BIO Web of Conferences **115**, 02003 (2024) https://doi.org/10.1051/bioconf/202411502003
RENA23

Assessment of physicochemical and microbiological quality using the SEQ-Eau approach for groundwater in the Saïss basin (Fez-Meknes region, Morocco)

Hajar Jaddi[1,*], *Abdellah* El-Hmaidi[1], *My Hachem* Aouragh[1], *Jihane* Saouita[1], *Habiba* Ousmana[1], *Zineb* Iallamen[1], *M'hamed* Boufala[2], *Hind* Ragragui[1], *Zahra* Kasse[3], *Anas El Ouali*[4], *Abdelhakim* Lahjouj[1]

[1]Department of Geology, Faculty of Sciences, Water Science and Environmental Engineering Team, Moulay Ismail University, BP 11201, Zitoune, 50000 Meknes, Morocco.
[2]ONEE, National Office for Electricity and Drinking Water, Water Branch, 50000 Meknes, Morocco
[3]Anassi High School (Annex 2), Ministry of National Education, 50000 Meknes, Morocco
[4]Department of Geomorphology and Geomatics, Scientific Institute, Mohammed V University, Avenue Ibn Batouta, BP 703, Agdal, Rabat, Morocco.

Abstract. The Saïss water table is one of Morocco's major agricultural regions. Its water resources satisfy domestic, agricultural, industrial, and tourist needs. The present work focuses on the technique used to detect spatiotemporal variations in the overall physicochemical, microbiological, and heavy metal quality of groundwater in the Saïss basin, as assessed by the SEQ-Eau water quality system. A total of 28 samples were collected during high and low water periods, respectively. The results show that 25% of the stations present average quality during the dry season, and are located mainly in the southern part of the Meknes plateau in the El Hajeb, Boufekrane, and Agouray regions, while this pollution is reduced during the wet season with a percentage of 7.14%. However, the poor quality of groundwater indicates that 75% and 92.85% occupy almost the entire rest of the basin during the dry and wet seasons. Mapping of nitrate pollution of groundwater indicates that the lowest nitrate concentrations were recorded in the southwest part of the aquifer. The highest values were recorded in the center of the study area, with a maximum value of 118 mg/l, which exceeds the Moroccan standard due to the anthropogenic impact of agriculture and water use.

Keywords: Saïss basin, groundwater, SEQ-Eau, nitrate, physicochemical, quality index.

1 Introduction

Groundwater is a precious resource for human life and economic development. Indeed, Groundwater is a vital part of the hydrological cycle and is located within a porous geological formation known as an aquifer. Globally, the majority of freshwater originates from groundwater sources [1] and constitutes a significant portion of the water ressources. However, the growing population, expanding industrial performance, climate change impacts, and intensified agricultural practices have significantly increased the pressure on water resources, particularly on groundwater stored in aquifers, leading to a deterioration in both quantity and quality [2].

Certainly, Ensuring the optimal quality and sufficient availability of water resources is a critical concern for humanity. Guaranteeing both the quality and quantity of water presents a significant challenge. Water quality is especially important because it directly affects human health. Numerous pollutants, such as organic, inorganic, and biological contaminants, can compromise water quality [3-5]. Groundwater contamination by nitrates, in particular, stands out as a significant environmental concern [6, 7].

This study aims to investigate the spatiotemporal fluctuations in the physicochemical attributes, microbiological features, and heavy metals in the groundwater of the Saïss aquifer. This approach relies on the utilization of the water quality assessment system (SEQ-Eau) for a comprehensive analysis. The results

* Corresponding author: hajar.jaddi@edu.umi.ac.ma

will be visually represented through thematic maps generated using specialized geographic information systems (GIS) software. These maps will highlight the spatiotemporal distribution of water characteristics, especially during periods of high and low water levels. In the aquifer system of Fez-Meknes

2 Materials and methods

2.1Study area

The Saïss basin stretches from East to West for 80 km, situated between the Rif Mountain range to the North and the Middle Atlas to the South, from the city of Fez in the East to the Western outskirts of the city of Meknes. It is an intra-mountainous continental basin filled with deposits ranging from the Upper Miocene to the Quaternary, overlaying a Mesozoic and Paleozoic basement. The maximum depth of this basin is approximately 1.5 km in the Northeast and is filled with deposits ranging from the Secondary to the Quaternary, covering a Paleozoic basement. The Meknes plateau contains two main aquifer formations: the Plio-quaternary phreatic aquifer and the deep Lias aquifer [8]. The water supply of the region heavily relies on these aquifers, highlighting their vital role, serving the agricultural, industrial, and potable water demands of the nearby community. The Saïss basin is divided into two sub-basins by a geological structure called the Ain Taoujdate flexure. This flexure extends in a predominantly Northwest-Southest direction and separates the Meknes plateau to the West from the Saïss of Fez, also known as the Saïss plain, to the East [9]. As shown in Figure 1, the altitude of the plain gradually declines towards the North.

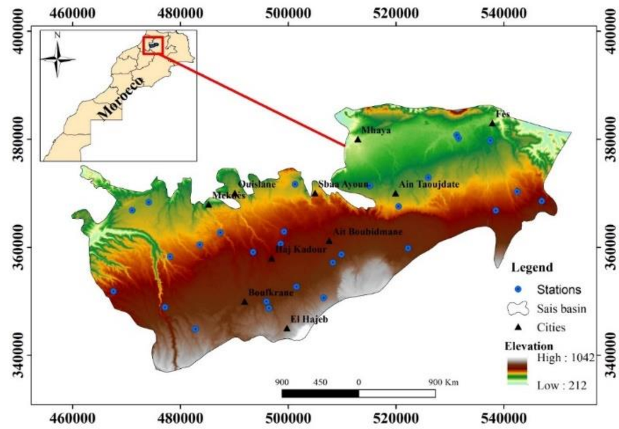


Fig. 1. Geographical area under study and spatial arrangement of sampling locations.

2.2 Data used

The study utilizes data relating to 25 parameters, including analysis data for 14 physicochemical parameters, 3 bacteriological parameters, and 8 heavy metal parameters of groundwater from the Saïss basin aquifer. Water samples were collected from 28 stations over two months during two sampling campaigns conducted successively during the dry summer low-water season (September 2018) and the wet spring high-water season (March 2018). The 25 parameters used in this study include pH, temperature (T°C), electrical conductivity (EC), orthophosphates (PO_4^{3-}), chloride (Cl^-), total dissolved solids (TDS), sulfates (SO_4^{2-}), magnesium (Mg^{2+}), calcium (Ca^{2+}), sodium (K^+), potassium (Na^{2+}), ammonium (NH_4^+), nitrites (NO_2^-), nitrates (NO_3^-), fecal streptococci (FS), , total coliforms (TC), fecal coliforms (FC), manganese (Mn), lead (Pb), zinc (Zn), arsenic (As), cadmium (Cd), iron (Fe), , and chromium (Cr). Evaluation and mapping of the results were conducted using Excel 2016 and ArcGIS 10.4 software.

3 Methodology

3.1 Water Quality Evaluation System (SEQ-Eau)

This system relies on the concept of the weighted quality index, which is computed for each parameter and alteration. Certainly, the values within the ranges established by the new grids for water quality assessment are converted into dimensionless values ranging from 0 for very poor quality to 100 for excellent quality. (Table 1).The index of each parameter is calculated through weighting, while the index of an alteration is determined by averaging the weighted values of the parameters associated with that alteration (IP) [10]. The overall quality index represents the minimum index obtained among all alterations considered. The groundwater quality grid establishes five quality classes, each determined by specific threshold values that must not be exceeded by the different parameters [11]. To visualize the physicochemical, microbiological, and metal quality, a distinct color palette is assigned to each category: Classes of groundwater quality: Excellent (blue), Good (green), FAverage (yellow), Poor (orange), and Very Poor (red).The formula for calculating the weighted index is as follows [11]:

$$IP_{pa}=Ii+ [(I_s – I_i)/ (b_s-b_i)]*(b_s-pa) \qquad (1)$$

Where IP_{pa} represents the weighted index for the analyzed parameter; I_i stands for the lower index; I_s represents the upper index; b_i denotes the lower limit; b_s indicates the upper limit; and *pa* represents the analyzed parameter value.

https://doi.org/10.1051/bioconf/202411502003

Table 1. Simple framework for assessing overall groundwater quality [11, 12].

Alteration	Quality Class		Excellent	Good	Average	Poor	Very poor
	Index		100 80	80 60	60 40	40 20	20 0
1	**Temperature**						
	Temperature	°C	0 - 20	20 - 25	25- 30	30 - 35	35 - 40
2	**Acidification**						
	pH		6.5 – 8.5		8.5 – 9.2	3-6.5 and 9.2-10	
3	**Nitrogenous matter**						
	Nitrites (NO_2^-)	mgO2/l	0.5 - 3	3 - 5	5 - 10	10 - 25	25 - 1000
	TDS	mg/l	<= 300	300 - 600	600 -900	900- 1200	>1200
	DO:Dissolved	mg/l	7 - 10	5 - 7	3 - 7	1 - 3	0 - 1
	Ammonium	$mgNH4^+$	0 – 0.1	0.1 – 0.5	0.5 - 2	2 - 8	8 - 50
4	**Phosphorus matter**						
	Orthophosphates	mg/l	0 – 0.2	0.2 – 0.5	0.5 - 1	1 - 5	5 - 20
	Total P. (TP)	mg/l	0 – 0.1	0.1 – 0.3	0.3 – 0.5	0.5 - 3	3 - 25
5	**Mineralization**						
	EC 25°c	µs/cm	100 - 750	750-1300	1300-2700	2700-3000	3000 -7000
	$SO4^{3-}$	mg/l	1-100	100-200	200-250	250-400	
	Cl^-	mg/l	0-200	200-300	300-750	750-1000	
	Ca^{2+}	mg/l	31-160			<32ou >160	
	Mg^{2+}	mg/l	<50	50-75	75-100	100-400	
	Na^+	mg/l	<200				
6	**Nitrates**						
	Nitrates (NO_3^-)	mg/l	<10	10-25	25-50	>50	
7	**Microorganisms**						
	Fecal coliform (FC)	/100ml	0-20	20-2000	2000-20000	20000-50000	
	Taotal coliform (TC)	/100ml	0-50	50-5000	5000-50000	>50000	
	Fecal streptococci (FS)	/100ml	0-20	20-1000	1000-10000	>10000	
8	**Metallic trace elements**						
	Zinc (Zn)	mg/l	0-0.5	0.5-1	1-5	>5	
	Cadmium (Cd)	mg/l	<=3	<3	3-5	>5	
	Lead (pb)	mg/l	<5	7.5	7.5-50	>50	
	Chromium (Cr)	mg/l	<25	30	40	50	
	Iron (Fe)	mg/l	<=50	125	200	10000	
	Arsenic (As)	mg/l	<=5	7.5	10	100	
	Manganese (Mn)	mg/l	<=20	30	50	1000	
	Copper (Cu)	mg/l	<=0.02	0.02-0.05	0.05-1	>1	

4 Results and discussion

Alternatively, the primary aim of the water Quality assessment system (SEQ-Eau) approach is to precisely identify significant water quality deteriorations, directing pollution control programs accordingly. In this present study, the weighted index will be calculated for each parameter as well as the alteration index for that alteration. Each type of alteration groups parameters of similar nature or with equivalent impact on the aquatic environment.

4.1 Assessment of the SEQ-Eau quality of alterations in various parameters during both high and low water level periods.

The weighting and alteration indices were calculated for all samples representing the collections at the 28 stations during the two successive high and low water seasons in 2018.

4.1.1 Temperature (Alteration 1)

The water temperature shows very good quality across all stations of the aquifer during the high-water period (Fig. 2a). However, during periods of high and low water levels, the temperature quality is classified as moderate for stations located in the Meknes-Boufkrane regions, while the rest of the basin exhibits good quality (Fig. 2b). This degradation in quality is due to the dry season.

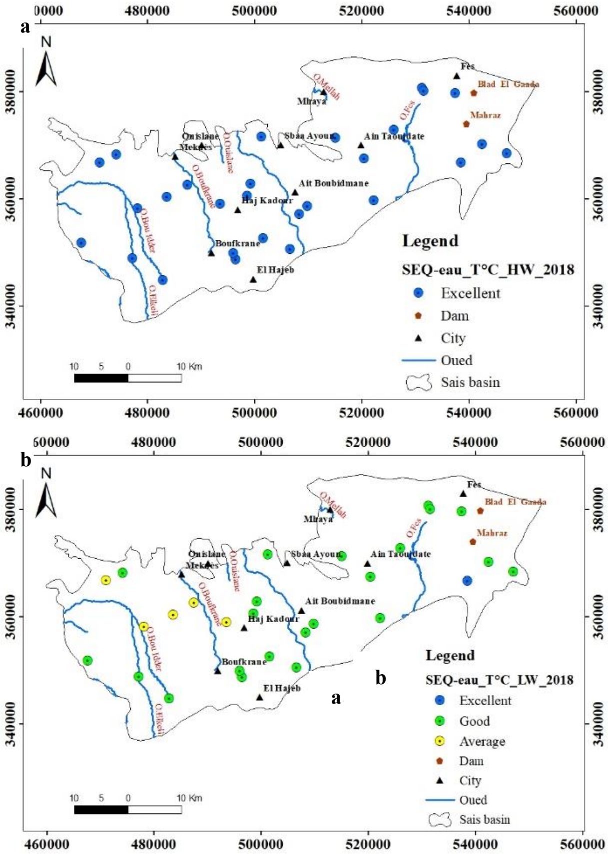


Fig. 2. Maps of alteration quality of temperature during a) the high-water and b) the low-water periods of 2018.

4.1.2 Acidification (Alteration 2)

The alteration of acidification (pH) indicates excellent quality for all the studied stations, whether during high-water or low-water seasons. The groundwater of the Saïss aquifer exhibits low alkalinity. The extreme pH values found range between 7.3 and 8.2 during high water periods, and between 7.0 and 7.6 during low water periods, as illustrated in Figure 3.

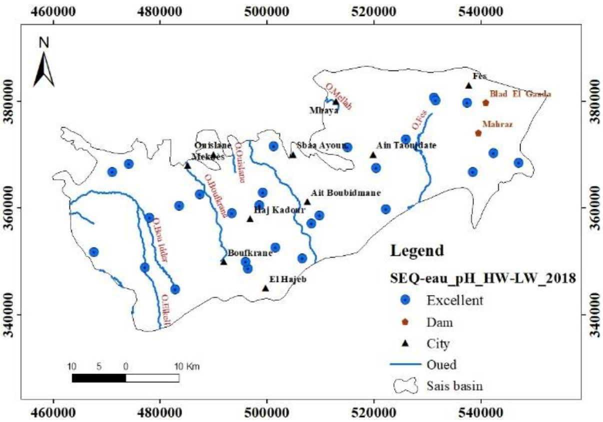


Fig. 3. Map of alteration quality of acidification during the high-water and the low-water periods of 2018.

4.1.3 Nitrogenous Matter (Alteration 3)

The alteration index of nitrogenous matter is represented by the average of the weighted parameter indices, specifically nitrites (NO2-), total dissolved solids (TDS), dissolved oxygen (DO), and ammonium (NH4+), as indicated by the water quality assessment system. According to the water quality assessment system, groundwater quality is typically rated as good in the Fez region and ranges from good to excellent in the rest of the aquifer during both seasons (Fig. 4a and 4b), except one station in the Haj Keddour region where the quality is moderate during the low-water period (Fig.4a).

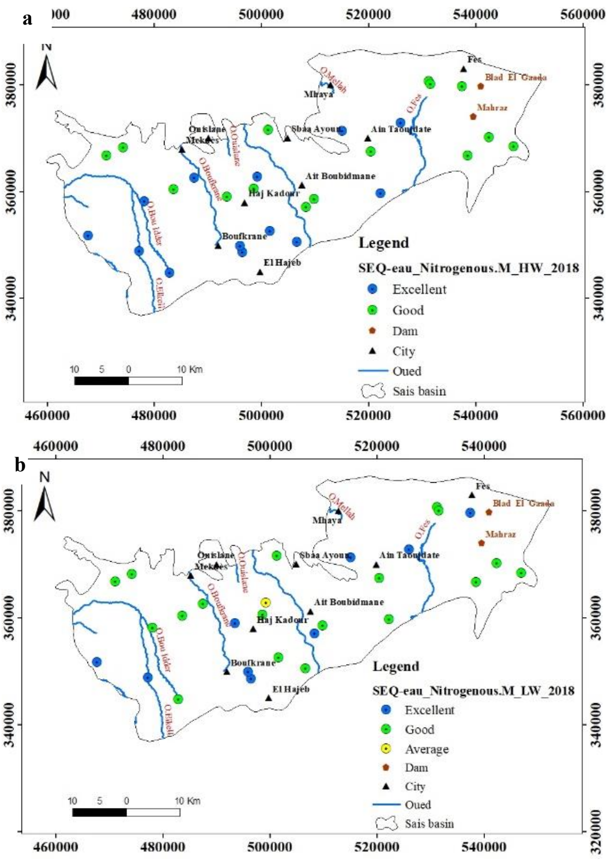


Fig. 4. Maps of alteration quality of Nitrogenous during a) the high-water, and b) low-water periods of 2018.

4.1.4 Phosphorous matter (Alteration 4)

The examination of the outcomes from the water quality assessment system (Fig. 5) reveals that the concentration of orthophosphates in the Saïss basin varies between 0.09 and 0.2 mg/l during both seasons. The levels of PO_4^{3-} are low and fall within the range of 0 - 0.2 [11], for both high and low water periods in the study area, indicating excellent quality at this level. These low to negligible levels suggest that this element does not pose a pollution risk to groundwater.

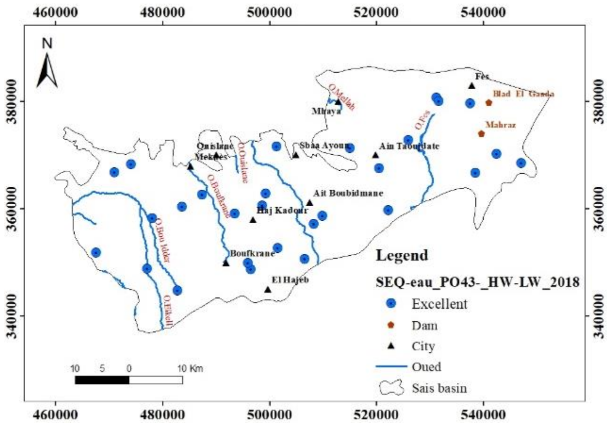


Fig. 5. Map of alteration quality of phosphorous matter during high water and low water of 2018.

4.1.5 Mineralization (Alteration 5)

The groundwater quality assessment system represents the alteration index of mineralization by expressing the average of the weighted indices of parameters like chloride (Cl-), electrical conductivity (EC), , calcium (Ca2+), sulfates (SO_43-), magnesium (Mg2+), and potassium (Na+). It was found that groundwater in Saïss for the "mineralization" alteration exhibits good to very good quality during both high and low water periods (Fig.6).

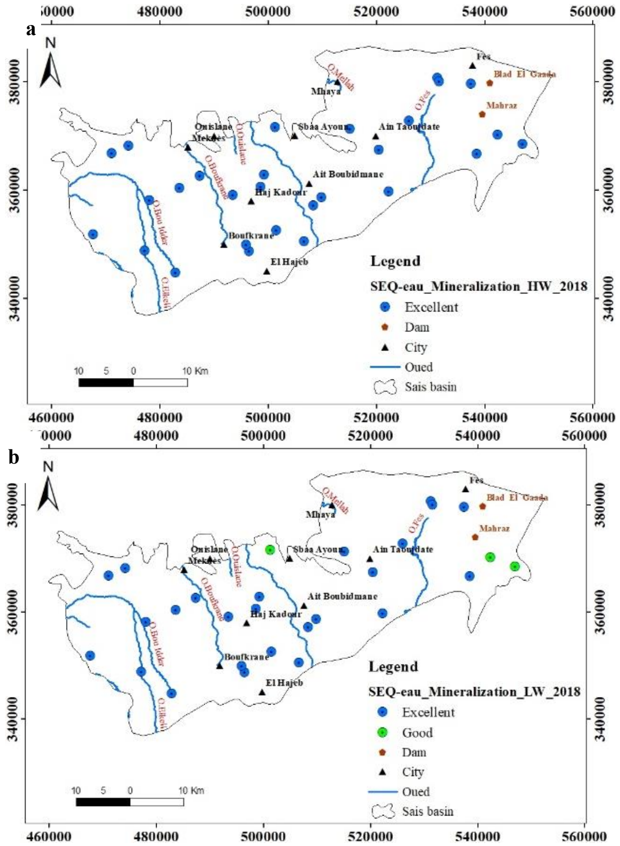


Fig. 6. Maps of alteration quality of mineralization during a) high-water and b) low-water of 2018.

4.1.6 Nitrates (Alteration 6)

Various chemicals, including nitrates, have the potential to percolate leach into the soil and contaminate groundwater [13]. Beneath agricultural areas, nitrates represent the predominant form of nitrogen. They are soluble in water and can readily permeate through the soil to reach the water table. Nitrates are notably the primary nitrogen form found in natural waters, frequently linked to human activities [14].

According to the SEQ-eau, the groundwater quality in the Saïss aquifer concerning nitrate alteration was determined (Fig. 7a and 7b). The concentration of nitrates exhibits a minimum value that influences poor water quality, covering almost the entirety of the basin, except for two stations located successively in the El Hajeb region and along the Sebou River during the high-water period (Fig. 7a). Conversely, this quality is improved to moderate quality in the El Hajeb-Boufkrane area during the period of low water flow, while the stations in the Meknes-Haj Kaddour and Fez-Taoujdate-Mhaya regions show poor quality (Fig. 7b). The degradation of groundwater quality is attributed to high nitrate concentrations in most stations of the saiss basin, exceeding the critical threshold of 50 mg/l during both seasons.

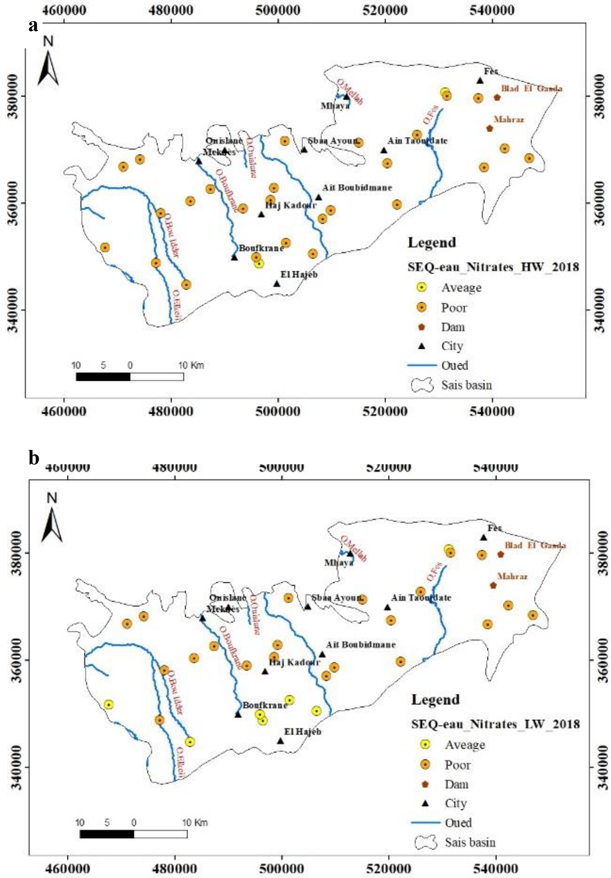
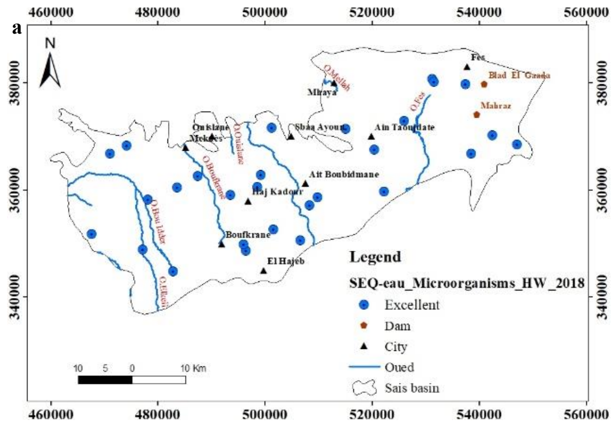


Fig. 7. Maps of alteration quality of nitrates during a) high-water, and b) low-water of 2018.

4.1.7 Microorganisms (Alteration 7)

The mean value of the weighted indices of the three parameters, namely fecal coliforms (FC), total coliforms (TC), and fecal streptococci (FS), following the water quality assessment system, constitutes the index reflecting the alteration of microorganisms.

Overall, the groundwater quality of the Saïss aquifer is excellent during the high-water period, while this quality has become good in the eastern part of the aquifer, particularly in the regions of Mhaya and Fez, whereas the rest of the basin remains in the excellent class during the low-water period, as indicated in Figures 8a and 8b, respectively.



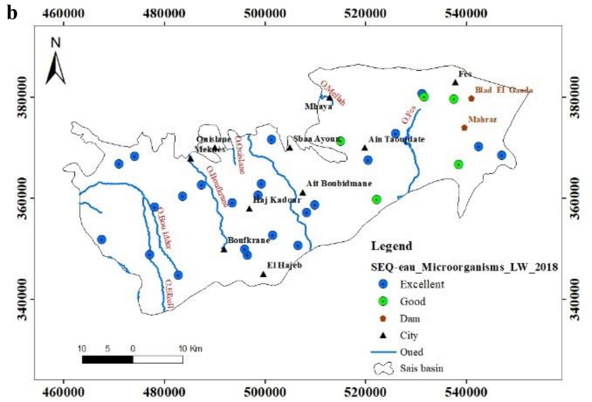


Fig. 8. Maps of alteration quality of microorganisms during a) high-water and b) low-water of 2018.

4.1.8 Metallic elements (Alteration 8)

The weighted average of parameters indices, cadmium (Cd), iron (Fe), arsenic (As), chromium (Cr), zinc (Zn), manganese (Mn), lead (Pb) and copper (Cu), as indicated by SEQ-eau, represents the alteration index of metallic elements. Figure 9 depicts the results obtained by the groundwater quality assessment system for both high and low water periods, showing very good quality across the entire aquifer. This indicates that the waters in the study area were not affected by heavy metal pollution during the two seasons of the year 2018.

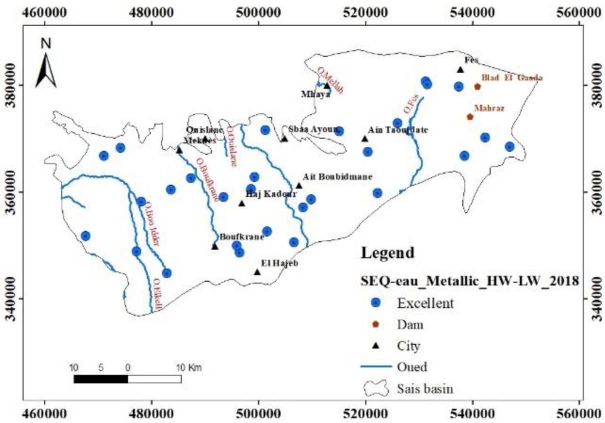
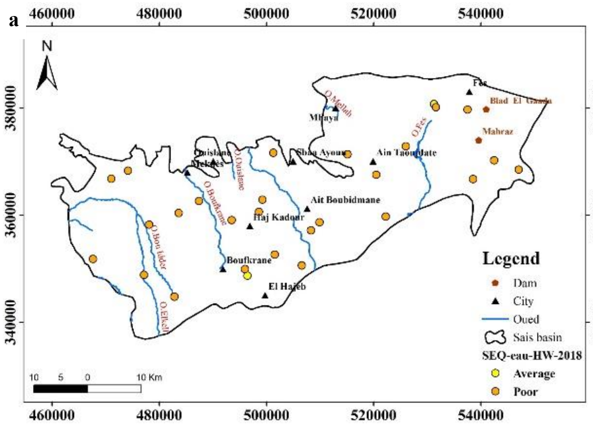


Fig. 9. Map of alteration quality of metallic matter during high water and low water of 2018.

4.2 Quality evaluation: SEQ-physicochemical

The water quality assessment system facilitated an evaluation of the physicochemical quality of water at each station, taking into account six alterations: temperature, acidification, nitrogenous matter, phosphorous matter, mineralization, and nitrates, during both seasons (Fig. 10a and 10b). Overall, the water quality recorded for the 28 stations during the high-water period indicates poor quality (Fig. 10a), during the low-water period, this quality improves to reach the moderate class at stations located in the El Hajeb-Boufkrane regions (Fig. 10b). However, the stations located in the regions of Meknes-Haj Kaddour and Fez-Taoujdate-Mhaya continue to exhibit poor water quality.

These poor qualities are attributed to the increase in nitrate levels in groundwater, potentially resulting from the leaching of fertilizers applied in agricultural soils within the Saïss aquifer, particularly in the Fez region. Additionally, a significant anthropogenic contribution may also be responsible for this degradation in quality.



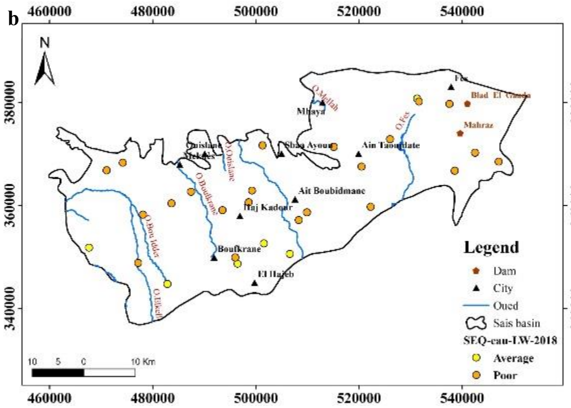
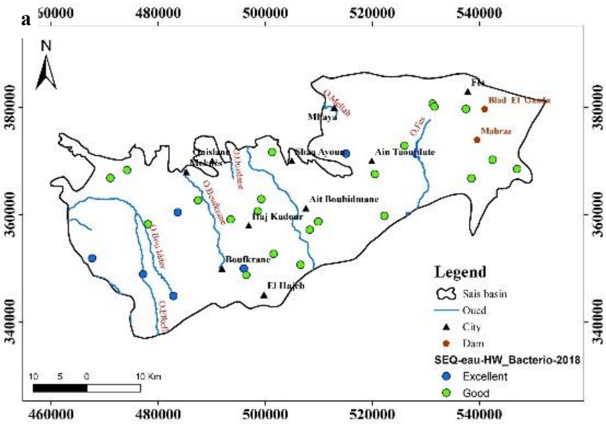


Fig.10. Maps of the SEQ-physicochemical quality during a) the high-water period, and b) the low-water period of 2018.

4.3 Quality evaluation: SEQ-bacteriological

The assessment of bacteriological water quality at every station, considering the alteration of microorganisms, was conducted through the water quality assessment system. The overall bacteriological quality remains consistently good to very good throughout the high-water season. (Fig. 11a).

The thematic map for the low-water period shows the emergence of a moderate-quality class at stations located in the Fez, Mhaya, and Sbaa Ayoun regions, as well as the North of Haj Kaddour (Fig. 11b). This fluctuation in quality during the dry season is due to the concentration of fecal and total coliforms, with a maximum of 8400 and 4200 (/100ml) respectively. These concentrations are classified in the moderate category, with index values ranging between 2000 and 20000 according to the groundwater grading system [11].



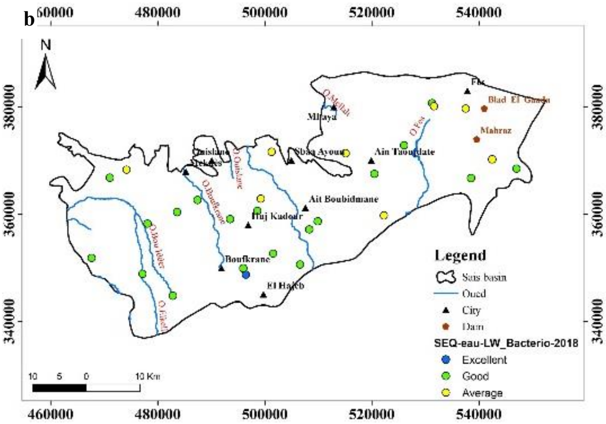
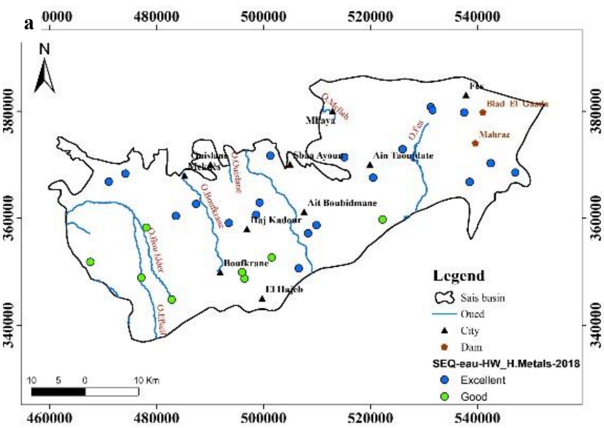


Fig.11. Maps of the SEQ-bacteriological quality during the high and the low water periods of 2018.

4.4 Quality evaluation: SEQ-metal

Figures 12a and 12b illustrate the evaluation of metal quality indicated by the SEQ-Eau extracted at each station, considering the alteration of metallic elements, showing that the overall quality of stations located in the Meknes-Haj Kaddour and Fez-Taoujdate-Mhaya regions is excellent. However, the region of El Hajeb-Boufekrane (South of the Meknes plateau) exhibits good quality during both high and low water periods in the studied area. According to the results obtained, the groundwater does not seem to be affected by the alteration of metallic elements.



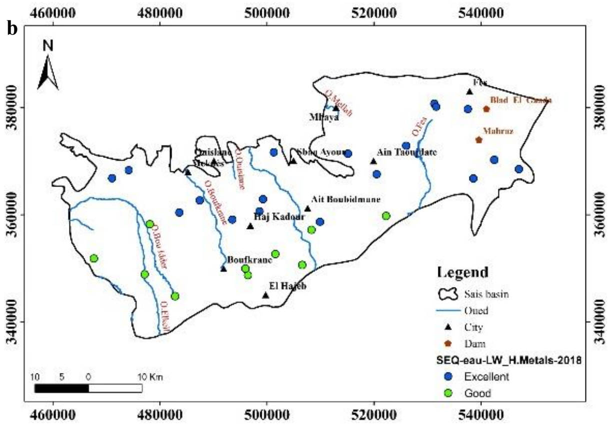
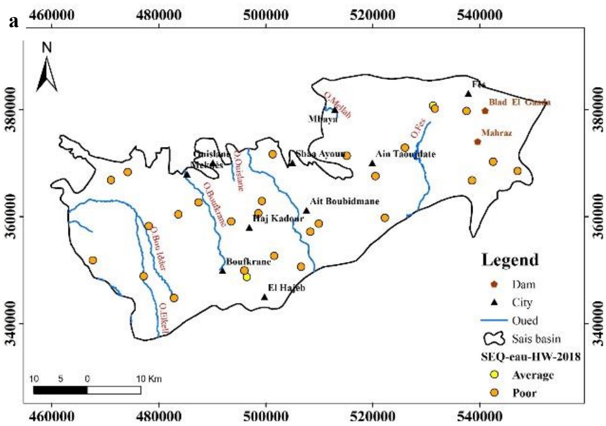


Fig.12. Maps of the SEQ- heavy metal quality during a) the high-water period, and b) the low-water period of 2018.

4.5 Global Water Quality Assessment: Calculations and Mapping

The water quality assessment framework has allowed for a comprehensive evaluation of the overall water quality at each station, considering the eight alterations mentioned above. It serves as an exemplary decision support tool in water management, designed to streamline the utilization and analysis of water quality data [15]. It's often used to assess and monitor the quality of surface and groundwater.

The integrated analysis of physicochemical, bacteriological, and heavy metal parameters of groundwater in the Saïss aquifer suggests that the overall quality according to SEQ-Eau is primarily influenced by physicochemical parameters, particularly nitrates. This predominant influence is significantly evident during both high and low water periods. Thematic maps (Fig. 13a and 13b) illustrating these specific parameters demonstrate a remarkable similarity with those obtained through the application of physicochemical SEQ-Eau (Fig. 11a and 11b). Nevertheless, the levels of nitrates, in particular, play a pivotal role in determining water quality, and this consistency enhances the credibility of assessments relying on the physicochemical component. These findings underline the importance of carefully monitoring and managing nitrate levels to maintain and improve water quality in the region throughout the seasons.



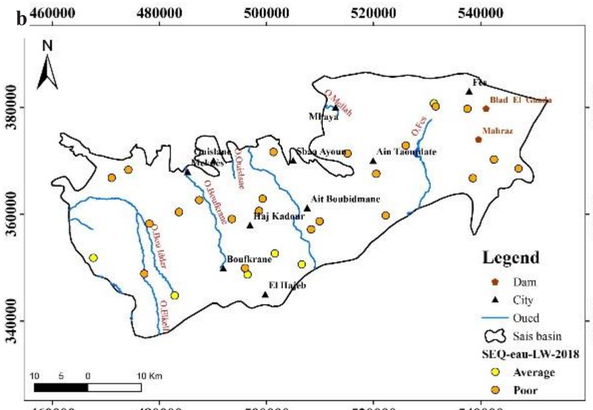


Fig.13. Maps of the overall SEQ-eau quality during a) the high-water period, and b) the low-water period of 2018.

In the high-water season, water quality is generally poor throughout most of the basin, except for two stations located respectively in the El Hajeb region and along the Sebou River, which exhibit better quality (Fig. 7a, 11a, and 13a). During the low-water period, a slight improvement is observed in El Hajeb-Boufkrane, but the quality remains poor in the Meknes-Haj Kaddour and Fez-Taoujdate-Mhaya regions (Fig. 7b, 11b, and 13b). This degradation of groundwater quality is attributed to high nitrate levels in the majority of stations in the study area during both seasons, exceeding the threshold of 50 mg/l considered to distinguish polluted wells from unpolluted ones [16] (Fig.14). The environmental deterioration of this quality in the Saïss aquifer, particularly in the Fez region, is linked to anthropogenic impact, especially agricultural development, including the excessive use of pesticides and chemical fertilizers, which can contaminate groundwater through leaching of fertilizers used in agricultural soils.

Similar results show that the increase in pollution, mainly of anthropogenic origin, is contributing to the degradation of water quality in multiple aquatic ecosystems across Morocco.For instance, studies like the one conducted by [17] has underscored that agriculture, along with domestic and industrial effluents along the Boufekrane River passing through Meknes city, are the primary contributors to this decline. Similarly, research conducted by [18] has underscored the same phenomenon in the rivers of Fez city. This coherence between the integrated results of SEQ-Eau and the specific outcomes in the chemical domain strengthens the credibility of these parameters' significance in assessing water quality in the studied region. This, in turn, leads to the development of water management strategies aimed at improving and maintaining water quality in the Saïss basin.

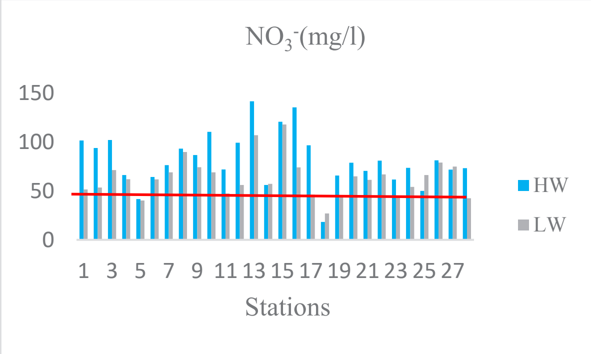


Fig.14. Nitrate concentrations at different stations during high and low water levels in 2018.

5 Conclusion

The present study focuses on developing a comprehensive diagnosis of groundwater pollution in the Saïss aquifer using SEQ-Eau. The results obtained demonstrate that:

The physicochemical SEQ indicates that the overall quality of groundwater is poor, except for two stations located in the regions of El Hajeb and along the Sebou River during periods of high water flow. However, this quality improves slightly to reach a medium level at the El Hajeb-Boufkrane station during periods of low water levels. Conversely, stations located in the regions of Meknes-Haj Kaddour and Fez-Taoujdate-Mhaya show poor water quality.

The bacteriological SEQ of groundwater reveals good quality during the high-water period. However, a seasonal degradation in quality is observed during the dry season, particularly in stations located in the region of Fez, Mhaya, Sbaa Ayoun, and the North of Haj Kaddour. This deterioration is mainly due to an increase in levels of fecal and total coliforms, exceeding acceptable thresholds for optimal quality.

The metal SEQ indicates good quality during both high and low water seasons. This suggests that the alteration of metal elements does not have a significant effect on the groundwater table. This could be the result of natural filtration or dilution processes within the aquifer system.

The physicochemical, bacteriological, and heavy metal analyses suggest that the overall quality of groundwater in the Saïss aquifer during both seasons is primarily controlled by physicochemical parameters, particularly nitrates. The overall SEQ-Eau results are consistent with those obtained from physicochemical SEQ analysis.

The decline in overall water quality in the study area is primarily attributed to elevated nitrate levels observed in the majority of stations, exceeding the standards established by Moroccan authorities (50 mg/l). This pollution is closely linked to human activity, particularly agricultural development and the excessive use of pesticides and chemical fertilizers.

References

1. Shiklomanov, I. A. World water resources: a new appraisal and assessment for the 21st century: a summary of the monograph World water resources. UNESCO International Hydrological Programme. Paris, France, 37p (1998).
2. Kadkhodaie, F., Asghari Moghaddam, A., Barzegar, R., Gharekhani, M., & Kadkhodaie, A. Optimizing the DRASTIC vulnerability approach to overcome the subjectivity: a case study from Shabestar plain, Iran. Arabian Journal of Geosciences, 12, 1-13 (2019).
3. Su, H., Kang, W., Xu, Y., Wang, J. (2017). Assessing Groundwater Quality and Health Risks of Nitrogen Pollution in the Shenfu Mining Area of Shaanxi Province, Northwest China. Exposure and Health, 10(2), 77-97. Doi:10.1007/s12403-017-0247-9
4. Mei, Y., Yuhong, F., Yiwen, J., Huaqi, L. Human Health Risk Assessment Model of Organic Pollution in Groundwater: Shijiazhuang Industrial Zone. Acta Geologica Sinica, 85(6), 1508-1517. (2011). doi:10.1111/j.1755-6724.2011.00602.x
5. Selvam, S., Antony Ravindran, A., Venkatramanan, S., Singaraja, C. Assessment of heavy metal and bacterial pollution in coastal aquifers from SIPCOT industrial zones, Gulf of Mannar, South Coast of Tamil Nadu, India. Applied Water Science, 7(2), 897- 913(2015).Doi:10. 1007/s13201-015-0301-3
6. Chen, F., Lao, Q., Zhang, S., Bian, P., Jin, G., Zhu, Q., Chen, C. Nitrate sources and biogeochemical processes identified using nitrogen and oxygen isotopes on the eastern coast of Hainan Island. Cont. Shelf Res., 207, 104209 (2020). [CrossRef]
7. Saha, P.; Paul, B. Suitability Assessment of Surface Water Quality with Reference to Drinking, Irrigation, and Fish Culture: A Human Health Risk Perspective. Bull. Environ. Contam. Toxicol, 101, 262–271 (2018). [CrossRef] [PubMed]
8. Essahlaoui, A., Sahbi, H., Bahi, L., & El-Yamine, N. Reconnaissance de la structure géologique du bassin de Saiss occidental, Maroc, par sondages électriques. Journal of African Earth Sciences, 32 (4), p 777-789 (2001). https://doi.org/10.1016/S0899-5362(02)00054-4
9. Fassi, D. Les Formations superficielles du Saïss de Fès et de Meknès du temps géologique à l'utilisation actuelle des sols. Service Géologique du Maroc (1999).
10. Errochdi, S., El Alami, M., Bennas, N., Belqat, B., Ater, M., & Fdil, F. Étude de la qualité physicochimique et microbiologique de deux réseaux hydrographiques nord marocains : Laou et Tahaddart. http://journals.openedition.org/mediterranee, (118), 41-51(2012). https://doi.org/10.4000/MEDITERRANEE.6221
11. SEEE (Secrétariat d'État auprès du ministère de l'Énergie des Mines, de l'Eau et de l'Environnement), fiche sur le nouveau système d'évaluation de la qualité des eaux, Maroc, 5 p (2008).
12. Système d'évaluation de la qualité des eaux souterraines SEQ - Eaux Souterraines. Rapport de présentation Version 0.1 - 75p. Août (2003).
13. Hutchins, M. G., Abesser, C., Prudhomme, C., Elliott, J. A., Bloomfield, J. P., Mansour, M. M., & Hitt, O. E. Combined impacts of future land-use and climate stressors on water resources and quality in groundwater and surface water bodies of the upper Thames River basin, UK. Science of the Total Environment, 631–632, 962 (2018). https://doi.org/10.1016/j.scitotenv.2018.03.052
14. Groupe scientifique de l'Eau, fiches synthèses sur l'eau potable et la santé humaine, Institut national de santé publique du Québec, 173 p (2003).
15. Abdellah El Hmaidi, Abdelghani Talhaoui, Imad Manssouri, Hajar Jaddi, Mohamed Ben Daoud, Zahra Kasse, Anas El Ouali, Ali Essahlaoui. Assessment of the physicochemical water quality of the Moulouya River -Morocco using the SEQ-Eau index. Environmental Monitoring Assessement.194 (1) (2021). DOI: 10.1007/s10661-021-09636-4.
16. Organisation Mondiale de la Santé (OMS). Les lignes directives sur la qualité de l'eau potable. In: Organisation Mondiale de la Santé, Directives de qualité pour l'eau de boisson: 4e éd, Intégrant le Premier Additif, OMS, Genève, 564 p (2017).
17. Ben Daoud, M., Mouhaddach, O., Essahlaoui, A., Layachi, A., Kestemont, M. P., & El Jaafari, S. Conception d'un SIG pour l'évaluation de l'impact des activités anthropiques sur la qualité des eaux superficielles de la ville de Meknès (Maroc). Cahiers de L'association Scientifique Européenne Pour L'eau et la Santé, 16(1), 17–25 (2011). https://doi.org/10.1051/asees/2011205
18. El Madani, F. Z., Lahlou, K., Idrissi, N., Elallaoui, N., Ben Abbou, M., Merzouki, M., Chetouani, A., Taleb, M., & Rais Z. Identification of the quality of sur- face waters in the city of Fez by the SEQ-GIS approach and analysis of variance. Moroccan Journal of Chemistry, 7(4), 673–682(2019).