Preliminary assessment of groundwater quality in the alluvial aquifer using GIS and water quality indices in the Goulmima - Tadighoust area, south-east, Morocco

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Abstract. The Goulmima-Tadighoust region faces significant challenges with its alluvial aquifer, mainly due to intensive groundwater exploitation driven by the Green Morocco plan. This study, conducted in 2019 and 2021, investigates the deterioration of groundwater quality in the area, mapping the Quaternary aquifer using physicochemical parameters. Geographic Information System (GIS) was employed to create thematic maps for spatial analysis. Groundwater in the region exhibits two distinct chemical facies, impacted by salinization processes, leading to elevated electrical conductivity. Water quality indicators suggest unsuitability for irrigation due to high salinity and alkalinity. Nitrate pollution is observed, posing a moderate health risk. Factors contributing to water quality degradation include natural contamination, untreated wastewater discharge, improper solid waste disposal, and geological factors. A considerable portion of the study area exhibits a Water Quality Index (WQI) exceeding 200, indicating poor water quality, particularly south of Tadighoust and east of Goulmima oasis.

Keywords. Groundwater quality, WQI, oasis, GIS, Rheris basin.

1. Introduction

The southeastern region of Morocco faces a potential threat of overexploitation, attributed to the impacts of climate change and intensified agricultural pumping [1, 2]. In the Goulmima-Tadighoust area, the primary groundwater source is the Quaternary alluvial aquifer situated along streams. Observations of the piezometric level reveal a substantial decline in the water table, particularly noticeable after the drought experienced in the 1980s [3]. The quality of water is at risk not only from natural contaminants but also from an increase in various pollution sources such as fertilizers and natural sources [4, 5], the release of untreated wastewater, indiscriminate disposal of solid waste, and urban expansion. The lack of sufficient data, especially in lower-income nations, severely hampers the early detection of water quality issues [6, 7, 8].

Hence, this study focused on examining the groundwater quality in the Goulmima-Tadighoust region to evaluate its appropriateness for both domestic use and irrigation. The specific objectives of this paper are: (i) to investigate the hydrochemical characteristics and understand the origins of salinization processes in the alluvial aquifer's groundwater, and (ii) to offer a preliminary assessment of its suitability for domestic and agricultural purposes.

2 Materials and methods

2.1 The study area

The study area is part of the Rheris watershed located in the southeastern part of Morocco (Fig. 1). In the study area, outcropping formations are of sub-tabular Cretaceous and Tertiary age, ranging from the oldest to the most recent: Cenomanian sandstone, clays, marls and sands with marl, limestone horizons; Turonian limestones, sandstones and red marls with limestone intercalations; Plio-quaternary formations consisting of conglomerates and alluvium.

The region's primary irrigation supply is groundwater. The Goulmima-Tadighoust groundwater is an unconfined aquifer that runs from NE to SW and is mostly made up of quaternary alluvium [9]. Rainfall infiltration, irrigation water return, flood inflows from sub-Cenomanian outcrops, and deep inflows from the Turonian often renew the water table. Traditional wells and khettaras are the primary sources of water table exploitation.

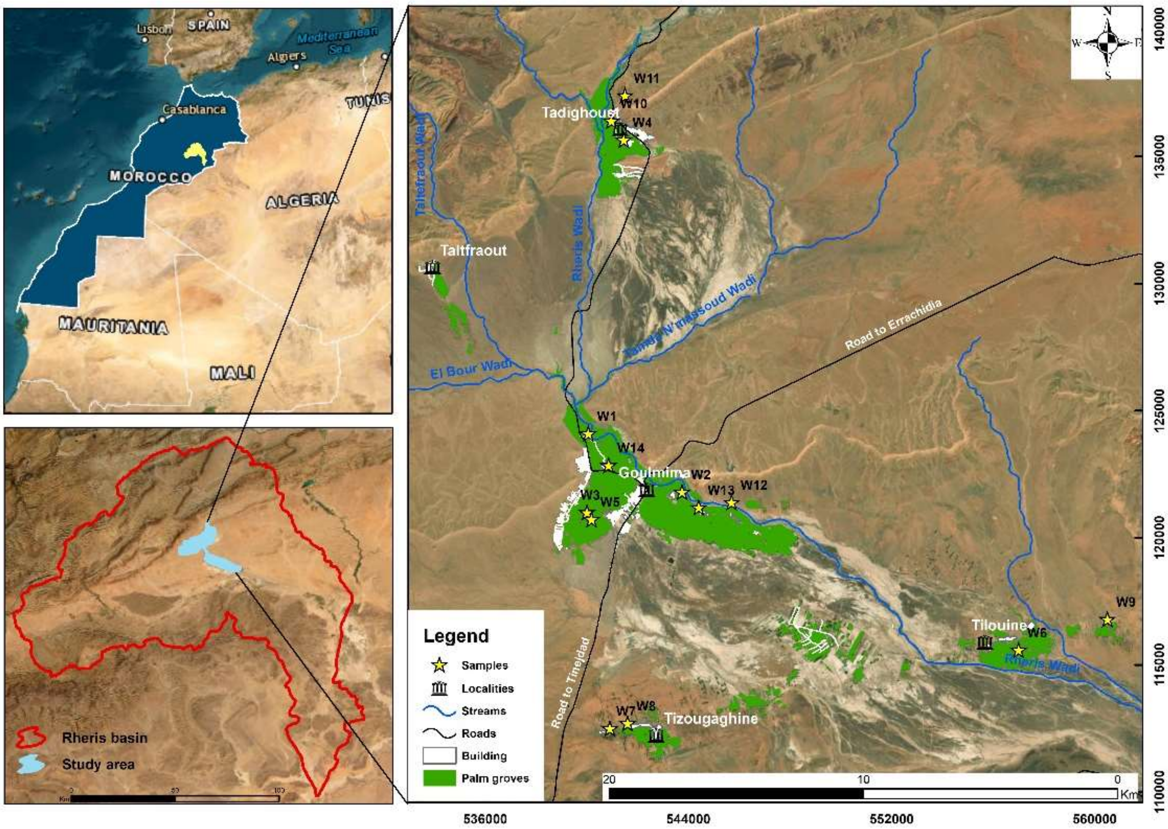

Fig. 1. Situation of the study area

2.2 Groundwater sampling and analysis

The samples were taken in pre-cleaned glass containers and stored at 4°C until they were analysed in the laboratory. Parameters such as temperature, hydrogen potential (pH), and electrical conductivity (EC) were measured in situ using a portable multi-parameter probe. Analyses included the determination of suspended solids by filtration, chemical oxygen demand by oxidation with potassium dichromate, phosphates and nitrates by spectrophotometry, and sulphates, chlorides, calcium, and magnesium by gravimetric method. The elements sodium and potassium were analyzed by flame photometry. Additionally, the data acquired during the fieldwork has been methodically cross-verified and complemented by the supplementary data supplied by the Guir-Ziz-Rheris Hydraulic Basin Agency (ABHGZR). The validity of these analyses was verified by calculating ionic balance (IB) values using the following formula [10]:

$$IB = \frac{(\sum Cations)-(\sum Anions)}{(\sum Cations)+(\sum Anions)} * 100 \qquad (1)$$

2.3 Water quality indices calculations

2.3.1 Water quality index (WQI)

The Water Quality Index (WQI) was used to assess the adequacy of Goulmima-Tadighoust area water resources for domestic use. This study selected eleven water quality metrics as priority parameters for monitoring [11, 12], including pH, Total Dissolved Solids (TDS), concentrations of calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}), potassium (K^{+}), bicarbonate ($HCO3^{-}$), sulfate ($SO4^{2-}$), chloride (Cl^{-}), nitrate ($NO3^{-}$), and Electrical Conductivity (EC). The WQI was calculated using these parameters as follows:

$$Wi = \frac{wi}{\sum_1^n wi} \qquad (2)$$

$$Qi = \frac{Ci}{Si} \times 100 \qquad (3)$$

$$WQI = \sum_1^n Wi \times Qi \qquad (4)$$

In the context of the analysis, *Wi* represents the weight assigned to each parameter, with *n* indicating the total number of parameters under consideration. The term wi signifies the relative weight assigned to each specific parameter. Additionally, *Qi* is employed to assess the overall water quality, while *Ci* denotes the concentration of a single physicochemical parameter in each water sample. *Si* corresponds to the World Health Organization (WHO) drinking water standard established for each physicochemical parameter.

2.3.2 Nitrate pollution index (NPI)

One valuable tool for assessing nitrate pollution in groundwater is the Nitrate Pollution Index (NPI), which provides a numerical representation of the contamination level [13]. The NPI is determined using the following formula:

$$NPI = \frac{Cs-HAV}{HAV} \qquad (5)$$

In the equation, *Cs* represents the measured concentration of nitrate in a specific sample, while *HAV* stands for the human-acceptable value of nitrate, commonly set at 50 *mg/L* according to the World Health Organization (WHO) guidelines from 2022.

3. Results and discussion

3.1 Piper diagram and Hydrochemical facies

Piper's diagram provides a valuable tool for estimating the proportion of various chemical elements and their categorization [14]. Through plotting the results of water analysis on the diagram (Fig. 2), we observe the predominance of two distinct phases. Firstly, we realize the prevalence of the mixed Cl-SO4-Ca-Mg phase in most of the wells. This suggests the presence of salt-bearing layers, which could be linked to the geological composition of the aquifer and the regional climate conditions. Conversely, we identify the SO4-Cl-Na phase in wells W6, W8, and W9. This phase indicates the presence of marl, clay formations, and gypsum in certain locations.

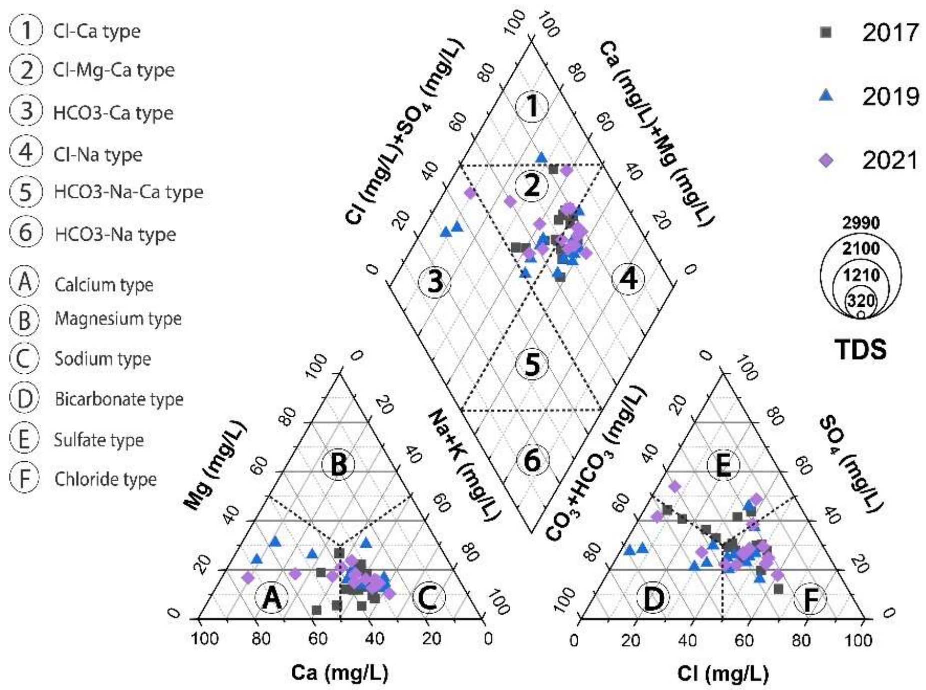

Fig. 2. Hydrochemical facies diagram of the study area

3.2 Assessment of groundwater quality

3.2.1 Water quality index (WQI)

Results indicates a decline in groundwater quality in the Goulmima-Tadighoust region between 2019 and 2021. The calculated water quality index for 2019 reveals that 57.14% of the samples and 21.43% of the samples fall into the poor and very poor categories for drinking water quality, respectively (Fig. 3a). However, sample W1 stands as the sole exception, exhibiting excellent quality, while samples W7 and W8 are classified under the good quality category. In the 2021 dataset, both classes (III) and (IV) are represented by an identical percentage of 42.86%, while the remaining two classes, (I) and (V), each constitute 7.14% of the samples (Fig. 3b). This shift toward a higher percentage of poor to very poor quality water indicates a concerning trend in deteriorating groundwater quality in the region. It emphasizes the importance of continued monitoring and potential remediation efforts to address these quality issues.

The spatial distribution of the Water Quality Index (WQI) parameter demonstrates significant variations in groundwater quality across the study area. Overall, the WQI maps for both 2019 and 2021 indicate that the majority of the study area exhibits a WQI > 200, indicating poor water quality in areas situated to the east of the Tadighoust and Goulmima palm groves, as well as in certain wells downstream of the region in close proximity to the Rheris Wadi.
In contrast, Site W1 displays good to excellent water quality and is positioned upstream of the study area, interfacing with the Jurassic formations of the High Atlas. This variation in water quality is likely influenced by the region's deficit in rainfall, a consequence of the ongoing impact of climate change. The decreasing trend in piezometric levels from year to year corresponds with an upward trend in Electrical Conductivity and, consequently, a degradation in water quality.

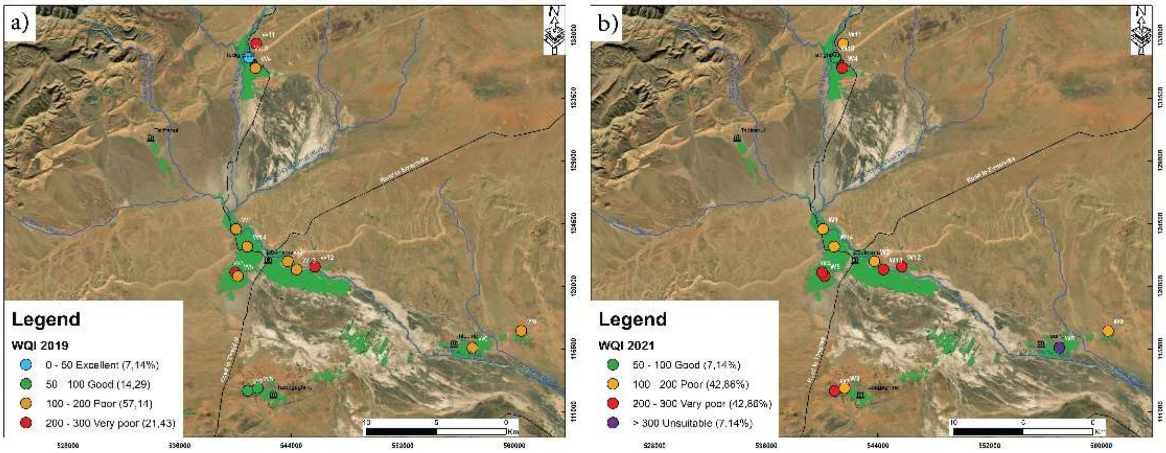

Fig. 3. Spatial variation of water quality index in the study area, a) 2019 and b) 2021 campaigns

3.2.2 Assessment of irrigation water quality

The USSL diagram, established by the U.S. Salinity Laboratory Staff in 1954 [15], has been employed to assess water salinity using parameters like electrical conductivity (EC) and the sodium absorption ratio (SAR). The majority of groundwater samples are distributed within the C4S2 and C3S1 zones (Fig. 4). 57.14% of groundwater samples fall into the C4S2 zone, while 21.42% of samples are in the C3S1 zone. The categories C2S1 and C4S3 each account for 8%, with one sample falling into each of these categories. Notably, the lone sample displaying good quality, corresponding to the C2S1 category, is found in Mouy (W10), situated upstream of the study area. Conversely, the sample indicating very poor quality is located in Anfar (W6), positioned in the central part of the study area, which includes a palm grove and a dense population.

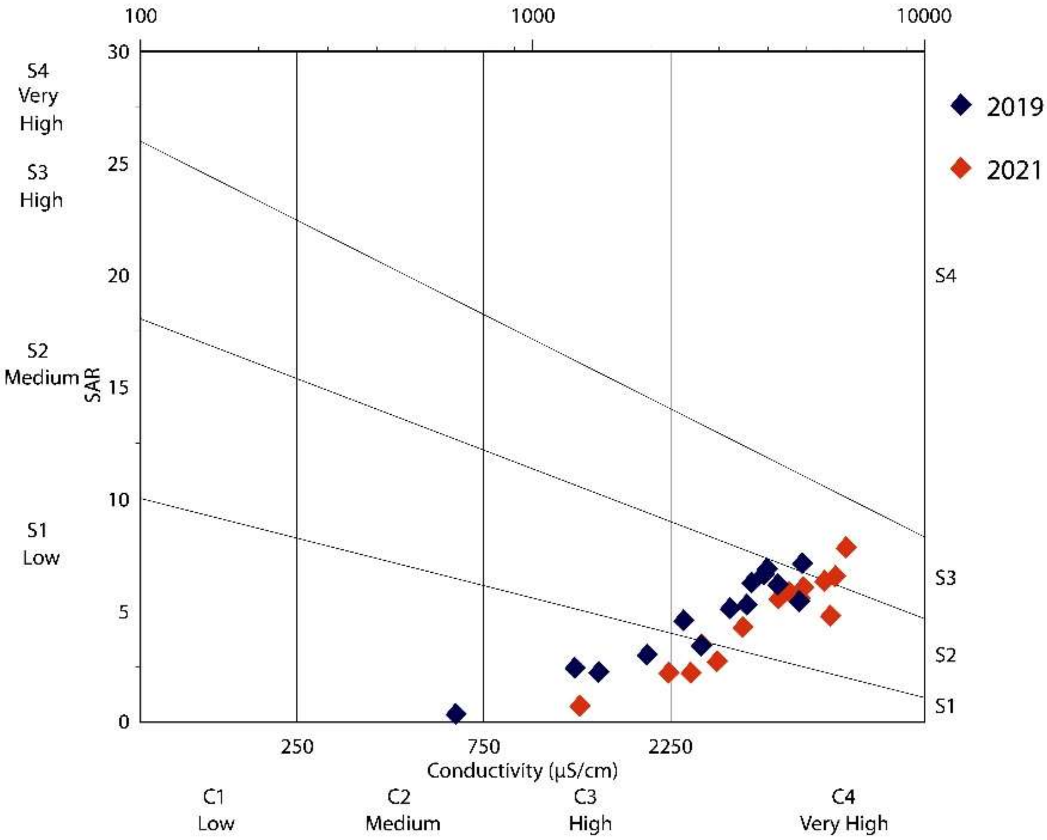

Fig. 4. United States Salinity Laboratory diagram for irrigation water classification

3.2.3 Nitrate pollution index (NPI)

In the research area, the NPI values spanned from -0.95 to 2.46, with an average of -0.36 for the 2019 campaign. The NPI ranged from -1 to 1.58, with an average of -0.13. Based on the groundwater classification, it's evident that 92.86% of the sampling locations were categorized as clean, indicating minimal nitrate pollution, while one site, representing 7.14% of all sampling sites, was classified as slightly polluted. Notably, Figure 5 highlights one sampling site, W12, which exhibited a particularly significant type of groundwater nitrate contamination.

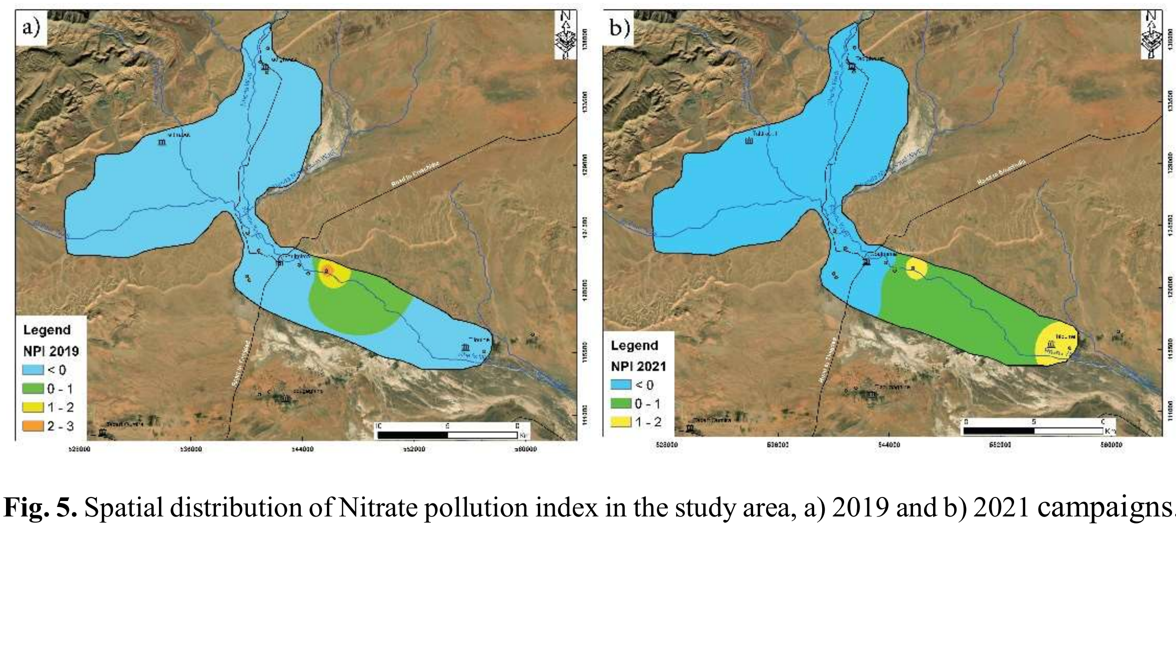

Fig. 5. Spatial distribution of Nitrate pollution index in the study area, a) 2019 and b) 2021 campaigns.

4. Conclusion

The groundwater samples from the Goulmima aquifer in the study area were found to be suitable for irrigation purposes, indicating good water quality for agricultural practices. The study highlights the importance of managing and preserving these water sources to ensure continued agricultural productivity in the region. Nitrate contamination and salinization are the major concerns in groundwater quality, and numerous indices were used to assess and quantify the extent of contamination. The deterioration of water quality in the region is attributed to natural contamination as well as various sources of pollution such as untreated wastewater discharges, uncontrolled solid waste discharges, and urbanization.

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