples
<50	Outstanding water	0	0%
50–100	High-quality water	15	45.45%
100–200	Subpar water	15	45.45%
200–300	Very subpar water	3	9.10%
>300	Not suitable for consumption	0	0%

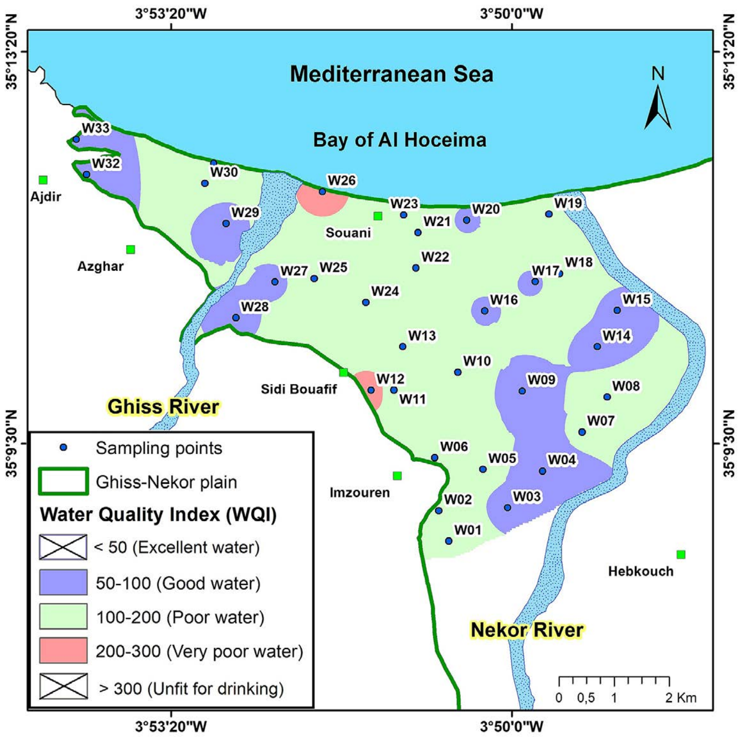

Figure 6. Geospatial assessment of water quality using WQI in the study area

of these, fifteen samples (45.45%) were classified as having good water quality, while fifteen wells (45.45%) exhibited poor water quality. Additionally, three wells (9.10%) were found to have very poor water quality, make them unsuitable for drinking. These results are presented in Table 6 and Figure 6. In a similar vein, two studies by Benaissa et al. (2023) and El Yousfi et al. (2022) employed the WQI to assess groundwater quality performance in the study area.

Nitrate Pollution Index

Nitrate NO_3^- influences the quality of groundwater (Xiao et al., 2022). In the present study, the NPI values exhibit a range from -1 to 3.48, with 60.61% falling within the category of unpolluted. As demonstrated in Fig. 7, the spatial distribution of NPI reveals intriguing patterns. Notably, two wells W11 and W12 stand out with NPI values surpassing 3. These specific wells are situated within regions characterized by high population density (as depicted in Fig. 5), where the prevalent use of septic tanks is evident.

Chronic Health Risk Index

Chronic Health Risk Index was computed for two distinct age groups. The outcomes of non-carcinogenic health risks are presented in Table 7. Notably, CHR values ranged from 0 to 1.87, averaging at 0.53 for adults. Meanwhile, in the case of children, CHR values exhibited variability between 0 and 2.8, with an average value of 0.79. Figure 8 offers a visual representation of the spatial distribution of CHR for both children and adults. Regions of heightened health risk vulnerability are notably concentrated between Imzouren and Sidi Bouafif. This geographic area exhibits an intensified CHR exceeding the value of 1, indicative of elevated health risks associated with the utilization of septic tanks and wells used by the local population.

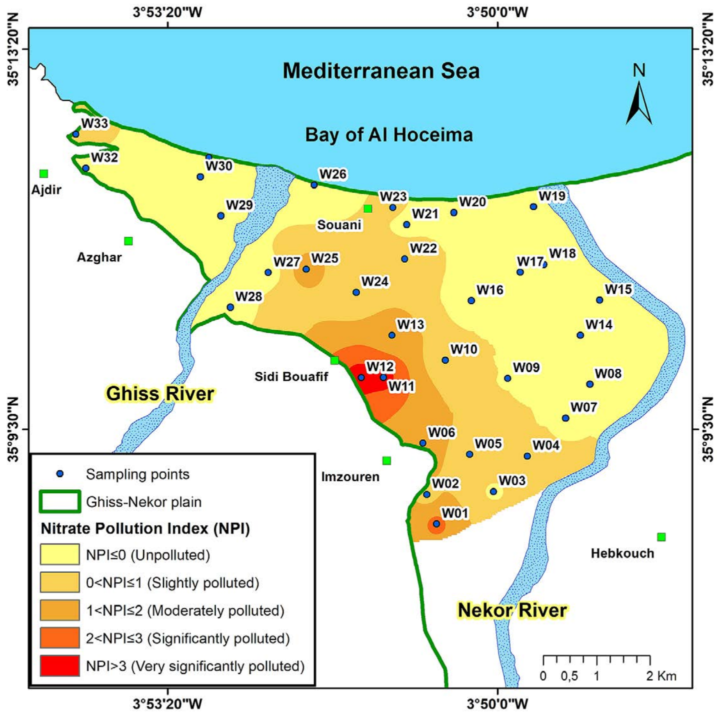

Figure 7. Spatial distribution of groundwater quality in the study area using NPI

Table 7. Assessment of Health Risks Associated with Nitrate Consumption Using CHR

CHR	Max	Min	Mean	Num	% of samples
Adults	1.87	0	0.53	5	15.15%
Children	2.8	0	0.79	8	27.27%

Note: Num – the count of groundwater samples surpassing the permissible threshold for CHR=1.

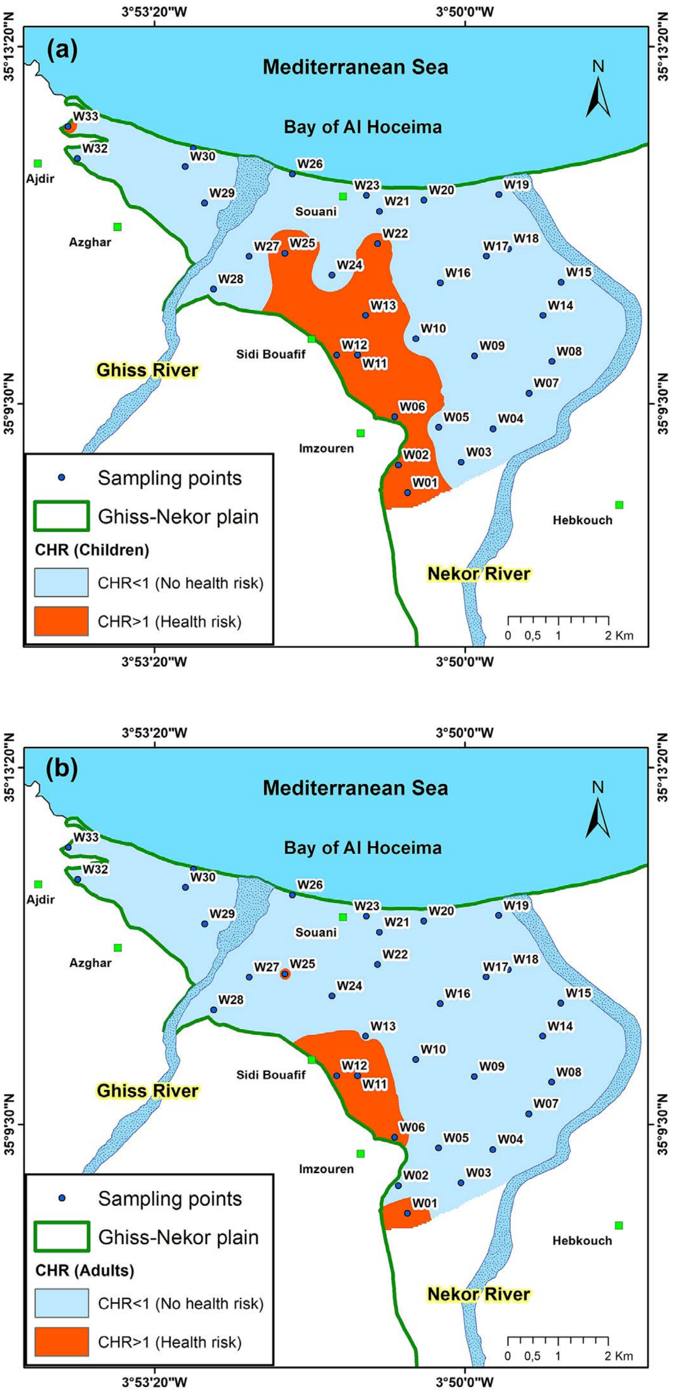

Figure 8. Cartographic representations displaying carcinogenic health risks for children (a) and adults (b)

CONCLUSIONS

The present study yielded significant findings. Among them, 72.73% of samples exhibited high salt enrichment, with Total Dissolved Solids (TDS) levels exceeding both WHO and Moroccan standards across all samples, indicating potential ecological concerns. The study also revealed that only 45.45% of samples met safe consumption criteria according to the WQI, raising a significant concern for human health. It was observed that areas with poor water quality tended to cluster around regions with high population density or proximity to the sea, emphasizing the impact of human activity and coastal factors. Additionally, the NPI values and their spatial distribution indicated the presence of anthropogenic pollution linked to nitrates in densely populated areas. Furthermore, CHR values demonstrated varying levels of risk for adults and children, particularly in wells W11 and W12 in densely populated areas. This suggests potential contamination by unregulated septic tanks, likely due to their proximity and the relatively shallow depth of the groundwater table. Given that groundwater serves as a vital source of consumption in this region, these results serve as a crucial warning for authorities and decision-makers regarding water resources. To address these concerns and improve the situation, further examinations, including bacteriological evaluations and heavy metal analyses, must be incorporated. Additionally, expanding the study area to encompass rural regions is essential. Measures should also be implemented to heavily preserve nitrogen-contaminated groundwater, thereby reducing health risks in this area. This comprehensive approach is crucial for safeguarding groundwater quality and public health in the study area.

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