EEET ECOLOGICAL ENGINEERING & ENVIRONMENTAL TECHNOLOGY

Ecological Engineering & Environmental Technology 2023, 24(9), 64–70
https://doi.org/10.12912/27197050/172939
ISSN 2719-7050, License CC-BY 4.0

Received: 2023.09.22
Accepted: 2023.10.16
Published: 2023.11.15

Assessment of the Physicochemical Quality of Groundwater in the Errachidia Region (SE, Morocco)

Maryam Azirar[1], Said Benyoussef[1,2], Mourad Arabi[3*], Abdellali Abdaoui[1], Younes Filali Zegzouti[1,4], Ali Ait Boughrous[1,4]

[1] Biology, Environment and Health, Faculty of Sciences and Technology, Moulay Ismail University of Meknes, PB 509, Boutalamine 52000, Errachidia, Morocco

[2] Environmental Management and Civil Engineering, National School of Applied Sciences, Al Hoceima, Abdelmalek Essaadi University, BP 32003, Al Hoceima, Morocco

[3] Laboratory for Improvement of Agricultural Production, Biotechnology and Environment (LAPABE)/Water, Environment and Health Team, Faculty of Science, Mohamed Premier University, Oujda, Morocco

[4] LABASE Laboratory, Faculty of Science of Meknes, Moulay Ismail University, Meknes, Morocco

* Corresponding author's e-mail: m.arabi@ump.ac.ma

ABSTRACT

This study aimed to assess groundwater quality in the Errachidia region, southeast Morocco, where a total of one hundred wells were periodically surveyed, and ten wells were selected for monthly monitoring based on their proximity to known surface pollution sources. Various physicochemical parameters were measured. Results outcomes encompass temperature fluctuations ranging from 21°C to 30°C, generally neutral pH levels, heightened electrical conductivity (900 to 2220 µS/cm), diminished dissolved oxygen levels (1.91 mg/L), and the presence of nitrates within prescribed thresholds for potable water. Nevertheless, one station exceeded the nitrate threshold (30 mg/L). Elevated sulfate ion concentrations were detected (764.6 mg/L), potentially originating from urban wastewater. Chloride levels fell within acceptable limits (67.45 to 245 mg/L), and calcium content displayed variability (89.6 to 208.6 mg/L), but remained below authorized values. Hierarchical clustering identified four distinctive well groups predicated on their physicochemical attributes, thereby underscoring the impact of pollution sources on water quality. The study indicated an improvement in the region's grouwater quality, transitioning from poor to moderate, and in some instances, to good quality.

Keywords: physicochemical quality, groundwater, climate change, pollution, Errachidia, Morocco.

INTRODUCTION

Groundwater represents the world's largest reservoir of freshwater, accounting for nearly 99% of directly accessible continental freshwater (Gibert et al., 2004). It serves as a vital component of the hydrological cycle (Gibert et al., 1994; Malard et al., 2002), offering essential hydrological functions such as regulating river flow, exchanging matter and energy, and providing water quality and protection superior to that of surface waters, which are often more polluted (Ait Boughrous et al., 2007; Benyoussef et al., 2021a). Groundwater holds significant socio-economic value as an invaluable natural resource for agricultural, industrial, and domestic needs in both developed and developing countries (Danielopol et al., 2003; Gibert et al., 2009).

The investigation of water resources in arid and semi-arid regions has become a focal point in contemporary scientific research. This emphasis stems from the inherent challenges posed by limited water resources in such areas, directly impacting their sustainable development (Roubil et al., 2022). Recent studies have underscored the profound influence of climate change and drought on terrestrial and aquatic ecosystems, particularly surface water and groundwater, within arid and semi-arid zones (Häder and Barnes, 2019; Wang et al., 2022; Zhang et al., 2021). Morocco's groundwater systems, especially those in oases, are undergoing significant transformations due to a combination of global-scale pressures and the cumulative effects of local and regional-scale impacts (Messouli et al., 2009). The Errachidia region, in particular, grapples with issues related to water scarcity and competition among various users. This has prompted the Moroccan government to adopt new policies aimed at promoting political and social stability. However, the expansion of urban areas at the expense of irrigated fields has intensified conflicts over water usage, particularly between domestic needs and tourism demands (Kuisma and Haanpera, 2012). Several factors contribute to the degradation of surface and groundwater quality in this region, including the pollution stemming from domestic and industrial wastewater, the seepage of fertilizers and pesticides, and soil erosion with sediment transport (Taleb, 2006). Furthermore, the high demand for water has led to the overexploitation of both surface and groundwater resources, resulting in a significant decline in the water tables of the aquifers (Hssaisoune et al., 2020). Kuisma and Haanpera (2012) highlight that soil degradation in the Atlas Mountains exacerbates this phenomenon, reducing water infiltration in degraded areas. Consequently, traditional underground water galleries known as khettaras, which historically conveyed groundwater for domestic use and irrigation, can no longer be utilized. Instead, deep fossil groundwater is currently being pumped for these purposes (Kuisma and Haanpera, 2012). This study aims to investigate the variations in groundwater quality within the Errachidia region, situated in the arid to semi-arid southeastern part of Morocco (Roubil et al., 2022). Specifically, we focus on assessing key qualitative parameters at ten selected monitoring stations (wells) within the region.

MATERIALS AND METHODS

Study area

The Errachidia area is located at Drâa-Tafilalet region at the southeast of Atlas Morocco between the south-atlases latitudes 29°30'N and 32°30'N. This area is bounded to the north by the province of Midelt, to the northeast by the province of Figuig, to the west by the two provinces of Tinghir and Zagoura and to the south and southeast by Algeria country. It covers 8.44% of Morocco's surface, or approximately 60 000 km^2. Demographically, Tafilalet has at present, a population of 70000 and is mainly rural (Figure 1) (HCP, 2021). Climatically, the studied area is characterized by its arid desert landscape, with the High

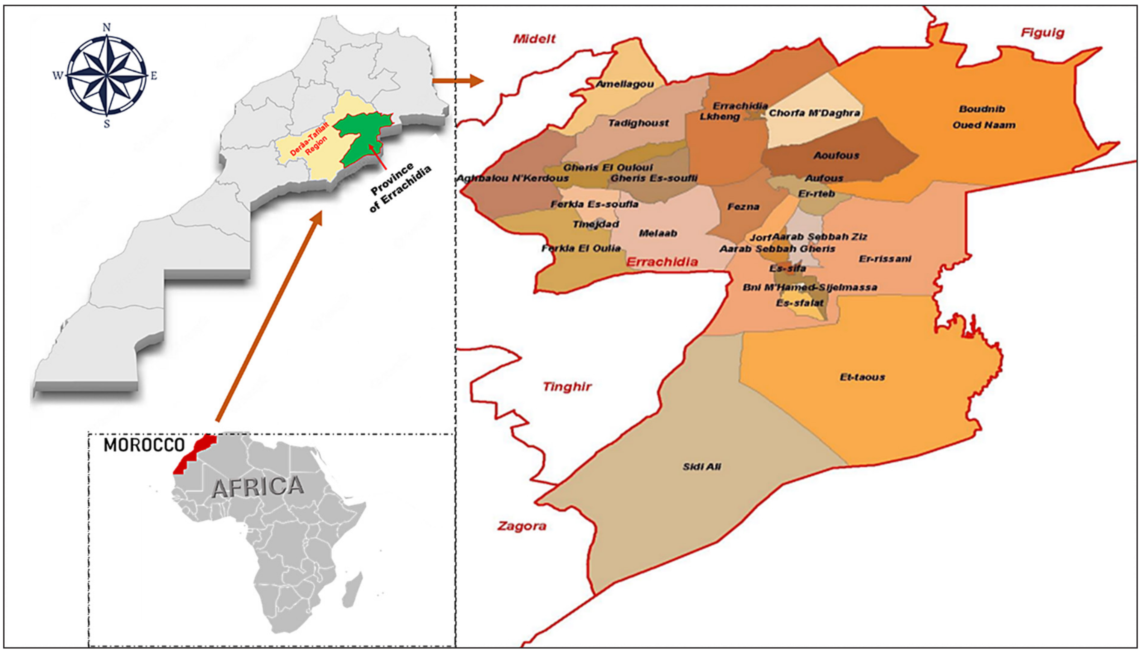

Fig. 1. The geographical location of the Errachidia region

Atlas Mountains to the east. The region's climate is typically desertic, with high temperatures during the summer, often exceeding 40 degrees Celsius during the day. Temperature variations between day and night can be substantial, with hot days followed by cool nights. Precipitation is rare and irregular throughout the year, significantly influencing the region's geology, fauna, flora, and way of life (ABHGZR, 2016).

Methodology

Groundwater samples were collected from ten wells during the study period in 2019 (Figure 2). Various factors were analyzed to characterize the water quality in terms of physicochemical and ecological parameters. Some measurements were taken in the field, while others were analyzed in the Hydrobiology Laboratory within the Department of Biology at the Faculty of Sciences and Techniques in Errachidia. Physical parameters of the ten wells were measured directly in the field at the time of water sampling.

These in-situ measurements included temperature, conductivity, and pH and were conducted using HACH multi-parameter conductometers and a WTW pH meter. The dissolved oxygen saturation level was measured using a WTW oximeter. Indicators of organic pollution, such as nitrate ions (NO_3^-), nitrite ions (NO_2^-), and ammonium ions (NH_4^+), as well as the concentrations of sodium ions (Na^+), sulfate ions (SO_4^{2-}), and chloride ions (Cl^-), were determined in the laboratory, following AFNOR standards and classical methods described by Rodier et al. (2009) (Table 1).

Statistical analysis and typology of studied waters

A comparison and classification of the stations based on the mean values of physicochemical characteristics of the water they provided were performed to establish a typology of the stations using Principal Component Analysis (PCA) and Hierarchical Clustering. Data processing was carried out using SPSS 10 software.

RESULTS AND DISCUSSION

Physicochemical characteristics of analyzed samples

The results of physicochemical analyses of water samples from the wells are presented in Table 1 (Azirar et al., 2023). The average water temperature values in the various stations varied slightly, ranging from 21°C in well W2, the coolest, to 30°C in well W7, the warmest. As for hydrogen potential (pH), which generally gives an overview of the equilibrium involving various forms of carbonic acid, thus reflecting the stability of the water

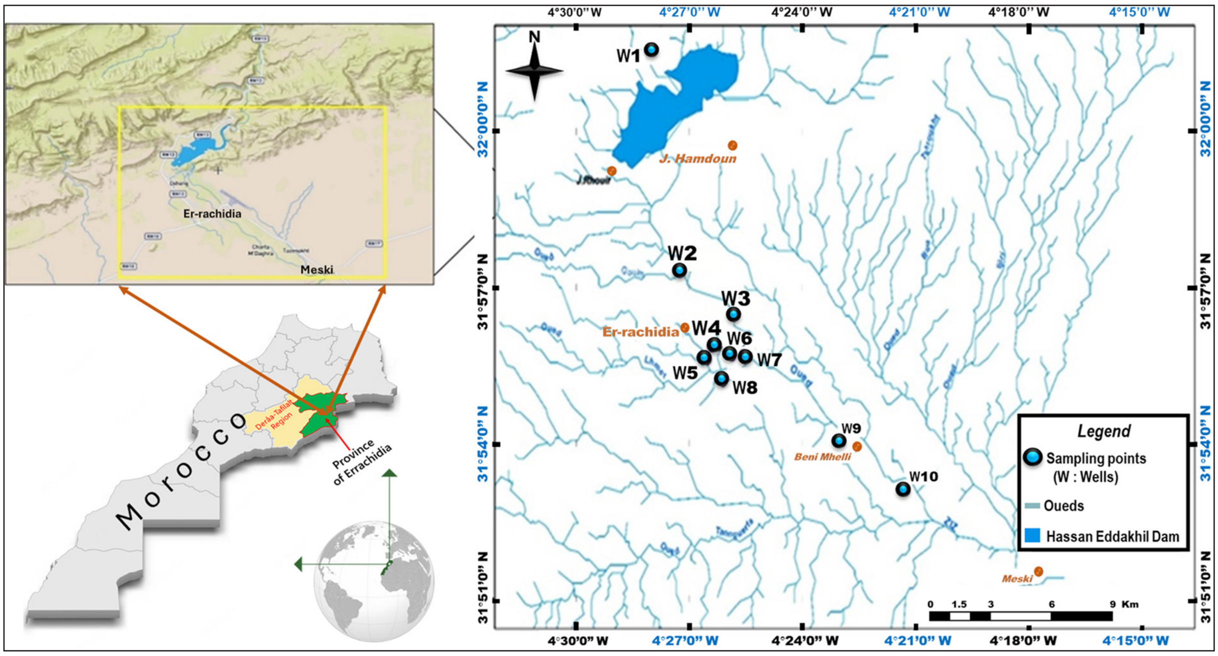

Fig. 2. Geographical location of the studied points (wells)

Table 1. Results of the analysis of physicochemical parameters of groundwater studied (in 2019)

Wells	Parameters											
	T (°C)	pH	Conductivity (µS/cm)	TAC	O_2 (mg/l)	NO_3^-	NO_2^-	NH_4^+	SO_4^{2-}	Ca^{2+}	Mg^{2+}	Cl^-
W1	22	7.37	900	4.3	6.92	10	0.03	0	138.3	89.6	250.4	67.45
W2	21	7.3	1318	5.8	5.32	5	0	0	182.4	101.6	322.4	148.39
W3	22	7.2	1277	5.9	5.29	10	0	0	183.8	108	346	130.29
W4	25	7.66	1738	6	4.93	20	0.02	0	294.1	124	466	191
W5	28	7.4	1915	5.4	8.41	25	0	0	473.3	187.2	644.8	185
W6	24	7.66	2220	6.1	5.32	30	0.05	0	494	190.4	683.6	245
W7	30	7.47	1925	5.75	4.4	28	0.03	0	463.7	174.4	613.6	196
W8	25	7.27	1990	4.95	8.41	30	0.02	0	495.4	178	682	242.11
W9	23	7.4	1946	3	1.91	5	0.8	0.6	764.6	208	736	136.32
W10	21.4	7.2	1919	7.05	2.77	20	0.03	0	208.6	112	380	163.3

ecosystem (Boumediene et al., 2023), its values in the studied stations were generally close to neutrality, with values ranging from 7.2 in wells W3 and W10 to 7.6 in wells W4 and W6 (Table 1).

This slight alkalinity can be attributed to the presence of varying levels of limestone in the aquifer through which the water flows, and thus, the pH values in the study area comply with Moroccan drinking water standards. While factors such as temperature and pH varied only slightly from one station to another and had values within the normal range, the other ten descriptors exhibited more notable and sometimes highly variable average values, allowing for the characterization of certain stations. Regarding the classic criteria proposed by Nisbet & Verneaux (1970), the average water mineralization was high to excessive everywhere, with consistently elevated electrical conductivity, ranging from 900 $\mu S \cdot cm^{-1}$ in well W1 to 2220 $\mu S \cdot cm^{-1}$ in well W6. Although these values are below the recommended threshold of 2700 $\mu S.cm^{-1}$ by Moroccan regulations (Moroccan Standard for Drinking Water Quality, 2006), they are relatively high, likely due to the presence of more or less soluble limestone layers in the soil (Boulal et al., 2017). Indeed, this high EC may interfere with the use of these groundwater for irrigation purposes as cited by Benyoussef et al. (2022).

The dissolved oxygen saturation levels in the well water ranged from 1.91 in W9 to 8.41 in W5 and W8, with minimal seasonal variations. Hypogenous aquatic environments, which are typically confined and lack photosynthesis, generally have low water oxygenation levels. Due to the depth of the water table and the hermetic sealing of wells with covers when equipped with a wellhead, oxygen saturation is often lowest in wells during air-water exchanges with the atmosphere.

Nitrates were present in the water of all ten wells at average concentrations ranging from 5 mg/L in W2 and W9 to 30 mg/L in W8, all of which remained below the recommended threshold. The World Health Organization (WHO) suggests a limit of 50 mg/L for water intended for human consumption (WHO, 2011a). According to the guidelines of the European Communities Council, the baseline level is 25 mg/L, with a maximum allowable concentration of 50 mg/L. Due to agricultural activities (such as the excessive use of inorganic nitrogenous fertilizers and manures), wastewater disposal, the oxidation of nitrous waste products in human and other animal excreta, such as septic tanks (WHO, 2011a), and leachate percolation from other organic waste (Arabi et al., 2020), nitrates can be found in both groundwater and surface water. The presence of nitrates in contaminated water, which are the final product of organic nitrogen oxidation, indicates that the self-purification process has already begun (Benyoussef et al., 2021b).

Nitrite ions were not detectable in the nine wells, with values ranging from 0 to 0.05 mg/L, classifying the water in these wells as Class 2B, suitable for drinking water, except for W8, which reached 0.8 mg/L, placing it in Class 7, the lowest class indicating poor water quality according to WHO (2011a). Groundwater in the study area was generally rich in sulfate ions, with average concentrations ranging from 138.3 mg/L to 764.6 mg/L. It is evident that these ions have an anthropogenic origin in the study area (Bremond et al., 1973), especially in wells located near the city or its immediate outskirts, where untreated urban wastewater is discharged. High sulfate concentrations were also observed downstream of the city of Errachidia, situated north of the disposal area where ions are released from wastewater and infiltrate into the groundwater. The groundwater was also low in chlorides, with chloride ion concentrations ranging from 67.45 mg/L in W1 to 245 mg/L in W6. All wells had chloride concentrations below Moroccan groundwater standards of 750 mg/L. Calcium content in drinking water primarily depends on the soil's nature (limestone or gypsum). The examined water samples had calcium concentrations ranging from 89.6 mg/L in W1 to 190.4 mg/L in W6. All sampled points had concentrations below the authorized value of 200 mg/L, except for W9, which had a maximum value of 208 mg/L. The dissolution of calcite, as well as other calcium-bearing minerals such as gypsum, may be the cause of the elevated calcium levels (Rodier et al., 2016).

Typology of studied waters

Hierarchical clustering of the stations (Figure 3) reveals four main groups of wells (G1 to G4) that can be distinguished based on their physicochemical water variables. The first group consists

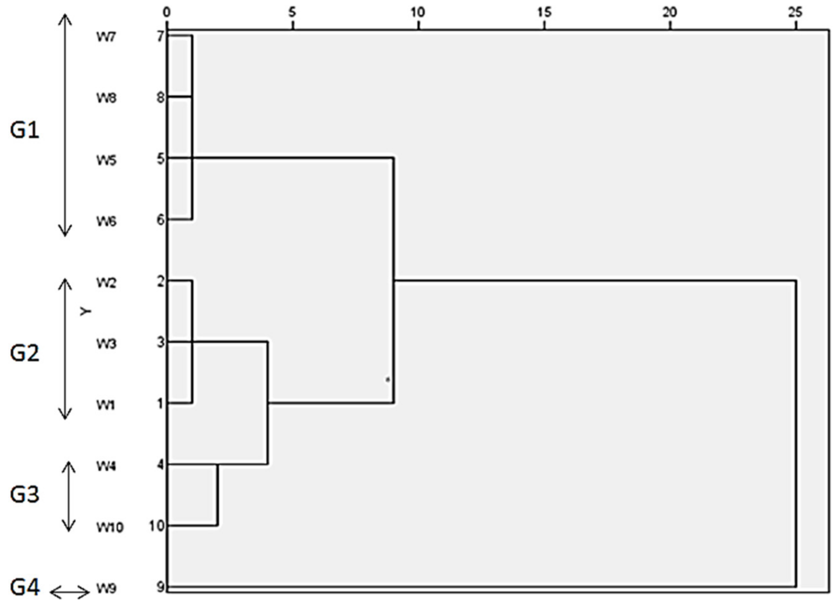

Fig. 3. Dendrogram representing the hierarchical classification of the 10 stations in the study area, described by the physicochemical variables of well water, G1 to G4: the four main groups of wells that individualize

Table 2. Correlation matrix of physicochemical parameters for samples analyzed in the area

	T	pH	O_2	CE	NO_3^-	NO_2^-	NH_4^+	SO_4^{2-}	TAC	Ca^{2+}	Mg^{2+}	Cl^-
T	1.000											
pH	.417	1.000										
O_2	.289	-.030	1.000									
CE	.484	.370	-.169	1.000								
NO_3^-	.675	.369	.391	.685	1.000							
NO_2^-	-.130	.048	-.587	.223	-.433	1.000						
NH_4^+	-.136	.015	-.571	.197	-.465	.998	1.000					
SO_4^{2-}	.459	.328	-.169	.726	.266	.704	.692	1.000				
TAC	.011	-.009	.011	.149	.412	-.755	-.761	-.549	1.000			
Ca^{2+}	.589	.368	-.007	.810	.475	.497	.483	.960	-.374	1.000		
Mg^{2+}	.590	.390	.006	.855	.535	.455	.439	.949	-.319	.988	1.000	
Cl^-	.497	.399	.200	.841	.827	-.204	-.224	.452	.362	.606	.691	1.000

of four wells (W5, W6, W7, and W8), with the first three located within the city's boundaries, and the W8 well situated near the slaughterhouse. These wells exhibited relatively low nitrogen ion levels, complying with recommended values for drinking water quality, except for station W8, which exceeded the WHO's potability threshold (50 mg/L) (2011b). The second group comprises three wells (W1, W2, and W3), located near the Hassan Eddakhil dam and distant from the city of Errachidia. These seven wells are subject to little or no urban pollution, maintaining good water quality. These wells displayed low levels of nitrogen ions and dissolved oxygen, making them the purest water sources among all stations. The third group includes two wells (W4 and W10), one situated within the city and the other on the right bank of the Oued Ziz. The latter is an unprotected well and, thus, vulnerable to pollution. The fourth group consists of a single station, W9, which is protected and has low nitrogen ion content (5 mg/L), resulting in water of moderate quality.The correlation matrix (Table 2) also indicated a strong positive correlation between NO_2^- and NH_4^+ (r = 0.998) and between Ca^{2+} and Mg^{2+} (r = 0.988).

These physicochemical parameters serve as indicators of water quality and environmental health. In this study, NO_2^- concentrations ranged from 0 to 0.8 mg/L, while NH_4^+ concentrations ranged from 0 to 0.6 mg/L, indicating that only one point, W9 (NO_2^- = 0.8 mg/L, NH_4^+ = 0.6 mg/L, Ca^{2+} = 208 mg/L, Mg^{2+} = 736 mg/L), exceeded the maximum allowed by WHO standards for drinking water (2011a).

CONCLUSIONS

This study conducted a comprehensive assessment of groundwater quality in the Errachidia region, located in the southeast of Morocco, considering various physicochemical parameters. The findings unveiled variations in water quality across distinct stations within the region. Stations positioned upstream, distanced from urban areas, demonstrated favorable water quality, whereas those situated in proximity to the city center and its pollution sources exhibited comparatively inferior water quality. The results indicate that the physicochemical characteristics of the studied stations decrease from upstream to the centre of Errachidia city. Stations located upstream, far from the city, are protected from pollution sources, resulting in good water quality. Conversely, stations located near urban areas, including the city centre, are in contact with various pollution sources, primarily stemming from inadequately maintained or non-existent wastewater management and non-compliance with recommended installation standards. Overall, this study underscores the significance of enhancing water infrastructure, optimizing wastewater management, adhering to well standards, and fortifying water quality surveillance in the region. Furthermore, the promotion of environmentally responsible agricultural practices and heightened public awareness constitute pivotal steps toward judicious water resource utilization and environmental preservation.

REFERENCES

1. ABHGZR (Agence de Basin Hydraulique de Guir-Ziz-Rhéris), 2016. Elaboration des monographies des ressources en eau des provinces et des communes relevant de la zone d'action de l'Agence du Bassin Hydraulique du Guir-Ziz-Rhéris-Ville de Riche, mission 2. Rapport technique, Maroc, 53 p.
2. Ait Boughrous A., Yacoubi Khebiza M., Boulanouar M., Boutin C. & Messana G., 2007. Groundwater quality in two arid areas of Morocco: impact of pollution on biodiversity and paleogeographic implications. Environmental Technology., 28(11), 1299-1315.
3. Arabi M., Sbaa M., Vanclooster M., Darmous A. 2020. Impact of the municipal solid waste typology on leachate flow under semi-arid climate – A case study. Journal of Ecological Engineering, 21, 94–101.
4. Azirar M., Filali Zegzouti Y., Benyoussef S., Arabi M., Zaki H., Abdaoui A., ElYousfi Y., Ait Boughrous A. 2023. Assessement of groundwater quality in the Tafilalet region of Southeastern Morocco Using Water Quality Index.). Ecological Engineering and Environmental Technology, 24(6), 117-126.
5. Benyoussef S., Arabi M., El Ouarghi H., Ghalit M., Azirar M., El Midaoui A., Ait Boughrous A. 2021a. Impact of anthropic activities on the Qualiy of Groundwater in the Central Rif (North Morocco). Ecological Engineering and Environmental Technology, 22(6), 96-78.
6. Benyoussef S., Arabi M., El Ouarghi H., Ghalit M., El Yousfi Y., Azirar M., Ait Boughrous A. 2022. Qualitative assessment of the waters of the coastal aquifer Ghis-Nekor (Central Rif, Northern Morocco) in view of agricultural use. Journal of Water and Land Development, 52, 245–250.
7. Benyoussef S., El Ouarghi H., Arabi M., El Yousfi Y., Azirar M., Ait Boughrous A. 2021b. Assesement

of the impact of Imzouren city's WWTP on the quality of the surrounding groundwater, at the Rif Central (Northern Morocco). In E3S Web of conferences The 2 Edition of Oriental Days for the Environment Development (JOE2). Oujda, Morocco, February 12-14.

8. Boulal M., Boulanouar M., Ghamizi M., & Boutin C. 2017. Qualité de l'eau et faune aquatique des puits dans la region de Tiznit (Anti –Atlas occidental, Maroc). Bull. Soc. Nat. Toulouse, 153, 25-41.
9. Boumediene B.C., Khoukhi Y., Chafi A., Arabi M. 2023. Study of the spatiotemporal variation of iron and manganese ions content in the Oued Moulouya water (North-East of Morocco), E3S Web Conf. EDP Sciences. 364, 02002.
10. Bremond R., Vuichard R. 1973. Paramètres de la qualité des eaux. Ministère de la Protection et de la Nature et de l'Environnement, SPEPE, Paris.
11. Danielopol D.L., Griebler C., Gunatilaka A., Notemboom J. 2003. Present state and future prospects for groundfwater ecosysytems. Environ. Conserv., 30(2) 104-130.
12. Gibert J., Deharveng L. 2002. Subterranean ecosystems: a truncated function biodiversity. Bioscience, 52, 473-481.
13. Gibert J., Culver D.C., Dole-Olivier M.J., Malard F., Christman M., Deharveng L. 2009. Assessing and conserving groundwater biodiversity: Synthesis and perpectives. Freshw. Biol., 54(4), 930-941.
14. Häder, D.P., Barnes, P.W. 2019. Comparing the impacts of climate change on the responses and linkages between terrestrial and aquatic ecosystems. Sci. Total Environ, 682, 239–246.
15. HCP. 2021. Monograph of Drâa – Tafilalet region. High Commission for Planning report, Morocco 2021.Avialable online: https://www.hcp.ma/draatafilalet/Monographies_r16.html.
16. Hssaisoune M., Bouchaou L., Sifeddine A., Bouimetarhan I., Chehbouni A. 2020. Moroccan groundwater resources and evolution with global climate changes. Geosciences, 10(2), 81.
17. Kuisma J., Haanpera, H. 2012. Water quality pressures and water management. In: Encounters across the Atlas: Fieldtrip in Morocco 2011; Minoia, P., Kaakinen, I., Eds.; Unigrafia: Helsinki, Finland, 2012; 58–71.
18. Malard F., Dole-Olivier M. J., Mathieu J., Stoch F. 2002. Sampling Manual for the Assessment of Regional Groundwater Biodiversity. European Project PASCALIS, 1-74.
19. Messouli M., Ben Salem A., Ghallabi B., Yacoubi-Khebiza M., Ait Boughrous A., El Alami El Filali A., Rochdane S., Ezzahra Hammadi F. 2009. In: El Moujabber M., Mandi L., Trisorio-Liuzzi G. , Martín I., Rabi A., Rodríguez R. (Eds). Technological perspectives for rational use of water resources in the Mediterranean region, Bari : CIHEAM, Options Méditerranéennes: Série A. Séminaires Méditerranéens, 88, 2009, 255-264
20. Nisbet M., Verneaux J. 1970. Composantes chimiques des eaux courantes. Discussion et proposition de classes en tant que bases d'interprétation des analyses chimiques. Annales De Limnologie - International Journal of Limnology, 6(2), 161-190.
21. Rodier J., Legube B., Merlet N. 2016. L'analyse de l'eau-10ème Éd., Dunod : Paris, France.
22. Rodier J., Legube B., Merlet N. 2009. L'analyse de l'eau; Eaux naturelles, eaux résiduaires, eau de mer, 9ème Éd. Dunod : Paris, France.
23. Roubil A., El Ouali A., Bülbül A., Lahrach A., Mudry J., Mamouch Y., Essahlaoui A., El Hmaidi A., El Ouali A. 2022. Groundwater Hydrochemical and Isotopic Evolution from High Atlas Jurassic Limestones to Errachidia Cretaceous Basin (Southeastern Morocco). Water, 14, 1747.
24. Taleb, H. 2006. Water management in Morocco. In G. Dura et al. (eds.): Management of Intentional and Accidental Water Pollution, Springer, Netherlands, 177–180.
25. Wang F., Lai H., Li Y., Feng K., Zhang Z., Tian Q., et al. 2022. Identifying the status of groundwater drought from a GRACE mascon model perspective across China during 2003–2018. Agric. Water Manag. 260, 107251.
26. WHO. 2011a. Guidelines for drinking water quality (4th ed). World Health Organization: Geneva, Switzerland 155-229.
27. WHO. 2011b. Guidelines for drinking water quality (3th ed). World Health Organization chronicle: Geneva, Switzerland, 8-104.
28. Zhang H., Ding J., Wang Y., Zhou D., Zhu Q. 2021. Investigation about the correlation and propagation among meteorological, agricultural and groundwater droughts over humid and arid/semi-arid basins in China. J. Hydrology 603, 127007.