R’mel groundwater quality as influenced by agricultural activities

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Abstract

R'mel groundwater constitutes an important source for the supply of drinking water for Larache city, and rural population of the Loukkos area as well as for agricultural irrigation. It is subject to several potential risks of contamination. In order to assess the impact of agricultural activities on groundwater quality, we examined the physico-chemical characteristics of 20 randomly selected wells of R'mel zone of Loukkos peremiter by performing the analysis for 4 physicochemical parameters (Temperature, pH, soluble salts and nitrates). The results revealed that 70% of the sampled wells had nitrate levels 3 times higher than national standard of drinking water, and Nitrate Pollution Index (NPI) values showing moderate (45%) to very high pollution (35%).Therfore, the recorded values are very worrying and very alarming. They can indicate a risk of major pollution for groundwater, especially for the wells located near agglomerations.

Keywords: Agricultural activities, Nitrate pollution, R'mel groundwater, Loukkos.

Influence des activités agricoles sur la qualité de la nappe R'mel

Résumé

La zone de R'mel est la principale zone agricole du périmètre du Loukkos. Dans cette zone, les eaux souterraines constituent une source importante pour l'approvisionnement en eau potable de la ville de Larache, pour la population rurale de la région ainsi que pour l'irrigation agricole. Il est soumis à plusieurs risques potentiels de contamination agricole. Pour mettre en évidence un potentiel impact négatif des activités agricoles sur la qualité des eaux souterraines, nous avons examiné les caractéristiques physico-chimiques de 20 puits de la zone R'mel du périmètre du Loukkos, sélectionnés au hasard en effectuant l'analyse de 4 paramètres physico-chimiques (Température, pH, sels solubles et nitrates). Les résultats montrent que 70 % des puits échantillonnés présentaient des niveaux de nitrates 3 fois supérieurs aux normes nationales pour l'eau potable, avec des valeurs d'indice de pollution par les nitrates (NPI) montrant une pollution modérée (45 %) à très élevée (35 %). Les valeurs enregistrées sont très inquiétantes et très alarmantes. Elles peuvent ainsi indiquer un risque de pollution majeure pour les nappes phréatiques, notamment pour les puits situés à proximité des agglomérations.

Mots clés : activités agricoles, pollution, nitrates, eaux souterraines, R'mel, Loukkos.

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تأثير الانشطة الفلاحية على جودة المياه الجوفية لمنطقة الرمل

بنعيشة محمد ومرابط رشيد

ملخص:

تعتبر منطقة الرمل من المنطاق الزراعية الرئيسية في محيط اللوكوس. تشكل المياه الجوفية في هذه المنطقة مصدراً هاماً لتزويد مدينة العرائش بمياه الشرب ولسكان المناطق الريفية وكذلك للري الزراعي. هذه المياه عرضة للعديد من المخاطر المحتملة للتلوث الزراعي. لتسليط الضوء على التأثير السلبي المحتمل للأنشطة الزراعية ، على المياه الجوفية ، قمنا بفحص الخصائص الفيزيائية والكيميائية لـ 20 بئراً تم اختيارها عشوائياً لمحيط الرمل، وذلك من خلال إجراء تحليل لـ 4 معلمات فيزيائية كيميائية (درجة الحرارة ، ودرجة الحموضة ، والأملاح القابلة للذوبان و النترات). أظهرت النتائج أن 70٪ من الآبار التي شملتها الدراسة، تحتوي على مستويات عالية من النترات، أعلى بثلاث مرات من المعايير الوطنية لمياه الشرب ، حيث أظهرت قيم مؤشر التلوث بالنترات (NPI) الى أن 45٪ من الابار معتدلة التلوث و 35٪ تتسم بتلوث مرتفع، بل مقلق للغاية، وبالتالي يمكن أن تشير إلى خطر حدوث تلوث كبير للمياه الجوفية ، خاصة بالنسبة للآبار الواقعة بالقرب من التجمعات السكانية.

الكلمات المفتاحية: الأنشطة الفلاحية، التلوث ، المياه الجوفية ، ااالنيترات، الرمل ، اللوكوس.

Introduction

Water is an essential element for life and is important for countless human activities and for environmental conservation as well. That's why its management occupies a strategic place in Moroccan national policy which aims at preserving this vital resource, especially since the climate of Morocco is arid or semi-arid in most of its area. In addition to its scarcity in these areas because of the drought years often recorded, its consumption requires a certain standard of quality. Non-point source pollution from agriculture, is one of the major causes of the deterioration of the groundwater quality in rural areas, especially in agricultural irrigated lands (Laftouhi et al. 2003; Malki et al., 2016; Ouhamdouch et al., 2019; Hssaisoune et al. 2020).

Loukkos is considered among the most important irrigated perimeters in Morocco. It is characterized by intensive by increasingly modern agricultural activities and has a significant and strategic groundwater potential. The R'mel aquifer represents the main source of groundwater in this perimeter. It covers an area of about 240 km^2 and is located in the bottom Loukkos basin south of Larache city. The depth of this aquifer ranges between 20 and 120m. Its supply is about 62 Mm^3/year and is provided mainly by the infiltration of rainwater and the return of irrigation water. The depth of water level varies overall between 5 and 20 m, and the overall exploitable volume from this aquifer amounts to 34 Mm^3/year, of which 8 Mm^3/year currently feed Larache city and 23 Mm^3/year serve as irrigation water. The rest serves as drinking water for the rural population of the region (Benkaddour et al., 2004; ABHL, 2010).

Despite this interesting development, Loukkos area, still suffers from a lack of data concerning the groundwater quality, especially since the irrigated area is surrounded by villages that supply directly from this aquifer. In fact, Loukkos area has recently undergone intensive agricultural activity (Tanji et al., 2014, 2015; Abbou et al., 2021; Benicha et al., 2022). As a result, a large number of fertilizers and pesticides has been recently introduced in order to intensify agricultural production and to improve crop yields.

Water quality of the R'mel aquifer would have undergone some deterioration in recent decades as a result of the intensive use of chemical fertilizers and pesticides in agriculture as well as its overexploitation and unsustainable use (Benicha et al., 2016a; Benicha et al., 2016b). On the other hand, the seawater intrusion due to the drop in the level of piezometric in some locations, aggravates the situation (El Hamidi et al., 2019).

These elements can modify the chemical quality of water and make it unsuitable for the desired uses and thus, may pose health problems especially since it supplies the population of Larache city with drinking water as well as rural agglomerations (El Hamidi et al., 2019). Moreover, the characteristics of the R'mel aquifer, which are manifested by shallow groundwater and sandy soils, make the situation more complex. This certainly raises new questions around the sustainability and the impact of agricultural activities, including fertilizers use on groundwater quality and the resulting risks.

Nitrate is one of the most significant elements that plays a vital role in the quality of groundwater (Chen et al. 2020; Qian et al. 2020). All around the world, it is a serious issue to monitor nitrate contamination and its effects on human health (Baghapour et al. 2014; Arauzo, 2017; Abascal et al. 2022). Chen et al. (2016) investigated groundwater nitrate contamination and health risk assessment in northwest China and reported that modern agriculture activities, synthetic fertilizers, and higher permeability of soil might cause a higher concentration of nitrate in groundwater.

The nitrogen pollution index (NPI) is an index value used to evaluate the level of nitrate pollution in groundwater. Applying the NPI index is indicative of nitrate pollution in the groundwater due to anthropogenic activity (Spalding and Exner, 1993; Obeidat et al., 2012; Balamurugan et al., 2020). According to NPI values, the water quality was classified into five types: clean (unpolluted) ($NPI<0$), light pollution ($0<NPI<1$), moderate pollution ($1<NPI<2$), significant pollution ($2<NPI< 3$) and very significant pollution ($NPI > 3$).

The importance of nitrate in evaluating groundwater pollution is likely to be crucial due to its widespread occurrence in most agricultural systems (Qian et al., 2020). In this context, and in order to identify possible effect of agricultural activities, including the use of Nitrogen-based fertilizers on the quality of the aquifer, we have undertaken this study.

Material and methods

Groundwater samples

20 groundwater samples were collected from different wells in agricultural plots of R'mel zone, 4 of which are located near agglomerations (figure 1). The depth of wells varies from 1 to 5 m for traditional wells, and from 7 to more than 20 m for modern wells. Before taking a sample, water were pumped from the boreholes outwards to ensure that the sample is in equilibrium with the water source. For traditional wells, sampling was carried out using a bucket that penetrates about 1 m into the water after thoroughly stirring the well water. All samples were taken in 1 litter glass bottles, labelled and transported in a cooler to the laboratory where they are first filtered out on filter paper to remove suspended solids, then analyzed.

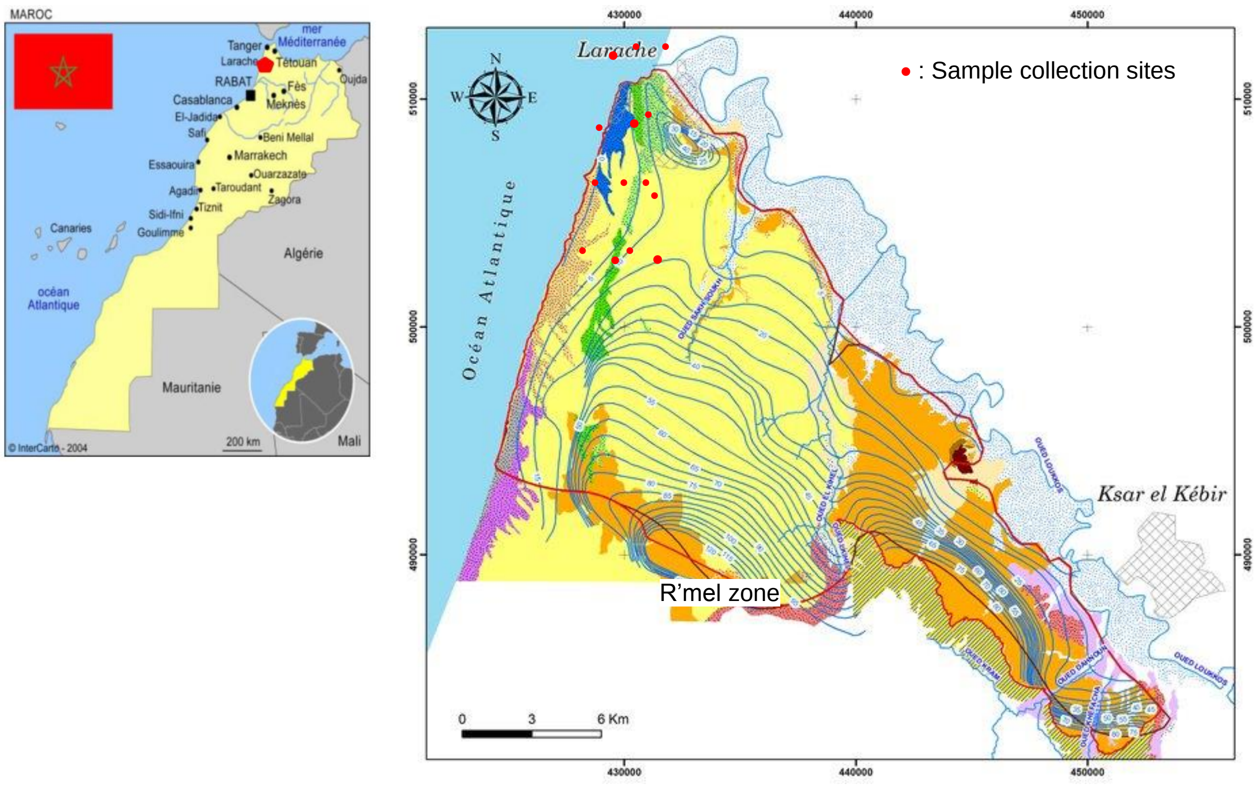

Figure 1. Maps showing location of R'mel aquifer and water sampling points

Physico-chemical parameters analyzed

The temperature was measured on the site using a thermometer. The pH was measured directly using the laboratory pH-meter. The determination of electrical conductivity was carried out using the laboratory conductivity meter and nitrate ions were determined using salicylate method (Rodier, 1996). A single-parameter water quality index named the nitrate pollution index (NPI) was applied to estimate nitrate pollution in the investigated wells. NPI was determined using the following formula (Spalding and Exner, 1993; Obeidat et al., 2012; Balamurugan et al., 2020):

$$NPI = \frac{Cs - HAV}{HAV}$$

Where Cs is the measured concentration of nitrate in sample and HAV is the human acceptable value of nitrate and is taken as 20 mg/L.

Then, the water quality was categorized into five classes according to the NPI values: clean (unpolluted), light pollution, moderate pollution, significant pollution, very significant pollution with the NPI value: <0.0, 0.0-1.0, 1.0-2.0, 2.0-3.0, >3.0, consecutively (Obeidat et al., 2012).

Results and discussion

Water temperature

In the study area, we observed that water temperature does not show large variations from one well to another. It ranges from 18.3°C to 19.7°C (Fig. 2) and remains, however, close to the average annual temperature of the regionn, i.e. 18.6°C (Achkar, 2009).

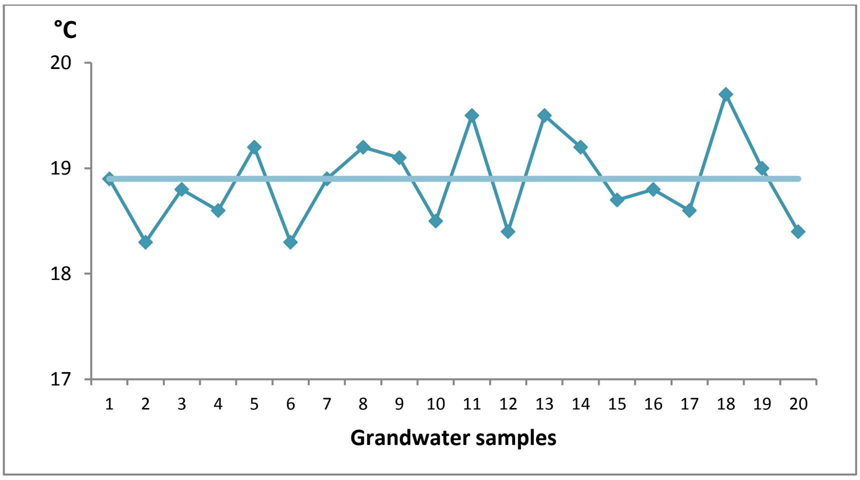

Figure 2. Temperature of R'mel groundwater samples

Water pH

According to WHO standards for water potability, the optimal pH values are between 6.5 and 9.5. In our study, the average pH values of waters of the R'mel aquifer are neutral (7.4) and show no significant variations, with a minimum of 6.8 and a maximum of 8.0 (Fig. 3).

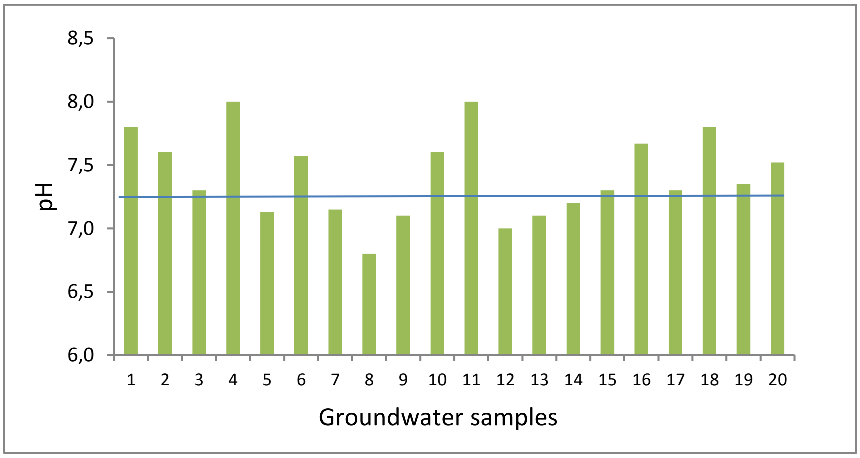

Figure 3. pH of R’mel groundwater samples

Salinity (total soluble salts)

The water samples of the R’mel aquifer have a medium to high salinity content ranging from 400 to 700 mg/l with an average of 500 mg/l representing the quantity of water-soluble salts (Fig. 4). The maximum recommended value for soluble salts by the WHO is 1000 mg/l, while it is only 500 mg/l in France.

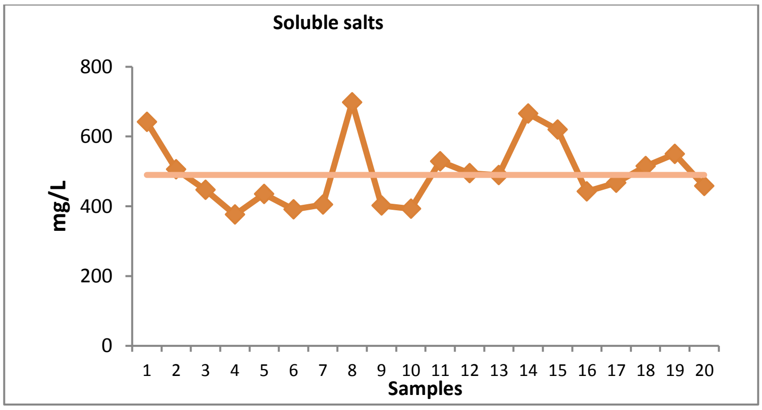

Figure 4. Levels of soluble salts of R’mel groundwater samples

The origin of this salinity could be attributed a priori, by percolation of irrigation water that transports nutrients and fertilizers (Naik et al., 2008). The nature of the sandy soil, the large and frequent irrigation doses as well as the heavy rainfall events aggravate this phenomenon. Thus, referring to Moroccan drinking water standards, values of all samples are considered acceptable for human consumption (Official Bulletin, 2002).

Nitrates

Nitrate is one of the most significant element that plays a vital role in the quality of groundwater (Chen et al., 2020; Qian et al., 2020). Nitrates are the most dominant nitrogen form in streams and groundwaters. High values indicate wastewater discharges into surface and groundwater aquatic environments, and especially excessive use of fertilizers in agriculture (Chapman et al., 1996).

In our study, the results (Fig. 5) show that water samples are very heavy loaded with nitrates. These ion levels far exceed the Moroccan standards of potability, set at 50 mg/l, in the majority of analyzed wells. The values ranged from 37 to 165 mg/l with an average of 76 mg/l. Nitrate contamination was subdivided into three groups, 1) low (<20mg/L), 2) medium (≥ 20 mg/L to <50 mg/L), and 3) high (≥50 mg/L). The concentration of nitrate in 30% of the samples meet the standards, while 70% have levels above the standards (50 mg/L), including 3 located near agglomerations. Nitrates are very soluble salts in water and are easily driven deep by water infiltration, facilitated by the coarse texture of the soil in the study area.

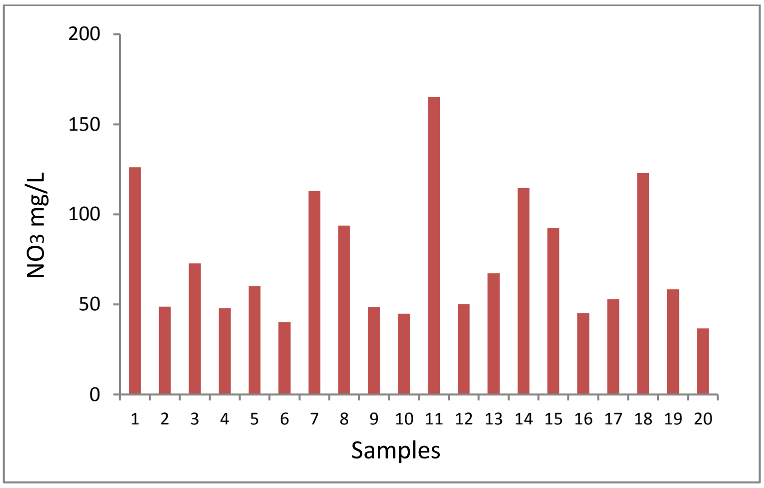

Figure 5. Nitrate levels in R'mel Groundwater samples

All traditional wells, having less than 5m deep, have nitrates rates higher than the standard of potability, while only 3 boreholes, with depths between 7 and 10m, exceed the potability standard. Likewise for mineralization (salinity); higher values correspond, in most cases, to traditional wells. This could be explained by the fact that the groundwater aquifer is split between two distinct layers; the upper mineral-rich layer with conductivities higher than 1000 µS/cm and nitrate levels exceeding 50 mg/l, and lower layer with conductivities between 300 and 400 µS/ cm and nitrate contents less than 50 mg/l (Ghheda, 2003).

At R'mel area, literature showed that vegetable crops consuming more nitrogen fertilizers, such as potatoes (300 to 600 kgN/ha), peanuts (200 to 700 kgN/ha), strawberries (150-400 kgN/ha), tomatoes (150 to 400 kgN/ha), sugar cane (200 kgN/ha) are those that generate more nitrate pollution (Achkar, 2002; Tanji et al., 2012, 2015).

The higher values are undoubtedly due to the accumulation of nitrate ions in the water generating mainly from overused fertilizers that are easily transported into the groundwater by percolating water from rainfall or from irrigation (Naik et al., 2008), especially since the retention of these elements by the sandy soils, characteristic of the area, is very low. Another reason for this phenomenon may be that, in this agricultural area, the aquifer is typically shallow, and because it is relatively close to the surface, it receives direct inputs of nitrate-rich leachate from the agricultural sandy soils. Thus, according to the study, it is estimated that total quantity of fertilizing units consumed in the irrigated area of Loukkos perimeter (26.400 ha) is more than 12.000 tons/year (67% of the total quantity used in the Loukkos perimeter).

The R'mel sector alone, consumes on average, more than 8.000 tons/year (44% total quantity) of which 4.250 tons/year (46.5%) only for nitrogen fertilizers (Achkar, 2002; Mourabit et al., 2002). Similar results were obtained by different researchers in Loukkos area. They obtained high values that exeed the national standard set at 50mg/l (ONEP, 2001; Mourabit et al., 2002; Sarti et al., 2021).

The different studies carried out in other agricultural regions of Morocco, have highlighted the importance of nitrate pollution which has already become of great concern and alarming issue, such as in Gharb Plain (Al-Qawati et al., 2015; Aziane et al., 2020; Bouita et al. 2021), irrigated Tadla perimeter (Berdai et al., 2004; Barakat, 2020), Triffa plain (eastern Morocco) (Benkaddour et al., 2004, 2020; Fekkoul et al., 2011), Berrechid (Moukhliss et al., 2021) and Souss Massa (Tagma et al., 2009; Attar et al., 2022).

Based on a global overview, it is estimated that average nitrate levels have increased by 36% in global water sources since 1990 (Zhang et al., 2020). According to Abascal et al. (2022), the Mediterranean basin has worried values and therefore is one of the most polluted areas worldwide in terms of nitrate presence in groundwaters. Chen et al. (2016) investigated groundwater nitrate contamination and health risk assessment in northwest China and reported that modern agriculture activities, synthetic fertilizers, and higher permeability of soils might cause a higher concentration of nitrates in groundwater. Teng et al. (2019) investigated the risk assessment of nitrate contamination in groundwater for regional management and found that excess utilization of fertilizers for high crop yield in agriculture causes the highest concentration of nitrates in groundwater. Tian et al. (2019) assessed the health risk assessment of nitrate pollution in China and reveal that attributed it to modern activities in human society including excessive use of agriculture fertilizers and disposal of domestic waste. Adimalla (2020) conducted a studied on potential health risk assessment of nitrate contamination in South India and revealed that domestic waste disposal and agricultural activities highly influence the nature of groundwater.

All Moroccan and international literature cited report that the highest nitrate levels are obtained in the areas of intensive field crops which confirms the agricultural origin of the nitrate pollution (MedECC, 2020).

Nitrate pollution index (NPI)

NPI is an effective index value to evaluate the level of pollution due to elevated concentration nitrate in groundwater. The NPI values of groundwater samples are presented in figure 6, and the NPI classification of groundwater is depicted in Table 1. In the current study area, NPI varies from 0.84 to 7.26, with an average of 2.78.

Based on the NPI values, four Water Quality Monitoring and Assessment classes were identified: light pollution, moderate pollution, significant pollution, and highly significant pollution, with NPI values of <0, 0-1, 1-2, 2-3, and >3, respectively (Obeidat et al., 2012). The results (fig. 6) show that no samples locations are clean. 5.0% of sample locations are light pollution and 45.0% of sample locations are moderate, while 15.0% of sample locations are significant, and 35.0% of sample locations are recorded as a very significant type of pollution due to higher concentration of nitrate in groundwater. Indicating that these wells are not suitable for human consumption as drinking water.

According to these results, R'mel groundwater samples are classifed as moderate to very significant pollution. The high NPI values reflect intensive use of nitrogen fertilizers in the study area. Such values are very expected as long since this area is known for intensive agriculture using large quantities of nitrogen fertilizers and for the coarse texture of the soil with low retention power.

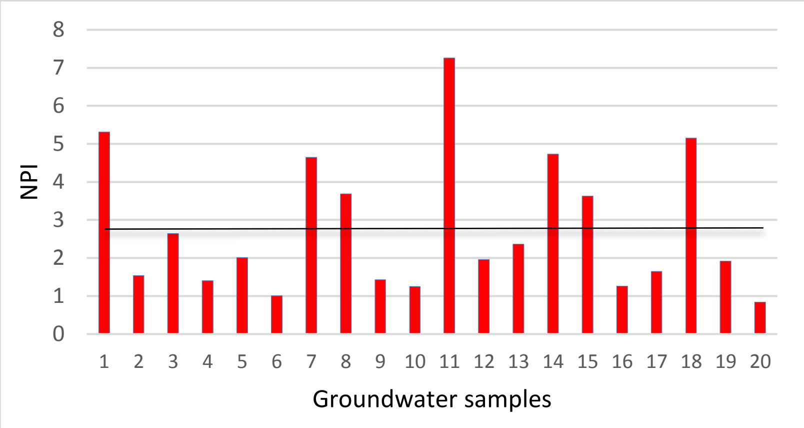

Figure 6. Nitrate pollution index (NPI) values of R'mel groundwater samples

Table 1. NPI classification of R'mel groundwaters

NPI value	Nitrate (mg/l)	Type of pollution	Number of samples	% of samples
< 0	< 50	Clean	0	0
0–1	= 50	Light	1	5
1–2	> 50	Moderate	9	45
2–3		Significant	3	15
> 3		Very significant	7	35

To our best knowledge, no data of NPI exist for R'mel groundwater. However, results are available for other Moroccan acquifers. El Mountassir et al. (2022) reported that NPI values in the Meskala-Ouazzi sub-basin in the Essaouira Bassin (Morocco), ranged between − 0.9 and 7.8. According to the classification of NPI, 44.8% of the total groundwater samples represent clean water. NPI studies by Sehlaoui et al. (2022) of the Benslimane groundwater reported that 78.3% of the sampled sites showed very high pollution as a result of intense anthropogenic activities including intensive agricultural activities. Sarra et al. (2020) reported that Doukkala Aquifer is under stress due to the impact on anthropogenic activities and climates. This study found NPI values ranging from -0.9 to 10.35 with a mean of 2.4. About 12.4% of the sample sites was moderate status, 13.4% of the sample sites was poor status, while 27.8 % of sample locations was bad status type of pollution.

On other parts of the world, the problem of nitrate in groundwater is an international problem. Bahrami et al. (2020) when studying temporal and spatial assessment of groundwater contamination of Fasarud Plain, southern Iran, reported that NPI values ranged between -0.88 and 3.80 with an average of 1.07 and nitrate concentrations ranged from to 2.46 to 96 mg/l with an average of 41.32 mg/l.

Unrational and inappropriate fertilizer application, combined with poor irrigation management practices, result in rapid nitrate leaching into the subsoil, accentuated/aggravated by the coarse texture of the sandy soil and the abundant rainfall in the region.

The examination of the impact of agricultural activities on nitrate pollution in R'mel region has shown that the intensification of agriculture, mainly the vegetable sector, seems to be the important cause. In fact, the establishment of nitrogen mass balances revealed quantities of

potentially leachable nitrogen exceeding 300 kg of Nitrogen per hectare and per year for vegetable crops (tomato and potato especially) and groundnuts.

The degradation of water quality by nitrates at R'mel aquifer is an evidence of unsustainable use and management of fertilizers in the R'mel area. Thus more than 150 kg of potentially leachable nitrogen/ha are used on average annually in this area. Organic manure, sandy soil texture and irrigation mode make the situation even more complex (Chouraichi and Achkar, 2001).

The values recorded in the present study are very worrying because the repeated absorption of large amounts of nitrate could promote the appearance of dangerous diseases such as brain damage, cancers, and methemoglobinemia (Freishtat et al., 2005; Venkateswari et al., 2007; Massoudinejad et al., 2018). The threshold of 50 mg/l, included in the definition of good water quality by WHO (2011), was defined in order to prevent such risks. This is agrees with the observations made by Ministry of Energy, Mines, Water and the Environment, which has classified the overall water quality of the R'mel aquifer and many other aquifers, from bad to very bad due to its high nitrate levels (Anonymous, 2009). Therefore, efforts to reduce the use of nitrogen fertilizers are more than urgent.

Conclusion

This study allowed us to highlight the contamination of groundwater in the R'mel aquifer as a result of agricultural intensification in this region. Parameters studied; T, pH, salinity of water showed normal values, while nitrate pollution study showed that 70% of the analyzed wells have levels higher than the standard of potability and the NPI results showed that R'mel groundwater quality was classified from moderate to very significant pollution. The situation has become alarming and therefore urgent actions are required to slow down the deteriorationof water bodies. Efforts to optimize or even reduce nitrogen fertilizers use must be taken immediately due to their serious related health impacts. Sustainable solutions should be adopted and mainstreamed at the R'mel basin in order to recover and protect the groundwater quality.

References

Abbou M., Chabbi M., and Benicha M. (2021). Evaluation de la pression d'utilisation phytosanitaire sur l'environnement : cas du fraisier de Loukkos nord-ouest du Maroc. Afrimed J. 30. p. 54-72.

ABHL (Agence du Bassin Hydraulique du Loukkos). (2010). Bassin hydraulique du Loukkos. Royaume du Maroc, Secrétariat auprès du Ministère de l'Energie, des Mines, de l'eau et de l'Environnement, chargé de l'eau et de l'environnement.

Abascal E., Gómez-Coma L., Ortiz L. and Ortiz A. (2022). Global diagnosis of nitrate pollution in groundwater and review of removal technologies. Science of the Total Environment 810 : 152233.

Achkar M. (2002). La rationalisation de l'utilisation des engrais et pesticides et la protection des ressources en eau et en sol dans la région du Loukkos, H.T.E. 123. p. 3-10.

Achkar M. (2009). Préservation des ressources en eau dans la région du Loukkos. Office Régional de Mise en Valeur Agricole du Loukkos, February.

Adimalla N. (2020). Spatial distribution, exposure, and potential health risk assessment from nitrate in drinking water from semi-arid region of South India. Hum Ecol Risk Assess. 26 (2). p. 310–334. doi:10.1080/10807039.2018.150832.

Aghzar N., Berdai H., Bellouti A. and Soudi B. (2002). Pollution nitrique des eaux souterraines au Tadla (Maroc). Revue des sciences de l'eau / Journal of Water Science. 15 (2). p. 459-492.

Al-Qawati M., Azami Idrissi Y. , Alemad A., Belhaili I., Marc I., Baichouti F., El Kharrim K. and Belghyti D. (2015). Analyse et Contrôle de la qualité physico-chimique des eaux souterraines De la région Sidi Allal Tazi-Gharb-Maroc. Inter. J. Innov. Applied Studies. 13 (2) . p. 420-429.

Anonymous. (2009). Etat de la qualité des ressources en eau au Maroc, année 2007-2008 ; Octobre 2009. Secrétariat d 'Etat auprès du Ministère de l 'Energie, des Mines, de l'Eau et de l'Environnement, chargé de l'Eau et de l'Environnement, Département de l'Eau. 6 pages. http://www.cleantechconseil.com/file/ea_qualite.pdf (accesed on january 21th, 2022).

Arauzo M. (2017). Vulnerability of groundwater resources to nitrate pollution: a simple and effective procedure for delimiting Nitrate Vulnerable Zones. Science of the Total Environment, 575: 799-812.

Attar O., Brouziyne Y., Bouchaou L. and Chehbouni A. (2022). A Critical Review of Studies on Water Resources in the Souss-Massa Basin, Morocco: Envisioning a Water Research Agenda for Local Sustainable Development. Water 14 (9). p. 1355. https://doi.org/10.3390/w14091355

Aziane N., Larif M., Khaddari A., Ebn Touhami M., Zouahri A., Nassali H., and Elyoubi M.S. (2020). State of nitric pollution of the Mnasra aquifer, Coastal zone of the Gharb plain (Morocco). Mor. J. Chem. 8(4). p. 965-981.

Baghapour, MA, Talebbeydokhti N., Tabatabee H., Fadaei Nobandegani A. (2014). Assessment of groundwater nitrate pollution and determination of groundwater protection zones using DRASTIC and composite DRASTIC (CD) models: the case of Shiraz Unconfined Aquifer. J. Health Sci. Surveill. Syst., 2. p. 54-65

Bahrami M., Zarei A. R., and Rostami F. (2020). Temporal and spatial assessment of groundwater contamination with nitrate by nitrate pollution index (NPI) and GIS (case study: Fasarud Plain, southern Iran). Environ. Geochem. Health. 42 (7).

Balamurugan P. , Shankar K. and Kirubakaran M. (2020). Evaluation of drinking and irrigation suitability of groundwater with special emphasizing the health risk posed by nitrate contamination using nitrate pollution index (NPI) and human health risk assessment (HHRA), Human and Ecological Risk Assessment: An International Journal. 27 (5). p. 1324-1348. DOI: 10.1080/10807039.2020.1833300

Barakat A. (2020). Groundwater NO_3 concentration and its potential health effects in Beni Moussa perimeter (Tadla plain, Morocco). Geoenvironmental Disasters. 7 (14). https://doi.org/10.1186/s40677-020-00149-9

Benicha M., Ayadi M., Zantar S. and Mrabet R. (2022). Sorption–desorption equilibria of Deltamethrin in two contrasting agricultural soils of Loukkos North-west of Morocco. Afrimed J. 135. p. 16-36.

Benicha M., Maadani S., Chabbi M, and El Amrani A. (2016a). Evaluation d'utilisation des pesticides par la détermination des indicateurs agro-environnementaux : cas du fraisier du Loukkos. In 10° congrès AMPP: Gestion des risques phytosanitaires liés aux organismes nuisibles. Rabat Morocco, 22-23 November 2016.

Benicha M., Maadani S., and Chabbi M. (2016b). Influence des activités agricoles sur la qualité physico-chimique des eaux souterraines : cas de la nappe R'mel du Loukkos. In 5ème Colloque International AMEDD "Environnement et Développement Durable », Sous le thème "Changements Climatiques : Causes, Impacts, Atténuation et Adaptation". Rabat, Settat Morocco, 10-15 october 2016.

Benkaddour R., Hammouti B., El-Mrabet M., Dahchour A, Aouniti A, Haouadi B and Ouardi A. (2004). Salinité et pollution par les nitrates des eaux souterraines de la plaine de Triffa. Actes Inst. Agron. Vet. (Maroc). 24 (3-4) : 147-158.

Benkaddour R., Merimi I., Szumiata T., Hammouti B. (2020). Nitrates in the groundwater of the Triffa plain Eastern Morocco. Materials Today: Proceedings. 27 (4). p. 3171-3174. ISSN 2214-7853. https://doi.org/10.1016/j.matpr.2020.04.120.

Berdai H., Soudi B. and Bellouti A. (2004). contribution a l'étude de la pollution nitrique des eaux souterraines en zones irriguées : cas du Tadla. Revue H.T.E. 128. p. 65-87.

Bouita M., El Madhi Y., Sbai H., Bouita I., El Bakouri A., Ibrahimi E.M. and Chakir E.M. (2021). Assessment of nitrogen pollution of groundwater in the Maamora Gharb aquifer, Morocco. Egyptian J. Aquatic Biol. Fisheries. 25 (3). p. 739-758.

Official Bulletin. (2002). Normes marocaines de l'eau potable, Bulletin officiel du Maroc, N° 5062 du 30 ramadan 1423.

Chapman D. and Kimstach V. (1996). Selection of water quality variables. Water quality assessments: a guide to the use of biota, sediments and water in environment monitoring. Chapman Edition, 2nd ed. E & FN Spon, London, p. 59-126.

Chen J., Qian H., Gao Y., Wang H. and Zhang M. (2020). Insights into hydrological and hydrochemical processes in response to water replenishment for lakes in arid regions. J Hydrol. 581. p.124386. doi:10.1016/j.jhydrol.2019.124386

Chen J., Wu H. and Qian H. (2016). Groundwater nitrate contamination and associated health risk for the rural communities in an agricultural area of Ningxia, northwest China. Expo Health. 8 (3). p. 349–359. doi:10.1007/s12403-016-0208-8

Chouraichi M. and Achkar M. (2001). Pratiques des agriculteurs en matière de conduite des cultures et maitrise de la fertilisation. H.T.E. 118. p. 73-80.

El Hamidi M.J., Larabi A. and Faouzi M. and Essafi R. (2019). Développement d'un sih pour l'amélioration des connaissances techniques sur le réservoir et le fonctionnement hydrodynamique de la nappe de Rmel (Maroc). Revue des sciences de l'eau / Journal of Water Science, 32 (2). p. 147–162. https://doi.org/10.7202/1065204ar

El Mountassir O., Bahir M., Ouazar D., Chehbouni A. and Carreira P.M. (2022). Temporal and spatial assessment of groundwater contamination with nitrate using nitrate pollution index (NPI), groundwater pollution index (GPI), and GIS (case study: Essaouira basin, Morocco). Environ. Sci. Pollut. Res. 29. p. 17132–17149. https://doi.org/10.1007/s11356-021-16922-8.)

Fekkoul A., Zarhloule Y., Boughriba M., Kabbabi A., Machmachi I. and Chafi A. (2011). Contamination par les pesticides organochlorés et les nitrates des eau souterraines du système aquifère de la plaine des Triffa (Maroc nord oriental). Science Lib. 3. p. 1-6.

Freishtat R.J., Chamberlain J.M., Johns C.M.S., Teach S.J., Ronzio C., Murphy-Smith M.M., et al. (2005). A cross-sectional ED survey of infantile subclinical methemoglobinemia. Am. J. Emerg. Med. 23. p. 574–576.

Ghheda K. (2003). Impact de la pollution sur les ressources en eau utilisées pour l'alimentation en eau potable «Cas de la nappe R'MEL». In 2ème colloque national de l'ACRPE: problématique de la réservation de l'eau entre la gestion, la pollution et la législation, ONEP/DCE/3/03, Rabat Morocco, 20 march 2003 .

Hssaisoune M., Bouchaou H., Sifeddine A., Bouimetarhan I. and Chehbouni A. (2020). Moroccan Groundwater Resources and Evolution with Global Climate Changes. Geosciences. 10(2). 81. https://doi.org/10.3390/geosciences10020081

Laftouhi N.E.; Vanclooster M.; Jalal M.; Witam O.; Aboufirassi M.; Bahir M.; Persoons É. (2003). Groundwater Nitrate Pollution in the Essaouira Basin (Morocco). Comptes Rendus Geosci. 335. p.307-317.

Malki M., Choukr Allah R., Bouchaou L., Ait Brahim Y., Hirich A. and Reichert B. (2016). Evolution of Groundwater Quality in Intensive Agricultural Zone: Case of Chtouka-Massa Aquifer. Morocco. Arab. J. Geosci. 9: 566.

Massoudinejad M., Ghaderpoori M., Jafari A., Nasehifar J. Malekzadeh A. and Ghaderpoury A. (2018). Data on nitrate and nitrate of Taham dam in Zanjan (Iran). Data Brief. 17, 431–437.

MedECC. (2020). Climate and Environmental Change in the Mediterranean Basin – Current Situation and Risks for the Future. First Mediterranean Assessment Report. Cramer W., Guiot J. and Marini K. Edition. France. 632 pages. ISBN: 978-2-9577416-0-1/ DOI: 10.5281/zenodo.7224821.

Moukhliss M., Abdeslam T., Khattabi Rifi S., El fathi B., Elbilali A. and Souabi S. (2021). Assessment of groundwater quality in Berrechid Acquifer, Morocco. Moroccan J. Chemistry. 9 (4). p. 800-812.

Mourabit F., Ouassini A., Azmani A. and Muelle R. (2002). Nitrate occurrence in the groundwater of the Loukkos perimeter. J Environ Monit. 4 (1) . p. 127-30. doi: 10.1039/b107323k.

Naik P.K., Tambe J.A., Dehury B.N. and Tiwari A.N. (2008). Impact of urbanization on the groundwater regime in a fast growing city in central India. Environmental Monitoring and Assessment 146. p. 339–373.

Obeidat M.M., Awawdeh M., Al-Rub F.A. and Ahmad Al-Ajlouni A. (2012). An Innovative Nitrate Pollution Index and Multivariate Statistical Investigations of Groundwater Chemical Quality of Umm Rijam Aquifer (B4), North Yarmouk River Basin, Jordan. Wat. Quality Monit. and Asses. 169-188.

ONEP, Office National de l'eau Potable. (2001). Renforcement de l'AEP de la ville de Larache. Etude de la qualité de la nappe du R'mel. Bellet Consult GMBH.

Ouhamdouch S., Bahir M., Ouazar D., Carreira P.M. and Zouari K. (2019). Evaluation of Climate Change Impact on Groundwater from Semi-Arid Environment (Essaouira Basin, Morocco) Using Integrated Approaches. Environ. Earth Sci. 78. p.1-14.

Qian H., Chen J. and Howard K.W. (2020). Assessing groundwater pollution and potential remediation processes in a multi-layer aquifer system. Environ. Pollut. 263. p. 114669. doi:10.1016/j.envpol. 2020.114669

Rodier J. (1996). L'Analyse de l'eau, eaux naturelles, eaux résiduelles, eau de mer. DUNOD 8ème Edition. 1383 pages.

Sarra EL-H., Bedoui I., Aghrib N., Lebkiri M., Challi D., Alaizari H. and Fadli M. (2018). Groundwater quality assessment using nitrate pollution index (NPI): Case study in Doukkala-Abda Region, Morocco. Journal of Xi'an Shiyou University, Natural Science Edition. 17 (12). p. 286-293**.**

Sarti O., Otal E., Morillo J. and Ouassini A. (2021). Integrated assessment of groundwater quality beneath the rural area of R'mel, Northwest of Morocco. Groundwater for Sustainable Development, 14. p.100620. [doi: https://doi.org/10.1016/j.gsd. 2021.100620]

Sehlaoui H., Hassikou R., Dakak H., Zouahri A., El Hasini S., Iaaich H., Ghanimi A. and Douaik A. (2022). Nitrate contamination and associated health risks of the Benslimane groundwater, Morocco. Environ Geochem Health. 44 (7). p. 1-16. DOI: 10.1007/s10653-021-01186-5.

Spalding R. F. and Exner M. E. (1993). Occurrence of nitrate in ground water- A review. J. Environ. Quality. 22. p. 392-402. doi.org/10.2134/jeq1993. 00472425002200030002x

Tagma T., Hsissou Y., Bouchaou L., Bouragba L. and Boutaleb S. (2009). Groundwater nitrate pollution in Souss-Massa basin (south-west Morocco). African J. Environ. Sci. Technol. 3 (10). p. 301-309.

Tanji A., Benicha M. eandt Mamdouh M. (2014). Techniques de production du fraisier : Résultats d'enquêtes au Loukkos, Bulletin de Transfert de Technologie en Agriculture, N° 201/juillet, 9p.

Tanji A., Benicha M. and Mamdouh M. (2015). Contribution à l'étude des adventices associées aux cultures dans les sols sableux du périmètre irrigué du Loukkos : cas du fraisier et de l'arachide. Rev. Maroc. Protec. Plantes. 7. p. 67-80.

Tanji A., Benicha M., Hamim A. and Mrabet R. (2012). Gestion des adventices et des problèmes phytosanitaires des cultures maraichères : cas de la pomme de terre de saison au Loukkos. In Symposium National « Protection Intégrée de la Pomme de Terre ». Settat, Morocco, 21 March 2012.

Teng Y., Zuo R., Xiong Y., Wu J., Zhai Y. and Su J. (2019). Risk assessment framework for nitrate contamination in groundwater for regional management. Sci Total Environ. 697. p. 134102. doi:10. 1016/j.scitotenv.2019.134102

Tian H., Liang X., Gong Y., Qi L., Liu Q., Kang Z., Sun Q. and Jin H. (2019). Health risk assessment of nitrate pollution in shallow groundwater: a case study in China. Polish J Environ Studies. 29 (1). p. 827–839. 10.15244/pjoes/104361.

Venkateswari R., Ganesh R., Deenadayalan M., Mahender E., Ramachandran B. and Janakiraman L. (2007). Transient methemoglobinemia in an infant. Clinic Brief. 74. p. 1037–1038.

WHO (2011). World Health Organization Guidelines for drinking water quality, 4th Edition. World Health Organization, Geneva. 564 pages.

Zhang Q., Xu P, Qian H. (2020). Groundwater quality assessment using improved water quality index (WQI) and human health risk (HHR) evaluation in a semi-arid region of northwest China. Expo Health. 12 (3):487–414. doi:10.1007/s12403-020-00345-w.