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Appraisal of Groundwater Quality Status in the Ghiss-Nekor Coastal Plain

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ABSTRACT

Deterioration of water quality is of great concern, particularly in coastal aquifers where it has become difficult to meet water quality standards with appropriate salt content. As groundwater is the only alternative source of freshwater in the coastal plain of Ghiss-Nekor in northern Morocco, there is a need to assess its sustainability and suitability for drinking and irrigation purposes. For this purpose, data obtained from ABHL, corresponding to 13 monitoring wells existing in the downstream part of Ghiss-Nekor aquifer, were gathered and analyzed using a combination of statistical methods and GIS mapping tools. Various qualitative parameters namely; pH, turbidity, salinity, dissolved oxygen, conductivity, Chloride (Cl^-), Sulphate (SO_4) and some Nitrogen compounds were investigated and compared according to World Health Organization standards. These results suggest that groundwater samples are chemically dominated by chloride anions followed by sulphate anions; high levels of SO_4 result from the mineral dissolving of evaporites in addition to the impact of seawater intrusion and the discharge of wastewater without adequate pre-treatment, while Cl^- concentrations (408.3–1512.3 mg/L), strongly correlated with electrical conductivity, are related to the impact of seawater intrusion. A few samples along the Nekor River, considered as the aquifer's recharge zone, showed the lowest salinity levels (<1.5 g/L) compared to the coastal samples which were classified as the most conductive and mineralized (EC greater than 3000 µS/cm) due to the combined impact of mixing with seawater and high evaporation rates. The outcome of this study reveals that the major dissolved anions assessed in the groundwater of the Ghiss-Nekor aquifer do not respect the stipulated criteria in terms of human consumption; therefore, all possible measures should be taken to protect and restore the water quality in this vulnerable coastal aquifer.

Keywords: Ghiss-Nekor plain; Morocco; coastal aquifer; water-quality deterioration; WHO standards; salinity; dissolved anions.

INTRODUCTION

Worldwide, freshwater is a vital resource for humans and ecosystems, and its availability depends mainly on both the climate-driven global water cycle and on society's management capacity to store and conserve these precious resources. In fact, 99% of freshwater in the planet is found in aquifers, however, nowadays, only a limited proportion is accessible without expensive pumping costs and aquifers depletion due to the poor governance of water resources (Carugi, 2016, Bonokwane, 2022). The most valuable source worldwide is Groundwater, since it provides an important percentage of drinking water. The increase of consumption due to population growth and the mediocre management of this valuable resource caused a diminution of surface waters in different regions (Nagaraju, 2016, Gad, 2022). Groundwater is an alternative resource that prevents the degradation of surface waters which are poorly distributed in time and space. Several risks threaten groundwater, including anthropogenic activities, over-exploitation, and chemical pollution, which causes seawater intrusion and environmental degradation (Samani, 2021, Stanly, 2021). A wise groundwater management is needed in arid and semi arid areas (Yifru, 2020).

In most aquifers, changes in groundwater quality broadly depends, on the one hand, on natural processes such as dissolution, minerals precipitate, groundwater velocity, quality of recharge water, and interaction with other types of water aquifer, on the other hand, on anthropogenic external factors. The Ghiss-Nekor coastal plain, located in the North-east of Morocco, under the influence of semi-arid Mediterranean weather, was identified as a suitable case study, since groundwater pumping became the primary source of water supply for its increasing population and for local agriculture, consequently, the alluvial aquifer of the studied plain is more exposed to contamination due to its phreatic surface and its coarse nature. Moreover, the situation is more alarming due to the low hydraulic gradients and the unplanned heavy abstractions of groundwater in coastal areas, which increases even further the risk of contamination by seawater intrusion.

The primary objectives of this study consisted in evaluating the current status of groundwater quality in the studied area, and its suitability for drinking and irrigation purposes, by the determination of hydro-chemical properties (Nas, 2010, Zouhri, 2010) of groundwater samples extracted from 13 monitoring wells implemented by the Loukkos Hydraulic Basin Agency, based on data interpolation using GIS tools as well as statistical analysis.

MATERIALS AND METHODS

Brief description of the study area

The Ghiss-Nekor plain lies between the latitudes 35°13’, 35°05’,35°12’ North, and the longitudes 3°46’, 3°49’ and 3°54’ West, a dozen kilometers to the south east of Al Hoceima city as shown in Fig. 1, located in the North-East of Morocco. The proximity of Mediterranean Sea adds a maritime influence to the semi-arid climate that prevails in the region which receives a mean annual sporadic rainfall of 346 mm. The average annual temperature in the region lies of 18ºC (Salhi, 2008, El Hammoudani, 2021, Elabdouni, 2022). The study area encompasses a watershed of 1765 km² divided between Nekor and Ghiss sub-basins covering respectively an area of 911 and 854 km². The Ghiss-Nekor aquifer underlies a triangular area, extending over 100 km², and ranks as one of the most relevant groundwater reserves in the Rif belt. Groundwater in the study area is hydraulically linked with two main rivers; Oued Nekor which is streaming over the center of the valley on a length of 15 kilometers, and Oued Ghiss flowing for a length of 3 Kilometers along the downstream -stated in an unpublished report entitled Study to develop a water resources management plan for the Ghiss-Nekor basin prepared by ABHL (Loukkos Hydraulic Basin Agency) (Benaissa, 2020, El Abdouni, 2021).

From the geological point of view, this depression is bounded by water tight flysch facies except for the north-western and north-eastern peripheral sides marked by limestone banks and Plio-Quaternary Vulcanites. Towards the east, the plain is circumscribed by a sequence of alluvial fans deposited by tributary rivers. The valley-fill consists of Plio-Quaternary deposits comprising predominantly sand, pebble and gravel, sometimes inter bedded with silty-clayey particles. According to detailed geophysical and hydrogeological investigation -demonstrated in Fig. 2 - carried out by GeoAtlas company, the thickness of the alluvium layers varies from 5 to over 400 meters with an average of about 240 meters. The maximum thickness of 430 meters was observed near Imzouren and Souani villages; which reflects the hydrogeological significance of this coarse-grained thick sediments as they tend to form an important aquifer system due to their highly transmissive nature taken from an unpublished report entitled Study to develop a water resources management plan for the Ghiss-Nekor basin prepared by ABHL (Loukkos Hydraulic Basin Agency).

Data sources

The dataset used in this research form part of the groundwater quality monitoring network within Ghiss-Nekor watershed, implemented by the Loukkos Hydraulic Basin Agency (ABHL). The selected data were gathered in spring from 13 wells spread across the north-central and downstream (Fig. 3), known to be the most productive and vulnerable parts of the studied aquifer. Water samples were immediately stored in an icebox at 4°C and then analyzed within 24 hours in order to measure the levels of various physico-chemical parameters namely; depths to water level, dissolved oxygen, electrical conductivity, pH, temperature, salinity, and turbidity as well as the

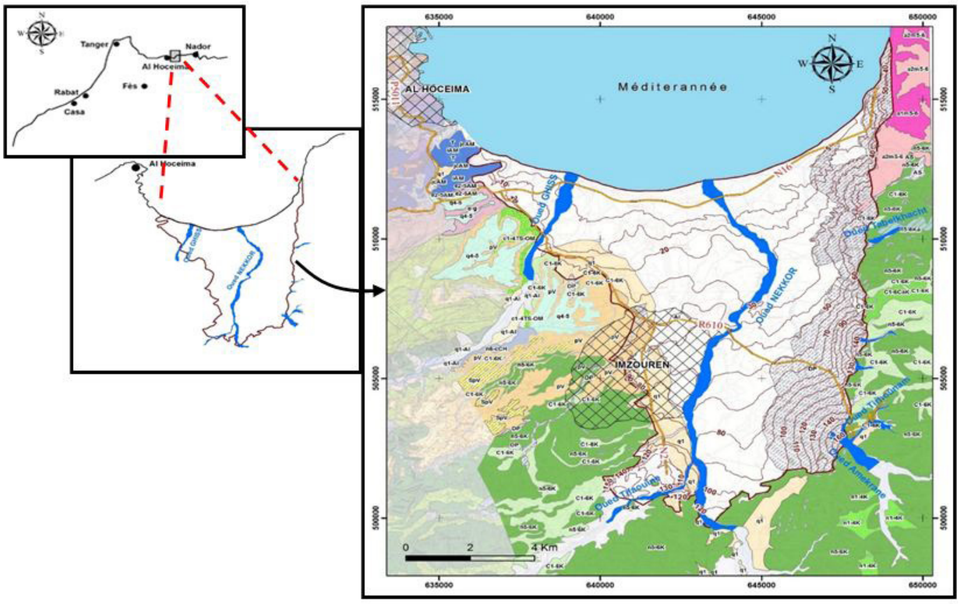

Fig. 1. Location map and boundaries of Ghiss-Nekor plain aquifer

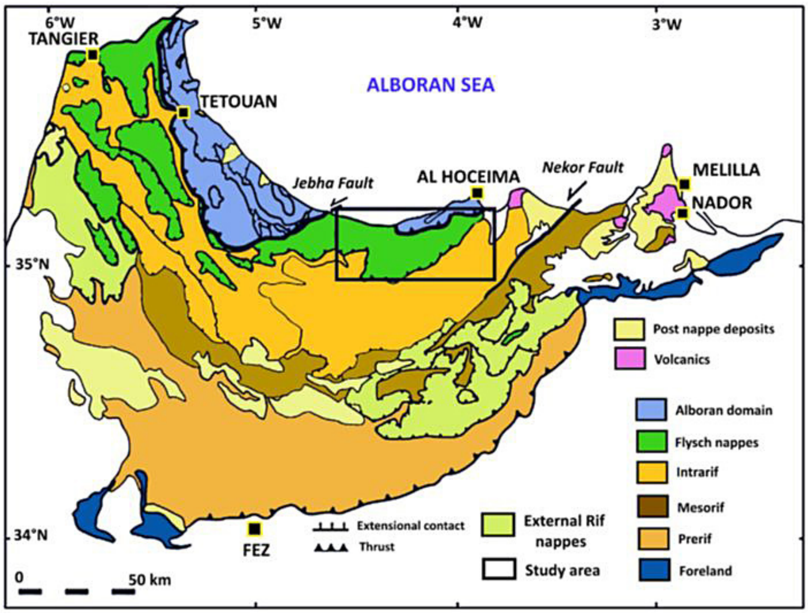

Fig. 2. Map showing the geologic boundaries and hydrogeological cross-section of Ghiss-Nekor aquifer

ionic composition (Rodier, 2009). Results interpretation relied on the hydrogeological context, statistical charts, and on the Inverse Distance Weighting interpolation procedure, conducted using ArcGIS 10.8.

RESULTS AND DISCUSSION

Table 1 provides a summary of the physicochemical properties obtained during groundwater monitoring performed by Loukkos Hydraulic Basin Agency in the downstream part of Ghiss-Nekor aquifer.

pH

A test of the acidity of water is pH, which is a measure of the hydrogen-ion concentration. The pH recorded values, varying between 7.25–7.7, are within the standard range for drinking water [6.5–8.5] set by the World Health Organization (Mohammed, 2017). Therefore, the groundwater type is slightly alkaline.

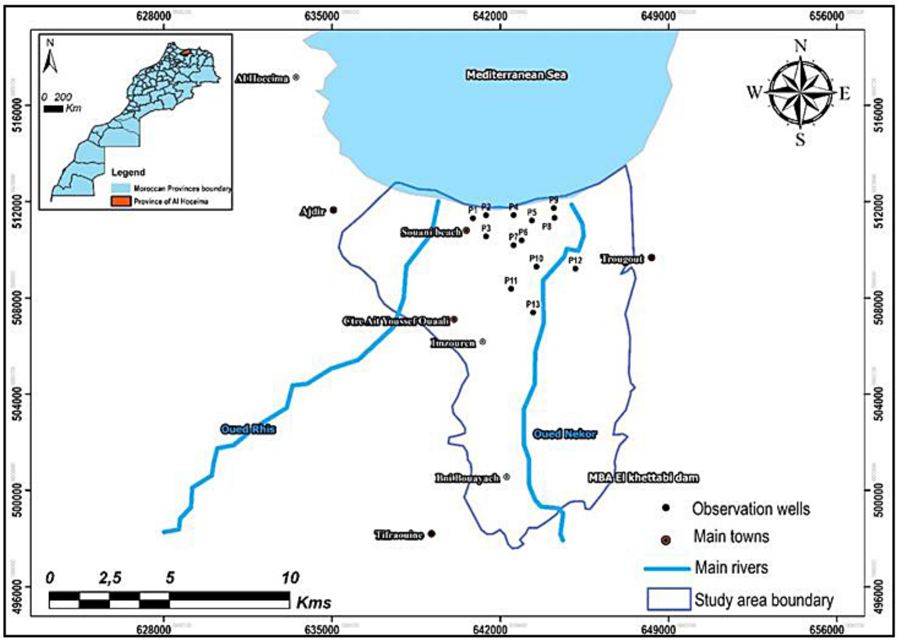

Fig. 3. Locations of the selected groundwater observation wells

Table 1. Summary of the location and concentrations of analytes

Sample	Longitude	Latitude	Depth of wells(m)	Dissolved oxygen mg/L	E.C µS/Cm	Salinity mg/l	pH	T°C	Cl^- mg/l	NO_3^- mg/l	NH_4^+ mg/l	NO_2 mg/l	SO_4^{2-} mg/l	Turbidity NTU
P1	3°51'6.7"W	35°11'35.3"N	15.4	2.5	6.5	3.1	7.3	23.1	1512.3	2.5	0.6	0.1	801.3	25.2
P2	3°50'45.3"W	35°11'39.3"N	13.4	2.8	5.8	2.7	7.4	22.6	1428.8	2.2	0.9	0.0	899.2	10.9
P3	3°50'45.8"W	35°11'10.5"N	18.7	2.7	4.1	2.2	7.4	22.2	1015.3	1.2	0.8	0.1	735.6	10.0
P4	3°49'59.9"W	35°11'38.9"N	14.5	3.4	5.9	2.9	7.4	21.9	892.0	1.1	0.3	0.1	720.8	10.0
P5	3°49'29.8"W	35°11'31.1"N	16.9	3.0	4.2	2.2	7.3	21.9	845.5	1.5	0.4	0.1	567.3	8.4
P6	3°49'47.3"W	35°11'4.5"N	21.1	3.8	3.5	1.8	7.4	21.5	987.8	1.8	0.3	0.0	616.8	7.8
P7	3°50'0.6"W	35°10'58.2"N	21.8	3.7	3.3	1.8	7.4	21.0	947.8	2.0	0.2	0.1	851.3	6.4
P8	3°48'52.8"W	35°11'34.1"N	17.5	3.9	3.0	1.7	7.4	20.7	515.3	1.9	0.3	0.2	533.9	5.3
P9	3°48'53.8"W	35°11'47.4"N	15.1	3.6	2.8	1.5	7.5	20.2	479.8	1.7	0.4	0.2	465.2	2.4
P10	3°49'23.6"W	35°10'28.9"N	24.1	3.2	2.8	1.5	7.7	19.0	465.0	0.4	0.5	0.2	701.6	9.2
P11	3°50'5.7"W	35°09'59.5"N	24.6	2.7	2.6	1.3	7.5	18.8	408.3	0.2	0.6	0.1	644.9	14.8
P12	3°48'19.6"W	35°10'25.5"N	24.9	3.0	2.9	1.5	7.5	19.7	456.0	1.2	0.3	0.1	417.6	7.1
P13	3°49'30.2"W	35°09'27.1"N	25.3	3.2	2.4	1.1	7.3	17.9	437.1	2.2	0.1	0.0	499.5	0.9

Dissolved oxygen

Concerning dissolved oxygen concentration, it is an important indicator of biological activity and chemical processes in groundwater. Oxygen is temperature-dependent as the solubility of gases decreases with increasing temperature. Furthermore, dissolved salt content is also a contributing factor that decreases the solubility of oxygen in water; since oxygen would have less room to dissolve due to increasing dissolved salts. Dissolved oxygen concentrations in the analyzed water samples, ranging between 2.5–3.91 mg/L, follow the same rule; the highest values were noticed in zone of low temperatures and low salt levels.

Temperature

The temperature variation range in the studied groundwater is between 17.9–23.1 °C; it does not exceed the standards prescribed by the WHO. The maximum values were found in the shallow piezometric levels towards the coastline while the

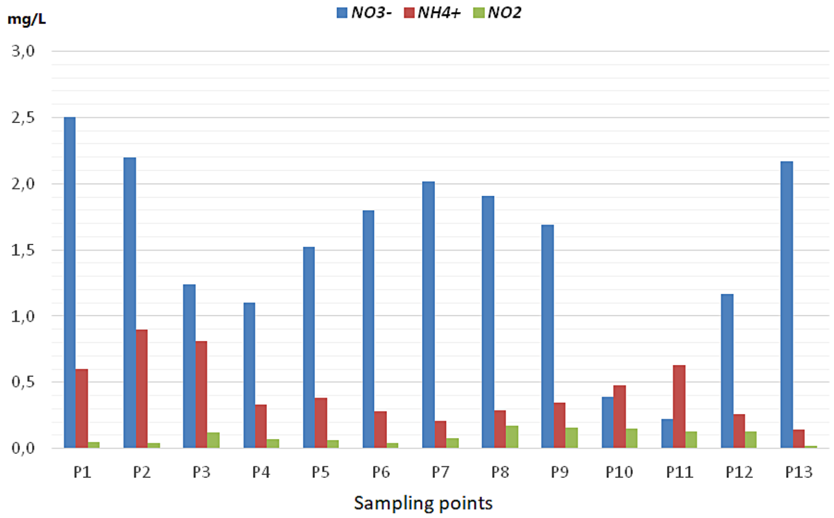

Fig. 4. Bar chart comparing concentration levels (in mg/L) of nitrogen species in groundwater samples

lowest temperatures were found near recharge zones. In general, temperature variation depends on the flow conditions and the alluvial constitution of the aquifer (Ngouala, 2016).

Dissolved inorganic nitrogen

According to the chart below (Fig. 4), describing the observed variation of nitrogen species' level NO_3^-, NH_4^+ and NO_2^-, Nitrates ions have the highest concentration among the three elements, in all the representative wells, whereas Nitrites are present in very low concentrations. Although the sampled wells are located in an unconfined aquifer system known for its vulnerability to pollution, Nitrogen inputs remain within the natural permissible amount provided by the World Health Organization 50 mg/L (Mohammed et al., 2017); which signifies that groundwater flowing through Ghiss-Nekor aquifer is far less contaminated by anthropogenic activities such as agricultural irrigation since the studied aquifer is not situated in an intensive agricultural area as only 815 Ha of the land is irrigated (as mentioned in an unpublished report entitled Study to develop a water resources management plan for the Ghiss-Nekor basin prepared by ABHL (Loukkos Hydraulic Basin Agency).

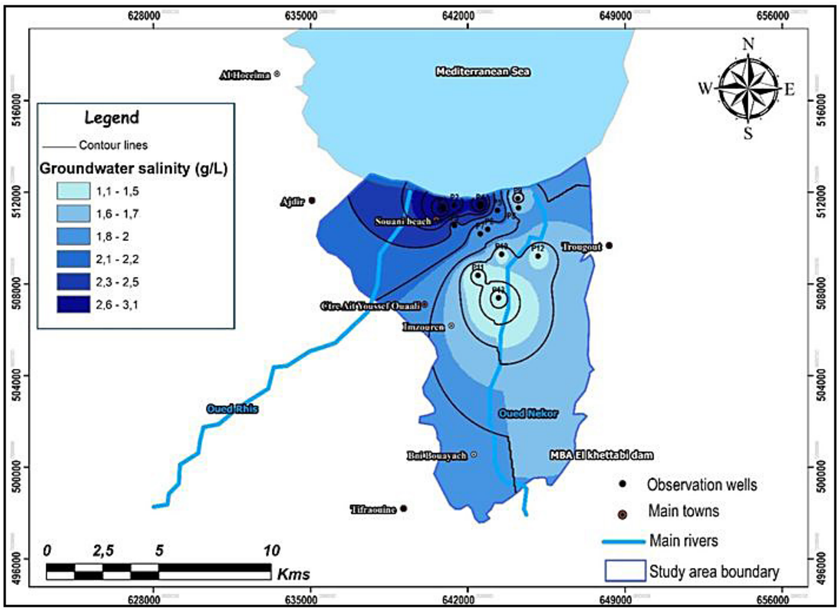

Fig. 5. Iso-salinity contour lines (mg/L) for Ghiss-Nekor aquifer

Discussion of main factors contributing to groundwater salinization (salinity, chloride, electrical conductivity)

The resulting map of interpolated values of groundwater salinity in the Nekor-Ghiss aquifer shown in Fig. 5 illustrates that the mineralization distribution is divided into two sectors; the Northern domain, near the coast, where salinity levels are equal or above 3 g/L associated with high chloride concentration exceeding 1.5 g/L due to contamination by seawater intrusion, and the central part along Nekor River characterized by low salinity values between 1-1.7 g/L compared to the general repartition of the groundwater mineralization; this decrease can be explained by the influence of the rising of groundwater levels towards the areas considered as significant recharge zones constituted from highly permeable thick sedimentary sequence (Salhi, 2008). Note that towards the Mediterranean Coast, along Souani Beach, the generated map also depicts anomalies manifested by the tight configuration of contour lines.

Water salinity is also defined by electrical conductivity (reported in MicroSiemens per Centimeter), which is typically measured in-situ during sampling; specifically, electrical conductivity is the ability of water to conduct electricity, which is proportional to the total concentration of ions in the solution and to their average electrical mobility (Lamontagne, 2021). According to WHO standards for potable water, the optimum values of E.C are 500–1500 µS/cm (Table 2). Therefore, based on E.C values, ranging between 2400–6500 mS/cm, all the groundwater samples were found to be unfit for drinking. According to Fig. 6 and table 3 shown below, only 15% of the groundwater samples were of moderate quality, while about 62% of the studied samples belong to the category of very poor water- quality. This significant increase in electrical conductivity leading to quality degradation is due to high amounts of Cl^-, occurring along the coastline, caused by mixing with seawater. As shown in the scatter plot below (Fig. 7), the positive linear correlation (R=0.87) existing between electrical conductivity and concentration of chloride

Table 2. Standards for drinking water at national and international levels

Parameters	Symbols	NM	WHO
pH	-	6.5–8.5	6.5–8
E.C.	EC	1500	-
DO	O_2	5–8	-
COD	COD	-	-
BOD_5	BOD_5	-	-
TSS	TSS	-	-
Nitrates	NO_3^-	50	50
Nitrites	NO_2^-	0.5	-
Ammonium	NH_4^+	0.5	-
Orthohosphates	PO_4^{3-}	-	-

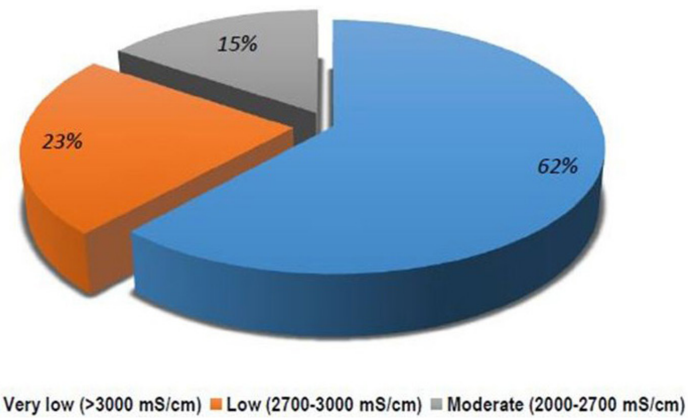

Fig. 6. Pie chart representing the classification of Ghiss-Nekor groundwater based on conductivity

Table 3. Water quality classification ranges

Parameters	Water quality				
	Excellent	Good	Moderate	Low	Very low
Electrical conductivity (µs/cm)	<400	400–1300	1300–2700	2700–3000	>3000
Chloride Cl^-(mg/l)	<200	200–300	300–750	750–100	>1000
NO_3^- (mg/l)	<5	2–25	25–50	50–1000	>100
NH_4^+ (mg/l)	<=0.1	0.1–0.5	0.5–2	2–8	>8

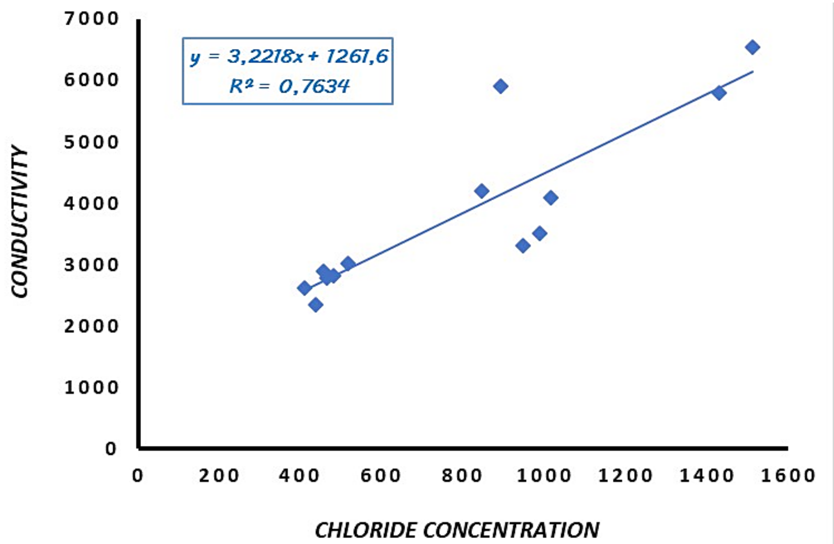

Fig. 7. Correlation plot of electrical conductivity versus Chloride concentrations (µS/cm)

confirms that the predominant dissolved ion in the water samples is Cl^- which means that a localized contamination by chloride affected Ghiss-Nekor groundwater originating from seawater infiltration into the downstream part of the aquifer, closer to the Mediterranean Sea, where chloride concentration of the groundwater sampled wells is above 1000 mg/L and where frequent local increases in both variables were observed (Alfarrah, 2018).

However, salinization rate also increases towards the coast due to the shallow groundwater levels under semi-arid climatic conditions prevailing in the study area which increases the groundwater discharge by direct evaporation process. Moreover, owing to low permeabilities of the sediments, in the shoreline inducing low groundwater velocities, salt content is likely to rise through the longer water-rock interaction.

Spatial distribution and sources of SO_4^{2-} ions

Sulphates content oscillates between 417.6 and 899.22 mg/L, exceeding in all the studied samples the Moroccan drinking water standard fixed at less than 400 mg/L. The examination of SO_4 spatial distribution (Fig. 8) reveals that the highest values were recorded in the shoreline wells which are indicative of the impact of seawater mixing with freshwater, since Sulphate and Chloride are among the dominant anions in seawater ionic composition (Cotruvo, 2005).

However, high levels of Sulfates noticed in groundwater samples obtained from wells located inland, are attributable to the eventual dissolution of minerals found in the Triassic evaporitic rocks-gypsum and saliferous mudrocks outcropping upstream of the Nekor River's by National Drinking Water Utility. Moreover, the significant amounts of SO_4, particularly in the north of Imzouren village, are also related to a discharge of untreated household sewage and septic tanks wastewater.

Water turbidity assessment

Turbidity is a measure of the light dispersion and absorption when passing through water. It is

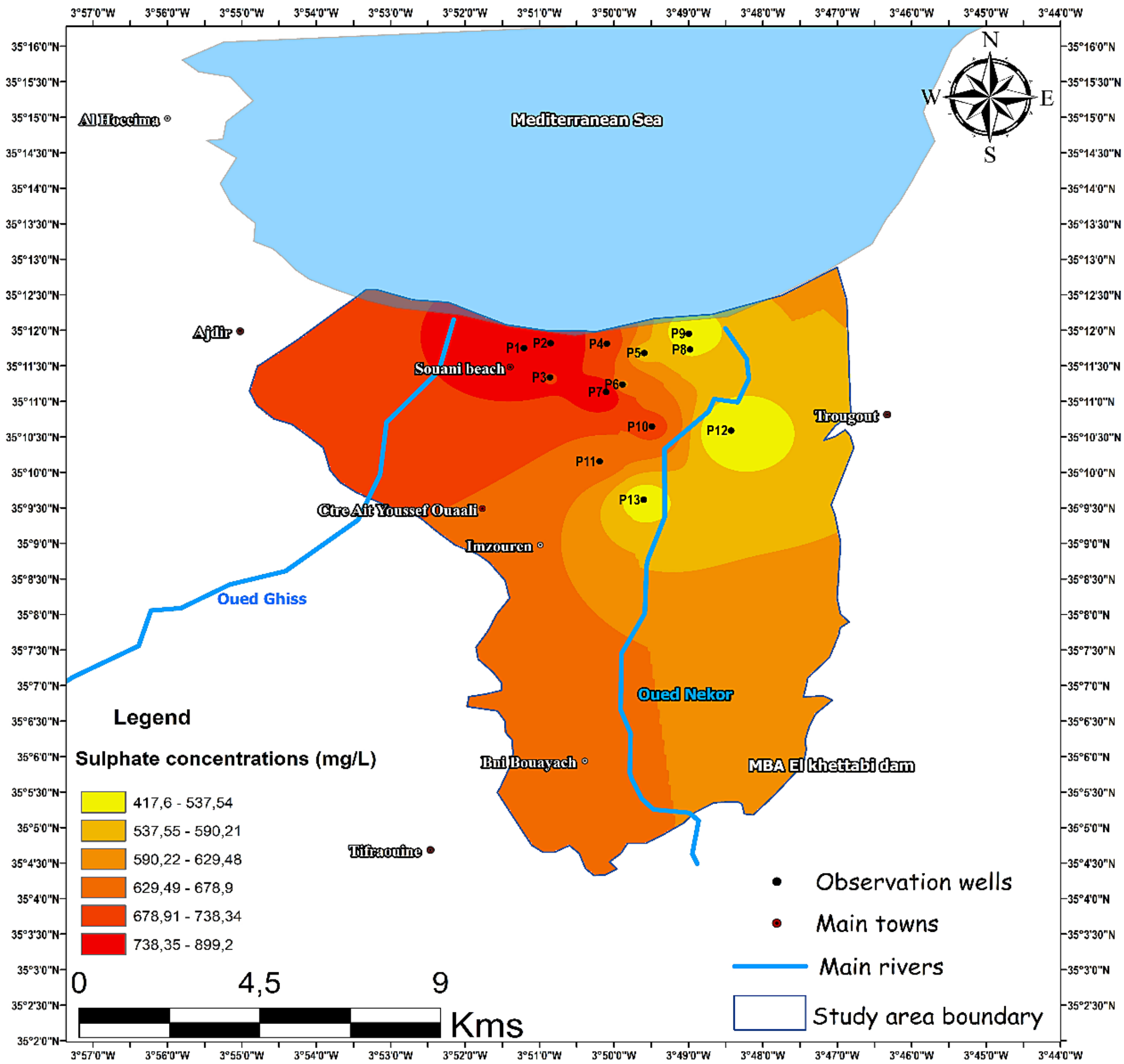

Fig. 8. Spatial distribution of dissolved Sulfate using IDW interpolation

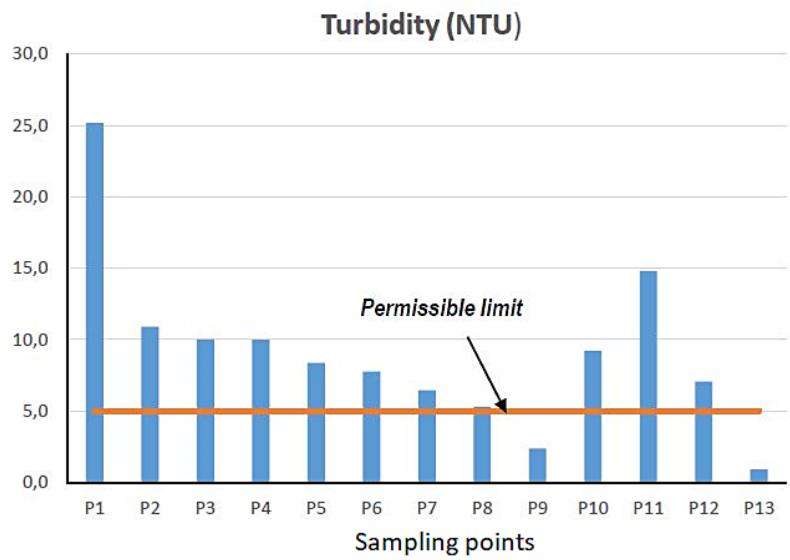

Fig. 9. Graph showing turbidity levels observed in the water samples

a measure of the ability of light to pass through water. It is caused by suspended insoluble material such as clay, silt, organic material, plankton, and other particulate substances in water.

This parameter interferes with disinfection by creating a possible shield for pathogenic organisms. Groundwater normally has very low turbidity due to the natural filtration that occurs as the water infiltrates into the soil (Nathanson, 2020). Turbidity of the analyzed samples ranged between 0.9–25.2 NTU (Fig. 9). The recorded values are beyond permissible limit of 5 NTU recommended by the World Health Organization for drinking water (WHO 2011), except in the monitoring wells n°9 and n° 13. Besides the geological conditions this phenomenon, increasing towards the coastline, could also result from the shallow depth of the wells, or improperly capped wells due to usage of poor-quality strainer-filter material (Solangi, 2017), which increases the intrusion of turbid surface water particularly during flood periods (Williamson, 2011).

CONCLUSIONS

The present study aimed to assess groundwater quality in Ghiss-Nekor coastal plain, located in the north-east of Morocco, through cartography and analysis of physical and chemical data generated from 13 monitoring wells. The use of GIS interpolation and statistical methods is a successful approach to provide a visual analysis in order to locate hotspot zones of low quality. The findings indicate that the aquifer's water is intensively mineralized with electrical conductivity values, ranging from 2400 to 6500 μS/cm, considerably above the limit of 1500 μS/cm prescribed by the WHO.

The potential source of salinization is the ubiquitous presence of chloride ions in groundwater, which is confirmed by the positive linear correlation between electrical conductivity and chloride concentrations; this increase is due to the influence of possible seawater intrusion; corroborated by the existence of steep iso-salinity contour lines towards the coastline.

On the other hand, one of the main contaminants encountered in the investigated samples are sulfate salts derived naturally from the dissolution of pre-existent evaporites suck as gypsum-bearing rocks, or from anthropogenic sources such as the discharge of domestic effluent directly into water bodies. Moreover, 15% of the groundwater samples showed SO_4 concentration values lower than 480 mg/L which is the maximum permissible limit for sulfates in groundwater used for agricultural purposes.

Similarly, only two samples were characterized by low turbidity (0.9–2.4 NTU), whereas 75% of the wells provided high turbidity water (exceeding 5 NTU) due to their shallowness and absorption of colloidal substances.

The obtained results also demonstrate that groundwater with acceptable salinity meeting the standards fixed by the WHO at 1.5 g/L is distributed along Nekor river in the north-central part of the plain. However, more than 60% of the observation wells provided unreliable low-quality water, especially in coastal areas with prevalence of a low hydraulic gradient; thus, in order to enhance water quality of the Ghiss-Nekor aquifer, particular attention must be paid to the resulting changes in groundwater levels and chemical constituents of the suspected zones of high salinity, coupled with a long-term seawater intrusion monitoring by tracking the migration of freshwater/saltwater interface, since it is one of the main sources of salinization process.

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REFERENCES

1. Alfarrah N. and Walraevens K. 2018. Groundwater overexploitation and seawater intrusion in coastal areas of arid and semi-arid regions. Water Journal, 2(10), 143.
2. Benaissa C., Bouhmadi B., Rossi A. and El Hammoudani Y. 2020. Hydro-chemical and bacteriological Study of Some Sources of Groundwater in the Ghis-Nekor and the Bokoya Aquifers (Al Hoceima, Morocco). Proc of The 4th Edition of International Conference on Geo-IT and Water Resources, 1–5.
3. Bonokwane M. B., Lekhooa M., Struwig M. and Aremu A. O. 2022. Antidepressant Effects of South African Plants: An Appraisal of Ethnobotanical Surveys, Ethnopharmacological and Phytochemical Studies. Frontiers in Pharmacology, 2(13), 895286.
4. Carugi C. 2016. Experiences with systematic triangulation at the Global Environment Facility. Eval Program Plann, 3(55), 55–66.
5. Cotruvo J. A. 2005. Water desalination processes

and associated health and environmental issues. Water Conditioning and Purification, 1(47), 13–17.

6. El Abdouni A., Bouhout S., Merimi I., Hammouti B. and Haboubi K. 2021. Physicochemical characterization of wastewater from the Al-Hoceima slaughterhouse in Morocco. Caspian Journal of Environmental Sciences, 3(19), 423–429.
7. El Hammoudani Y. and Dimane F. 2021. Occurrence and fate of micropollutants during sludge treatment: Case of Al-Hoceima WWTP, Morocco. Environmental Challenges, 1(5), 1–8.
8. Elabdouni A., Haboubi K., Bensitel N., Bouhout S., Aberkani K. and El Youbi M. S. 2022. Removal of organic matter and polyphenols in the olive oil mill wastewater by coagulation-flocculation using aluminum sulfate and lime. Moroccan Journal of Chemistry, 1(10), 191–202.
9. Gad M., Saleh A. H., Hussein H., Farouk M. and Elsayed S. 2022. Appraisal of surface water quality of nile river using water quality indices, spectral signature and multivariate modeling. Water, 7(14), 1131.
10. Lamontagne S., Suckow A., Gerber C., Deslandes A., Wilske C. and Tickell S. 2021. Groundwater sources for the Mataranka Springs (Northern Territory, Australia). Scientific Reports, 1(11), 1–11.
11. Mohammed A.-Q., Mouhcine E.-Q., Nabil Darwesh M. S., Hamdaoui F., Kherrati I., El Kharrim K. And Belghyti D. 2017. Hydrogeochemical Study of Groundwater Quality in the West of Sidi Allal Tazi, Gharb area, Morocco. Journal of Materials and Environmental Science,
12. Nagaraju A., Muralidhar P. and Sreedhar Y. 2016. Hydrogeochemistry and groundwater quality assessment of Rapur area, Andhra Pradesh, South India. Journal of Geoscience and Environment Protection, 4(4), 88–99.
13. Nas B. and Berktay A. 2010. Groundwater quality mapping in urban groundwater using GIS. Environmental Monitoring and Assessment, 1(160), 215–227.
14. Ngouala M., Mbilou U., Tchoumou M. and Samba-Kimbata M. 2016. Characterization surface water-groundwater aquifer in coastal watershed of the republic of Congo Loémé. Larhyss Journal, 28, 237–256.
15. Rodier J., Bernard L. and Nicole M. (2009). Water analysis, natural water, wastewater, seawater, 9th edn (Dunod, Paris, 2009).
16. Salhi A. 2008. Geophysics, Hydrogeology And Mapping. PhD. Thesis, Ecole Normale Supérieure.
17. Samani S. 2021. Analyzing the groundwater resources sustainability management plan in Iran through comparative studies. Groundwater for Sustainable Development, 12, 100521.
18. Stanly R., Yasala S., Oliver D. H., Nair N. C., Emperumal K. and Subash A. 2021. Hydrochemical appraisal of groundwater quality for drinking and irrigation: a case study in parts of southwest coast of Tamil Nadu, India. Applied Water Science, 11, 1–20.
19. Yifru B. A., Mitiku D. B., Tolera M. B., Chang S. W. and Chung I.-M. 2020. Groundwater potential mapping using SWAT and GIS-based multi-criteria decision analysis. KSCE Journal of Civil Engineering, 8(24), 2546–2559.
20. Zouhri L., Toto E. A., Carlier E. and Debieche T.-H. 2010. Salinity of water resources: saltwater intrusion and water-rock interaction (western Morocco). Hydrological Sciences Journal, 8(55), 1337–1347.