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Depletion curve analysis and assessment of chemical indicators for pollution detection in seraidi springs (Annaba - Algeria)

Analisi delle curve di esaurimento e valutazione di indicatori chimici per determinare l'inquinamento nelle sorgenti del seraidi (Annaba - Algeria)

Salima GUECHI[a], **Laroussi BELOULOU**[a]

[a] Laboratoire Ressources Naturelles et Aménagement. Département de géologie, Université Badji Mokhtar Annabat, Algérie.

e-mail : *salima.guechi@univ-annaba.dz* - e-mail: *laroussi.beloulou@univ-annaba.dz*

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Correspondence to:
Salima Guechi :
salima.guechi@univ-annaba.dz

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Parole chiave: sorgenti del Seraidi; curva di esaurimento; flusso in periodo di magra; riserve acquifere; indicatori di inquinamento.

Riassunto

Negli ultimi anni, l'Algeria ha affrontato un crescente stress idrico a causa dei cambiamenti climatici e dell'aumento dell'attività antropica. Nella regione del Seraidi, il sovrasfruttamento delle sorgenti ha reso queste risorse sempre più vulnerabili. Questo studio ha due obiettivi: (1) esaminare le curve di esaurimento delle sorgenti nel massiccio dell'Edough durante i periodi di magra e stimare le riserve idriche dell'acquifero circostante, e (2) analizzare le variazioni degli indicatori di inquinamento. Le portate medie sono inferiori a 1 L/s, classificando la maggior parte delle sorgenti del Seraidi come di magnitudo 6. L'obiettivo principale di questo studio è applicare il modello della curva esaurimento di Maillet per analizzare il flusso di dodici sorgenti durante un periodo di magra (Maggio–Ottobre 2018). Il modello mostra una buona corrispondenza con i dati, come indicato dai valori di R^2 compresi tra 0.62 e 0.98. Questo modello consente di prevedere i volumi delle riserve idriche sotterranee durante i periodi di magra e di caratterizzare il regime di deflusso delle sorgenti. I risultati indicano che le sorgenti del Seraidi sono perenni, con coefficienti di recessione che variano da 0.0011 d-1 a 0.0365 d-1, garantendo un approvvigionamento idrico costante nell'area di studio. Tuttavia, le portate rimangono molto basse durante i periodi di magra. Lo studio ha anche monitorato nove composti chimici che posso suggerire un inquinamento, tra cui fosfati (PO_4^{3-}), metalli (Fe^{3+}, Cu^{2+}, Ni^{2+}, Al^{3+}, Mn^{2+}) e composti azotati (NO_3^-, NO_2, NH_4^+). Questi ioni presentano concentrazioni e distribuzioni variabili nell'area di studio. Le concentrazioni di Fe^{3+} variano da 0 a 0.53 mg/L, superando il limite raccomandato di 0.3 mg/L stabilito nel 2015. Le concentrazioni di Ni^{2+} hanno superato in alcune aree gli standard algerini di potabilità dell'acqua (0.02 mg/L) nel 2018, con un valore massimo di 0.35 mg/L registrato ad Ain Bouhaddada. Inoltre, questo studio evidenzia un aumento significativo dei livelli di nichel in alcune sorgenti, attribuibile principalmente ad attività antropiche che minacciano la qualità dell'acqua delle sorgenti. Tuttavia, la presenza di metalli pesanti nell'acqua, anche a concentrazioni inferiori rispetto agli standard di potabilità, solleva importanti preoccupazioni per la salute pubblica.

Questo studio mette in luce la vulnerabilità delle sorgenti del Seraidi causata da portate ridotte e dall'aumento dei livelli di inquinamento. Sebbene le sorgenti siano perenni, le loro portate diventano criticamente basse durante i periodi di siccità. L'aumento delle concentrazioni di inquinanti, in particolare metalli pesanti come nichel e ferro, sottolinea l'impatto negativo delle attività umane sulla qualità dell'acqua. Questi risultati evidenziano l'urgenza di adottare strategie per l'utilizzo sostenibile delle risorse idriche con lo scopo di proteggere queste importanti risorse e garantire la sicurezza idrica della regione.

Abstract

In recent years, Algeria has faced increasing water stress due to climate change and rising human activities. In the Seraidi region, the overexploitation of water springs has made these resources increasingly vulnerable. This study has two main objectives: (1) to assess the depletion of springs in the Edough Massif during low-flow periods and estimate the water reserves within the surrounding aquifer, and (2) to examine changes in the pollution indicator levels of these springs. The average flow rates of these springs are below 1 l/s, categorizing most Seraidi springs as magnitude 6. The primary objective of this study is to apply Maillet's depletion model to analyze the flow of twelve selected springs during the low-water period (May–October 2018). The model shows a strong fit to the data, as indicated by an R^2 value ranging from 0.62 to 0.98. This model facilitates the prediction of underground water reserve volumes during low-flow periods and helps characterize the spring discharge regime. The results indicate that the springs in Seraidi are perennial, with recession coefficients ranging from 0.0011 d^{-1} to 0.0365 d^{-1}, ensuring a consistent water supply in the study area. However, the flow rates remain very low during low-water periods.

This study also monitored nine pollution indicator elements, including phosphate (PO_4^{3-}), metals (Fe^{3+}, Cu^{2+}, Ni^{2+}, Al^{3+}, Mn^{2+}), and nitrogen compounds (NO_3^-, NO_2^-, NH_4^+), which exhibit varying concentrations and distributions in the study area. Fe^{3+} concentrations ranged from 0 to 0.53 mg/L, exceeding the recommended limit of 0.3 mg/L in 2015. Ni^{2+} concentrations exceeded Algeria's drinking water standards (0.02 mg/L) in some areas in 2018, with a peak value of 0.35 mg/L observed in Ain Bouhadada. Furthermore, the study highlights a notable rise in nickel levels in certain springs, primarily due to anthropogenic activities, which threaten the water quality of springs. However, the presence of heavy metals in the water, even at concentrations below drinking water standards, raises significant public health concerns.

This study highlights the vulnerability of Seraidi's water springs due to low flow rates and increasing pollution levels. Although the springs are perennial, their discharge becomes critically low during dry periods. The rising concentrations of pollutants, particularly heavy metals such as nickel and iron, emphasize the adverse impact of human activities on water quality. These findings underscore the urgent need for sustainable water management strategies to protect this vital resource and ensure the region's water security.

Introduction

The demand for water has intensified worldwide by about 1% per year since the 1980s (Abdin et al., 2021) due to several factors, including population growth and socio-economic development. Potable water has various sources, such as groundwater (e.g., wells and springs) and surface water. Springs are natural outlets of groundwater that emerge at the ground surface. They are an integral part of the groundwater system, resulting from the concentrated discharge of water from an aquifer. In particular, mountain springs are among the world's most precious sources of potable water (Gizzi et al.,2022; Thapa et al., 2023).

Springs can form in various settings, including those influenced by discontinuities such as faults or tectonic fractures, as well as in karst systems or alluvial deposits (Baechler et al.,2019; Manga, 2001). The occurrence of springs is fundamentally linked to the hydraulic head within the source aquifer, which is the driving force that allows groundwater to emerge at the surface. For a spring to discharge water, the hydraulic head within the aquifer must exceed the topographic elevation at the point of spring emergence, known as the spring geomorphic threshold (Keegan-Treloar et al., 2022).

Conceptually, the rates of spring discharge in crystalline terrains are controlled by both the hydraulic head of the source aquifer and the conductance of structural features, such as faults, which often influence groundwater flow. In crystalline rocks, faults frequently act as conduits, facilitating the movement of water from confined aquifers to the surface.

Although other mechanisms, such as permeability contrasts between rock types, can also influence spring development, fault-related springs are particularly significant in crystalline terrains, where such structural features commonly dominate groundwater flow paths. (Bense et al.,2013 ; Brehme et al., 2016; Keegan-Treloar et al., 2021).Therefore, the interaction between the aquifer's hydraulic head and fault conductance is crucial for understanding and predicting spring behavior. Variations in either of these factors can lead to changes in discharge rates, influencing the availability and sustainability of spring water resources. Due to the impacts of climate change and the overexploitation of groundwater resources, mountain springs face significant hydrologic issues, such as the risk of disappearing, drying up, or exhibiting low flow rates during the low-flow period (Abdin et al., 2021; Citrini et al., 2020; Costanza & Walter, 2000; Fiorillo et al., 2007; Gattinoni & Francani, 2010;; Pandit et al., 2024). To address these issues and improve spring yield, several studies have been conducted to protect and optimize the present and future management of mountain groundwater resources (Diodato et al., 2023; Gattinoni & Francani, 2010; Hunt, 2004; Pandit et al., 2024; Poudel & Duex, 2017).

In Algeria, springs are the primary source of potable water, essential for sustaining both urban and rural communities (Khaldi et al., 2018). Their crucial role in supporting agricultural activities, particularly in suburban areas surrounding cities, as well as in most villages and rural settlements, cannot be overstated. Natural springs provide vital drinking water and enable irrigation, thereby enhancing agricultural productivity and livelihoods in these regions.

The significance of springs in both urban and rural contexts underscores the urgent need for their preservation and sustainable management. The increasing water demand from springs, coupled with periods of low availability observed in recent years, highlights the necessity for effective management of this natural resource, especially in regions unaffected by human intervention. For instance, the Seraidi region in Annaba is home to numerous mountain springs that flow under gravity and are fed primarily by precipitation (Djorfi et al., 2017).

These springs have been continuously used by local inhabitants, posing a threat to the sustainability of this vital resource. Therefore, it is imperative to implement measures to conserve these springs and ensure their long-term viability for the well-being of present and future generations.

This research aims to investigate the depletion of 12 springs in the Seraidi region, to estimate underground reserves, and to determine recession coefficients through recession analysis methods, thereby providing an understanding of the reservoir's discharge regime (Gischer, 2012). Moreover, building upon previous scholarly works in the field (Elina et al., 2021; Lang & Gille, 2006; Lang, 2007), this study offers new insights through statistical analyses.

The number of studies on depletion and discharge reserves in the study area is very limited, with the exception of the study conducted by Alem et al. (1991), which addresses only a few springs.

Springs and their distinctive waters and ecosystems are extremely vulnerable to degradation due to excessive water use and pollution. To ensure sustainable development and improve water quality, this study tracks nine pollution indicator elements: phosphate (PO_4^{3-}), metals (Fe^{3+}, Cu^{2+}, Ni^{2+}, Al^{3+}, and Mn^{2+}), and nitrogen compounds (NO_3^-, NO_2^-, NH_4^+). The selection of these elements is based on findings from previously unpublished and published studies (Alem et al., 1991; Benouara et al., 2016; Djorfi et al., 2017; Hani et al., 1997; Majour, 2010), which observed a concerning increase in their concentrations over time.

Materials and Methods

Study area

Geographic/Climate Setting

The study area is situated within the Edough Massif in north eastern Algeria. It encompasses a mountainous terrain, with its highest point reaching 1,008 meters above sea level. Bounded to the north by the Mediterranean Sea and to the south by the Annaba plains, the area is characterized by its humid, well-watered, forested landscape, receiving a mean annual rainfall of approximately 1,200 mm (Djorfi et al., 2017). This rainfall contributes to a shallow aquifer, which feeds numerous springs of varying magnitudes. These springs are primarily situated along the Seraidi-Bouzizi-Ain Barbar axis, notable for its fractured crystalline basement (Fig. 1). Snowfalls are also frequent, lasting an average of seven days during the wet season. The snowmelt typically takes around 12 days on average, contributing to the recharge of underground aquifers. The temperatures exhibit a decreasing thermal gradient with altitude. The mean temperature in the Seraidi region is approximately 15°C. The minimum temperatures are observed during winter (December–February), with the mean minimum temperature around 4°C. During January, the coldest month, thermometers record an average of approximately 6°C in Seraidi. The monthly mean temperatures from May to October 2018 ranged from 18°C in May to a peak of 26°C in July.

Moreover, the Edough Massif is characterized by steep slopes that often maintain their convex shape until reaching the bottoms of the many valleys that cut through it. In periods unaffected by external influences, the continuous flow of the main watercourses is primarily supported by the emergence of springs of varying magnitudes.

Torrential wadis that flow into the Mediterranean represent the primary watercourses in the study area

Geological setting

The Edough Massif, located in the easternmost part of the Maghrebides, forms the south eastern segment of the western Mediterranean orogen. Structurally, it is classified as an asymmetric "core complex" (Caby & Hammor, 1992), oriented in a NE–SW direction. The massif is overlain by greenschist-facies Tellian units, which represent the thrust sheets of the Mesozoic to Eocene passive paleomargin of northern Africa. These were deposited on a thinned continental crust (Durand-Delga, 1980; Wildi, 1983).

The structural geology of the Edough Massif is dominated by NE–SW and NW–SE conjugate fault systems formed during the compressive phase associated with the Alpine orogeny (Aissa, 1996; Caby et Hammor,1992; Brunel et al.,1988; Hammor, 1992; Marignac, 1985; Vila, 1970). This tectonic phase caused significant crustal shortening and fracturing, leading to the development of these fault systems. These faults act as critical conduits for fluid circulation, facilitating groundwater migration and discharge, as evidenced by the numerous springs aligned along these structures. Furthermore, the metamorphic core of the massif consists of biotite gneisses and two-mica gneisses of Hercynian age, locally interspersed with leptynites, which further underscore its complex tectono-metamorphic evolution (Hadj Zobir, 2012).

The Edough Massif is composed of a Paleozoic metamorphic basement, a sedimentary cover of Meso-Cenozoic age, and igneous rocks of Miocene age (Auzende et al.,1975; Bouillin, 1979; Carminati et al., 2012; Cohen, 1980; 1986; Hilly, 1962; Laouar et al., 2002, 2005; Maraignac, 1985; Maury et al., 2000) (see Fig. 1). The metamorphic basement is divided into three lithological units (Gleizes et al., 1988; Hadj Zobir, 2012; Hammor, 1992):

1. Lower unit: composed of gneisses abundant in mica and quartz-feldspar, this basal unit is situated in the central region of the massif. Amphibolites and ultrabasic rocks are present in the upper sections of the gneisses and the basal layers of the micaschists. These formations are characterized by their rich content of quartz, plagioclase, biotite, amphibole, and pyroxene, and they are exposed in the northern part of the massif.
2. Intermediate unit: overlying the lower unit, this unit features a succession of alumino-micaschists interlayered with marbles, amphibolites, and pyroxenites.
3. Upper unit: consists of alternating layers of feldspathic quartzite and alumino-garnet-rich micaschists with tourmaline.

The sedimentary formations of the Edough massif are allochthonous and mainly composed of two flysch nappes:

1. Cretaceous flysch nappe:These flysch deposits outcrop in windows beneath the Numidian nappe, particularly in the regions of Aïn Barbar and Mellah (Hilly, 1962; Maraignac, 1985). They consist of intercalations of bluish-black argillites and thin beds of calcareous sandstones, typical of distal Massylian-type turbidites. The calcareous levels contain foraminifera, which date this series to the Maastrichtian (Villa, 1970). Additionally, Maraignac (1985) reports the presence of volcaniclastic materials, including volcanic quartz, fragments of vitreous or microlithic lavas, and, in some areas, pyritic inclusions.
2. Numidian flysch nappe of Oligocene age: Structurally, this nappe forms the highest part of the Alpine edifice. It is composed of an alternation of metric beds of silicified sandstones and thin clayey layers, providing it with the characteristics of an impermeable cover (Hilly, 1962; Maraignac, 1985). The initial thickness of this formation varies between 1,000 and 1,500 meters. It is not involved in the major thrust contacts that occurred prior to the Upper Miocene (Wildi, 1980). In the Edough massif, the clay layers with Tubotomaculum and the Numidian sandstones outcrop in the northern and southern parts of the massif (Hilly, 1962).

The Edough Massif exhibits a complex magmatism characterized by leucogranites, pegmatites, microgranites, and rhyolites, which are associated with the internal zones of the North African Alpine belt. This magmatism is attributed to the tectonic collision between the African and European plates during the Oligo-Miocene period (Auzende et al., 1975; Bouillin, 1979, 1986; Cohen, 1980). The magmatic activity in the region has left a significant geological record that includes both plutonic and volcanic rocks, providing insights into the tectonic and thermal processes of the time. Leucogranites are primarily exposed in the Bouzizi region, around Seraidi, and in the northeastern part of the Edough Massif (El Bir). Pegmatites, which are commonly found within gneisses and mica schists, represent another key lithology of the region. Microgranites, the most prominent group of rocks in the massif, are extensively exposed in the northwest, where their contact with gneisses, sandstones, and mica schists is marked by zones of intense silicification. These silicified zones extend several meters into the granites. When the microgranites interact with the late cretaceous flysch, hornfels are produced, highlighting the metamorphic influence of magmatic intrusions (Hilly, 1962). Rhyolites, which contain quartz, feldspar, biotite, and tourmaline phenocrysts, are found in several locations, including K. Guelaâ, K. Fidjel, and K. Ahrach. These volcanic rocks, are associated with the volcanic activity of the Miocene epoch. Microgranites and rhyolites are particularly prevalent in the northern part of the massif, where they represent significant volcanic activity during this time (Abbassene et al., 2016; 2019; Ahmed Said et al.,

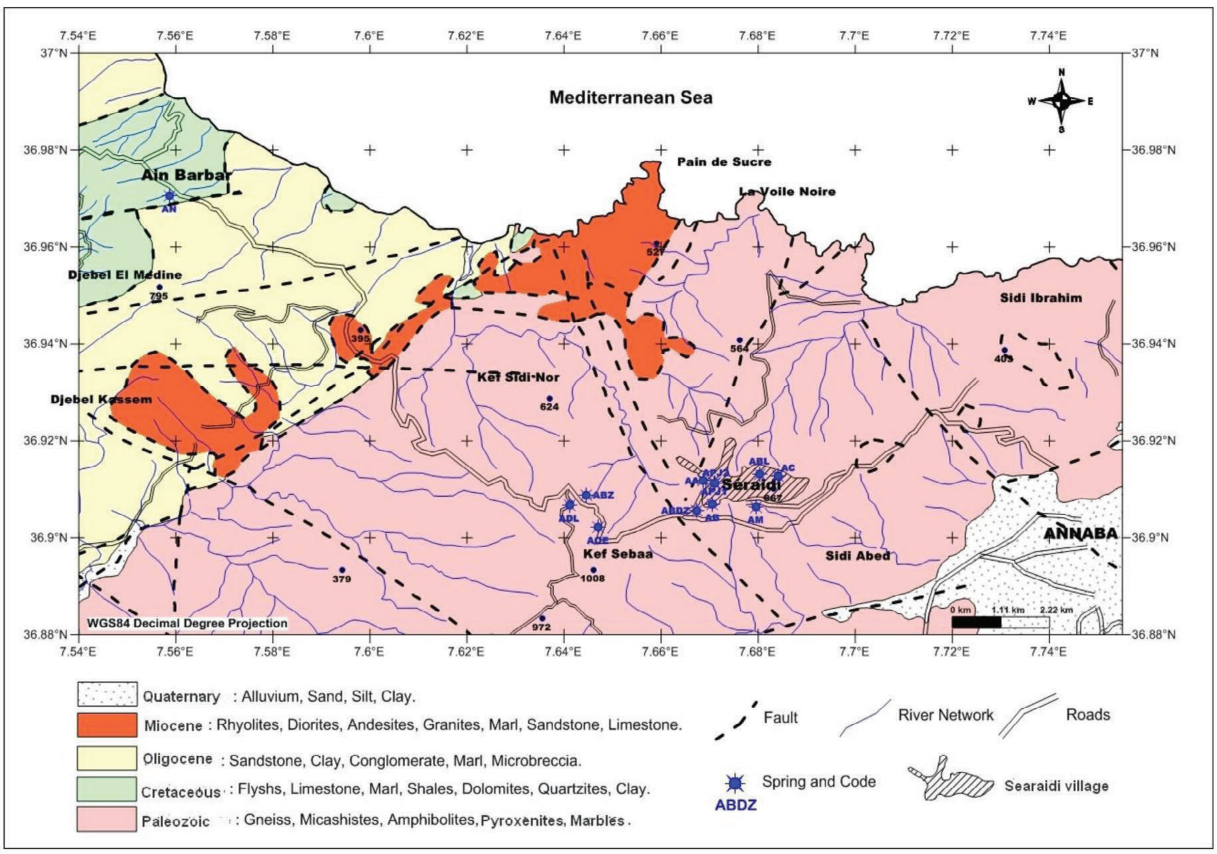

Fig. 1 - Geological map of the study area extract from sheet NJ-32-II, geological maps of Algeria at 1:200,000 (ANRH Editions, 2008).

Fig. 1 - Carta geologica dell'area di studio estratta dal foglio NJ-32-II della carta geologica dell'Algeria a scala 1:200,000 (ANRH Editions, 2008).

1993; Belanteur et al., 1995; Mitchell et al., 1988; Penven & Zimmermann, 1986). Together, these magmatic and volcanic features provide a detailed record of the tectonic evolution and magmatic processes of the Edough Massif.

The Quaternary units of the Edough massif are primarily composed of alluvial deposits and colluvium, reflecting the erosion and transport processes associated with glacial and interglacial periods. The alluvial deposits, consisting of gravel, sand, and silt, are laid down by rivers flowing through the region, as indicated by Hilly (1962) and Vila (1970). The colluvium, made up of finer materials such as clays and silts, accumulates on the slopes of the massif due to erosion. Traces of glacial processes are also observed, notably morainic formations in the higher areas of the massif, linked to cold periods during which alpine glaciers left traces, as reported by Hilly (1962).

Hydrogeological Setting

The study area features a shallow groundwater aquifer with a minimum thickness of up to 10 meters in some locations (Hani et al., 1997). This aquifer is situated along the edge of the metamorphic massif due to bedrock weathering, and it is used for potable water supply. The surface weathering and numerous faults within the metamorphic and overlying sedimentary formations impart significant hydrogeological importance, particularly due to their fracture permeability. These formations can also serve as recharge zones for groundwater. The natural discharge of this hydrogeological system occurs through a series of springs distributed along two preferential orientations (Fig. 1): NE-SW and NW-SE. These orientations correspond to the directions of two conjugate fault families.

The aquifer's recharge is primarily due to the infiltration of precipitation. Evapotranspiration is determined using the Thornthwaite water balance method for the period spanning from 1982/1983 to 2021/2022. The water balance is calculated for the mean year, with a value of 100 mm assigned to the readily available water reserve. As determined by the Thornthwaite formula, the water balance reveals that the annual mean potential evapotranspiration (ETP) in Seraidi is approximately 765 mm. In this region, runoff accounts for 45% of the total rainfall, which averages around 1,166 mm annually, and the mean infiltration rate is estimated to be 13%.

The mineralization of groundwater in the study area is influenced by several factors, including soil leaching during high water periods, the infiltration of meteoric water, and wastewater inputs, particularly near the village of Seraidi. Soil leaching and meteoric water infiltration dilute chemical elements while increasing potassium concentrations through the hydrolysis of feldspars, feldspathoids, and micas, especially muscovite. Wastewater significantly contributes to mineralization, while the dissolution of the aquifer's rock matrix, driven by carbon dioxide, further enhances groundwater mineralization.

Mineralization also depends on the residence time of water in the aquifer. During high-water periods, limited interaction between spring waters and aquifer materials results in low mineralization, indicating minimal alteration of gneiss. Conversely, during the dry season, concentrations of endogenous elements such as chlorides, bicarbonates, nitrates (except in polluted areas), calcium, and magnesium increase, while potassium and sodium levels, derived from the weathering of superficial layers, decrease.

Studies by (Hani et al., 1997, 2002; Majour et al., 2008) confirm that reduced flow during recession periods corresponds to increased mineralization, while high flow rates during heavy rainfall reduce mineralization but elevate potassium concentrations due to enhanced hydrolysis of feldspathic minerals.

Data collection

In the Seraidi region, certain springs are frequently subject to excessive use, which may impact their discharge rates. To assess the average flow of 12 springs during the low-water period from May to October 2018 (Fig. 2 and Tab. 1), a series of measurements was conducted primarily using the volumetric method. This approach involves utilizing a volume-calibrated bucket and a stopwatch. In cases where springs were not fully contained or exhibited leaks, measurements were supplemented with Parshall flumes. Subsequently, correction coefficients were calculated to refine the flow rates obtained through the volumetric method. Monitoring flows during dry periods provides critical insights into inflows from aquifers or nearby reservoirs and sheds light on the dynamics of reservoir depletion. In this context, depletion refers to the progressive reduction in the flow of a watercourse or spring in the absence of meteoric inputs or human interference (Fig. 3).

Fig. 2 - Photo showing springs from the study area (a: Ain Abbatoir; b: Ain Nechaa; c: Ain Bouhadada; d: Ain Boumendjel).

Fig. 2 - Sorgenti nell'area di studio (a: Ain Abbatoir; b: Ain Nechaa; c: Ain Bouhaddada; d: Ain Boumendjel).

Tab. 1 - List of springs investigated in this study and their location.

Tab. 1 - Lista delle sorgenti studiate in questo lavoro e la loro posizione.

Spring name	Spring code	Latitude (deg-min-sec)	Longitude (deg-min-sec)	Elevation (m a.s.l)
Ain Mohkim	AM	36°54'23.2"	7°40'46.5"	782
Ain Bouhadada	AB	36°54'24.9"	7°40'14.3"	816
Ain Parc aux jeux1	APJ1	36° 54' 40.8"	7° 40' 15.7"	839
Ain Parc aux jeux 2	APJ2	36° 54' 40.3"	7° 40'15.3"	837
Ain Abattoir	AA	36°54'42.3"	7°40'7.28"	795
Ain Dar lakehal	ADL	36°54'24.3"	7°38'28.0"	863
Ain Boumendjel	ABL	36°54'47."	7°40'49.2"	829
Ain Chifa	AC	36°54'45.6"	7°41'2.7"	795
Ain Nechaa	AN	36°58'14"	7°33'31.5"	341
Ain Oued Erbiba	AOE	36° 54' 7.92"	7° 38' 49.44"	813
Ain Bassin Dzair	ABDZ	36° 54' 20.22"	7° 40' 2.76"	709
Ain Bouzizi	ABZ	36° 54' 31.8"	7° 38' 40.62"	816

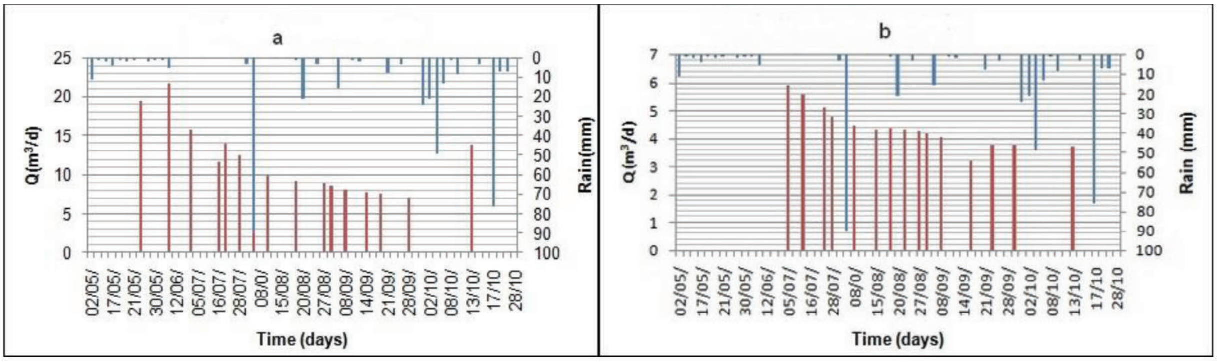

Fig. 3 - Example of the relationship between flow rates and rainfall (a: Ain Boumendjel; b: Ain Bassin Dzair).

Fig. 3 - Esempi della correlazione fra portata delle sorgenti e precipitazione (a: Ain Boumendjel; b: Ain BassinDzair).

This study aimed to analyze and interpret the decline in spring flows during the low-water period under natural conditions, offering a detailed understanding of flow variations in relation to aquifer and reservoir behavior. A range of mathematical models exists to ascertain the depletion coefficient, facilitating the comprehension of discharge rates from underground reservoirs (Dewandel et al., 2003). The Maillet law, a decreasing exponential model, has been adopted to calculate this coefficient (Gischer, 2012; Tallaksen, 1995). The two parameters of the Maillet model (Q_0 and α) are determined through regression analysis using the STATGRAPHICS Centurion XV software (Website: hattps://www.statgraphics.com). The following equation expresses this model.

$$Q = Q_0 e^{-\alpha(t-t_0)} \quad (1)$$

Q (t): flow rate at time t (m^3/d)

Q_0: flow rate at the beginning (t=0) of the recession flow

α: recession coefficient (d^{-1})

The logarithmic transformation of the (Eq. 1) leads to determining α through the (Eq. 2):

$$\alpha = \frac{\log Q_0 - \log Q_t}{t - t_0} \quad (2)$$

The Maillet equation facilitates the estimation of the volume (S) of underground reserves stored at a given time (t), also known as hydrological reserves (Cosandey & Robinson, 2000). The groundwater storage at any given time is expressed by the equation developed by Réméniéras (1974):

$$S(t) = \frac{Q_t}{\alpha} \quad (3)$$

S (t): volume of groundwater storage (m^3) at time t (in days).

Figure 4 illustrates various types of spring recession in Seraidi, including moderate and slow patterns.

Using this model, spring discharges and groundwater storage values were computed at the end of September, middle of October, and the end of October ($Q_{end-Sept}$, $S_{end-Sept}$, $Q_{mid-Oct}$, $S_{mid-Oct}$, $Q_{end-Oct}$, and $S_{mid-Oct}$).

In the present study, four physicochemical parameters (pH, dissolved oxygen, temperature, and electrical conductivity) were measured in situ during the low-flow water period (May-October 2018) using a WTW multi-parameter device (website: https://www.xylem.com). Turbidity measurements were conducted with a portable turbidimeter featuring infrared technology (2100Q ISO). Water pollution assessment considered various indicators, including the concentration

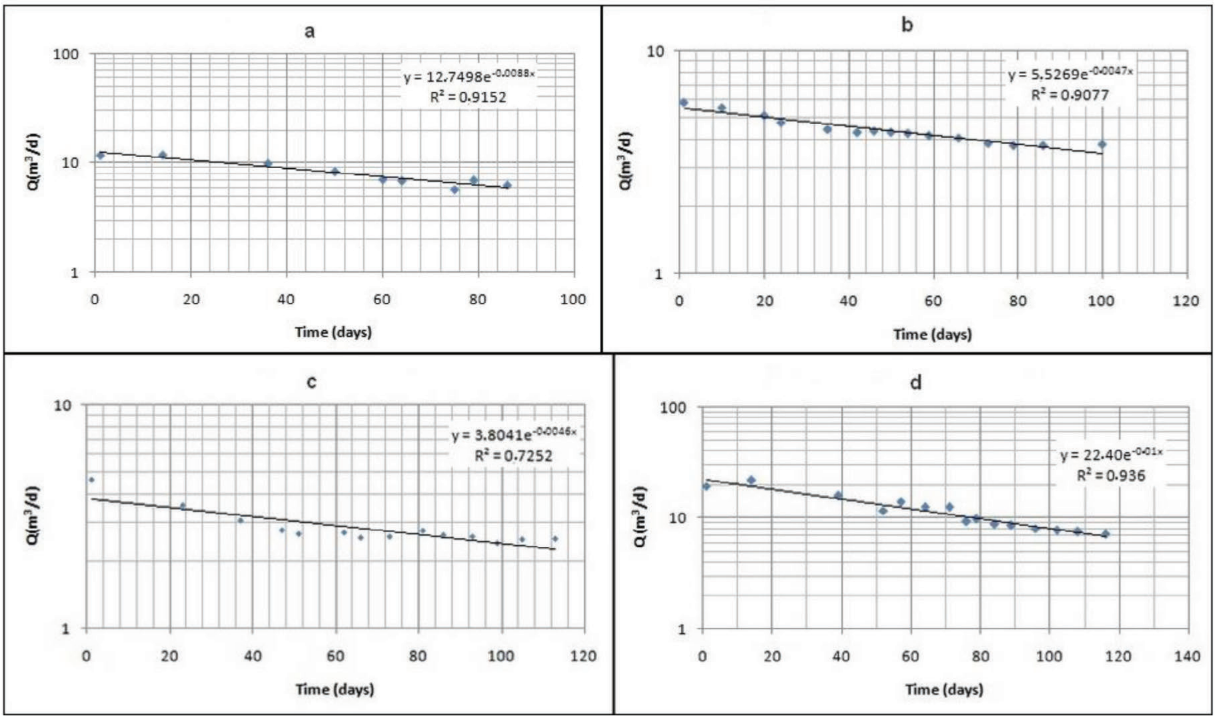

Fig. 4 - Recession curves of different springs (May-October 2018; a: Ain Bouhadada; b: Ain Bassin Dzair; c: Ain Parc aux jeux1 ; d : Ain boumendjel).

Fig. 4 - Curve di esaurimento di alcune sorgenti analizzate (Maggio-Ottobre 2018; a: Ain Bouhadada; b: Ain BassinDzair; c: Ain Parcaux jeux1; d: Ain Boumendjel).

of dissolved oxygen (DO) and the concentrations of nine chemical elements: phosphate (PO_4^{3-}), trace elements (Fe^{3+}, Cu^{2+}, Ni^{2+}, Al^{3+}, and Mn^{2+}), and nitrogen compounds (NO_3^-, NO_2^-, NH_4^+).

Nitrates were assessed using Spectrophotometry DIN 38405-D9-2, while nitrites were analyzed through Spectrophotometry DIN EN 26777-D10. Phosphates were measured using Spectrophotometry DIN EN ISO 6878-D11, and ammonium levels were evaluated via Spectrophotometry DIN 38406-E5. Nickel concentrations were determined using Spectrophotometry (Diméthylglyoxine), while aluminum was analyzed using Spectrophotometry APHA 3500-ALD. Iron levels were measured through Spectrophotometry (Formazin method), and manganese and copper were evaluated using Spectrophotometry DIN 38406-E2 and Spectrophotometry (cuprizone method), respectively.

Results And Discussion

The statistical analysis (Tab. 2) indicates that the average flow rates of these springs are below 86.4 m³/d (1 l/s), with approximately 70% assigned a score of 6 or higher on the Meinzer scale (1923). For Ain Parc aux Jeux 1 (APJ1), Ain Parc aux Jeux 2 (APJ2), and Ain Bassin Dzair (ABDZ), the average flow is even lower, categorizing these sources as magnitude 7 ($10 \le Q \le 100$ cm³/s), or ($0.864 \le Q \le 8.64$ m³/d).

Although the frequency of measurements may not be sufficient for a comprehensive statistical analysis, the data synthesis reveals moderate to high variability in water supplies across most sources. The analysis further highlights significant variability in water discharge, with average flow rates ranging from 2.9 m³/d in Ain Parc aux Jeux1 (APJ1) to 49 m³/d in Ain Bouzizi (ABZ). Noteworthy average discharge rates are observed in Ain Nechaa (AN) (28 m³/d), Ain Chifa (AC) (38 m³/d).

Figure 5 emphasizes the importance of spatial and temporal variability for each spring. The maximum flow in Ain Nechaa (AN) reaches approximately 140 m³/d, while it is around 4.6 m³/d in Ain Parc aux Jeux1 (APJ1), illustrating the marked spatial variability in flow rates among the springs.

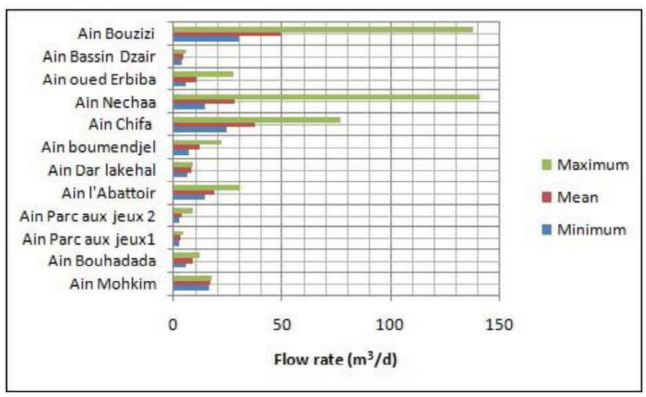

Fig. 5 - Variability of flow rates of studied springs (May-October 2018).

Fig. 5 - Variabilità della portata delle sorgenti studiate (Maggio-Ottobre 2018).

Significant variability in the flow rates is evident among the springs, notably in Ain Boumendjel (ABL), Ain parc aux jeux (APJ 2), Ain Chifa (AC), Ain Oued Erbiba (AOE), Ain Bouzizi (ABZ), and Ain Nechaa (AN). The coefficient of variation (CV) generally spans from 36.9% to 117.7%, with extreme value ratios (Q_{max}/Q_{min}) ranging from 4.6 to 9.89

Tab. 2 - Variability of spring flow rates during low waters period May-October 2018) (CV: coefficient of variation).

Tab. 2 - Variabilità della portata delle sorgenti durante il periodo di magra Maggio-Ottobre 2018 (CV: coefficiente di variazione).

Spring name	Qmin (m^3/d)	Qmean (m^3/d)	Qmax (m^3/d)	CV%	Magnitude	Qmax/Qmin	Frequency
Ain Mohkim	15.9	16.6	17.6	2.4	6	1.11	16
Ain Bouhadada	5.7	8.7	11.9	20.4	6	2.09	17
Ain Parc aux jeux1	2.4	2.9	4.6	21.2	7	1.92	15
Ain Parc aux jeux 2	2.7	3.9	8.7	42.2	7	3.22	15
Ain l'Abattoir	14.5	18.6	30.5	22.0	6	2.10	15
Ain Dar lakehal	6.3	8	8.6	6.7	6	1.37	17
Ain boumendjel	7.1	11.8	21.7	36.9	6	3.06	16
Ain Chifa	24	37.6	76.6	42.3	6	3.19	13
Ain Nechaa	14.2	27.8	140.4	117.7	6	9.89	14
Ain ouedErbiba	5.3	10.5	27.6	50.3	6	5.21	16
Ain BassinDzair	3.7	4.4	5.9	14.9	7	1.59	15
Ain Bouzizi	29.8	49.3	137.4	54.7	6	4.61	14

The most pronounced variation is observed in Ain Nechaa (AN), with a coefficient of variation of 117.7% and an extreme value ratio of 9.89 The maximum flow rate of this source is approximately 140 m³/d. However, springs like Ain Mohkim (AM), Ain Dar Lakehel (ADL), and Ain Bassin Dzair (ABDZ) exhibit more or less regular flows, with extreme value ratios ranging from 1.1 to 1.6 (Tab. 2). Intermediate fluctuations are observed at the sources of Ain Abatoir (AA), Ain Bouhadada (AB), and Ain parc aux jeux1 (APJ1), with the ratio of extremes hovering around 2.

Depletion of selected springs and estimation of groundwater reserves during the dry period

The study of spring hydrographs focused on assessing the stored flow volume and predicting when flow might stop during the dry season. It identified distinct drying patterns among the Seraidi springs, with Ain Boumendjel (ABL) and Ain Bouhadada (AB) showing moderate drying, while Ain Bassin Dzair (ABDZ) and Ain Parc aux jeux1 (APJ1) exhibited milder drying. This analysis highlights how different springs respond to seasonal changes, providing valuable insights into their flow dynamics.

The outcomes of the calculations performed using STATGRAPHICS Centurion XV software are outlined in Tables 3, 4, and 5. The 2-parameter Maillet-type decreasing exponential model demonstrates generally good accuracy (with $0.62 \le R^2 \le 0.98$) in depicting the recession patterns of the springs (Tab. 3), except for the Ain Bouzizi (ABZ) spring ($R^2 = 0.54$), suggesting a limited predictive capability of the Maillet model for this specific source. The recession coefficient values (α) in the Maillet model highlight the perennial nature of the Seraidi springs, ensuring a reliable water supply supported by shallow and fissured aquifer formations. These values exhibit notable variability, ranging from 0.0011 d^{-1} at Ain Abattoir (AA) to 0.0254 d^{-1} and 0.0365 d^{-1} at Ain Oued Eribiba (AOE) and Ain Bassin Dzair (ABZ), respectively (see Fig. 6). Most springs show low coefficients, indicating substantial aquifer support during low water levels.

Tab. 3 - Parameters of Maillet model.

Tab. 3 - Parametri del modello di Maillet.

Spring	Q_0 (m^3/d)	α (d^{-1})	R^2
Ain Mohkim	17.72	0.0014	0.82
Ain Bouhadada	12.76	0.0088	0.91
Ain Parc aux jeux1	3.82	0.0046	0.75
Ain Parc aux jeux 2	7.99	0.0158	0.92
Ain Abattoir	30.35	0.0011	0.99
Ain Dar lakehal	8.74	0.0024	0.62
Ain Boumendjel	22.39	0.0103	0.94
Ain Chifa	61.46	0.0104	0.67
Ain Nechaa	31.16	0.0254	0.92
Ain Oued Erbiba	22.27	0.0365	0.71
Ain Bassin Dzair	5.55	0.0048	0.90
Ain Bouzizi	28.32	0.0116	0.54

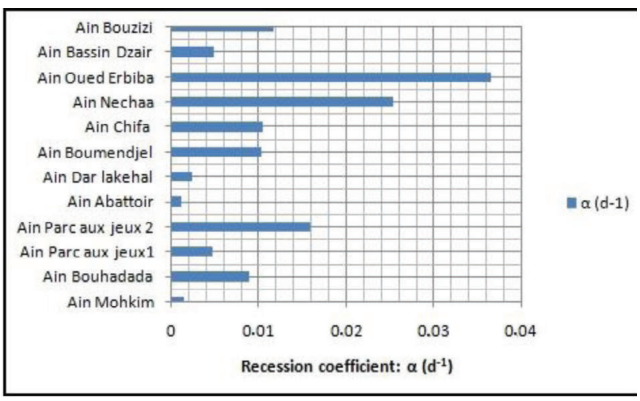

Fig. 6 - Spatial variability of recession coefficient (May-October 2018).

Fig. 6 - Variabilità spaziale della costante di esaurimento del modello di Maillet (Maggio-Ottobre 2018).

Tab. 4 shows considerable variability in the estimated low-water flows across most selected springs, except for Ain Bassin Dzair (ABDZ), which exhibits less variability. On the other hand, springs like Ain Mohkim (AM) and Ain Dar Lakehal (ADL) show minimal variation in low-water flows. These fluctuations, as illustrated in Table 5, are closely tied to underground reserves. Springs such as Ain Bassin Dzair (ABDZ), Ain Mohkim (AM), and Ain Dar Lakehal (ADL) exhibit only minor variations, whereas more pronounced fluctuations are observed in other springs, highlighting the vital role of underground aquifers in sustaining low water levels. This concept is similarly reflected in the Ain Bouzizi (ABZ) spring, where the terrain and altitude influence the flow intensity. Located at 816 m at the base of Mount Bouzizi (1,008 m above sea level), the steady water supply from the spring is primarily influenced by the gravitational flow of groundwater, which is closely linked to the extent of the aquifer feeding the spring. Additionally, the spring benefits from its location near moisture-rich northwesterly winds, which bring heavy rainfall, further supporting the flow. This combination of factors plays a significant role in maintaining the spring's water supply. This illustrates how both underground reserves and environmental factors, such as precipitation, contribute to the overall water availability in the region.

Tab. 4 - Parameters of Maillet model.

Tab. 4 - Parametri del modello di Maillet.

Spring	Q_0 (m^3/d)	$Q_{end\text{-}Sept}$ (m^3/d)	$Q_{mid\text{-}Oct}$ (m^3/d)	$Q_{end\text{-}Oct}$ (m^3/d)
Ain Mohkim	17.72	0.0014	0.82	14.5
Ain Bouhadada	12.76	0.0088	0.91	3.1
Ain Parc aux jeux1	3.82	0.0046	0.75	1.9
Ain Parc aux jeux 2	7.99	0.0158	0.92	0.7
Ain Abattoir	30.35	0.0011	0.99	6.0
Ain Dar lakehal	8.74	0.0024	0.62	6.1
Ain Boumendjel	22.39	0.0103	0.94	4.9
Ain Chifa	61.46	0.0104	0.67	12.3
Ain Nechaa	31.16	0.0254	0.92	1.6
Ain Oued Erbiba	22.27	0.0365	0.71	0.3
Ain Bassin Dzair	5.55	0.0048	0.90	3.2
Ain Bouzizi	28.32	0.0116	0.54	92.4

Tab. 5- Underground storage estimated by the Maillet model (S_0: Initial volume of groundwater storage).

Tab. 5 - Volume immagazzinato nell'acquifero stimato utilizzando il modello di Maillet (S_0: volume iniziale immagazzinato nell'acquifero).

Spring	S_0 (m^3)	$S_{end\text{-}Sept}$ (m^3)	$S_{mid\text{-}Oct}$ (m^3)	$S_{end\text{-}Oct}$ (m^3/d)
Ain Mohkim	12657.3	10777.7	10574.1	10360.2
Ain Bouhadada	1449.5	467.4	405.8	355.4
Ain Parc aux jeux1	830.1	486.6	453.8	423.3
Ain Parc aux jeux 2	505.8	76.6	59.4	46.8
Ain Abattoir	27587.7	7630.8	6453.1	5457.1
Ain Dar lakehal	3640.0	2745.2	2648.5	2555.2
Ain Boumendjel	2174.0	647.4	549.3	470.9
Ain Chifa	5909.8	1611.9	1379.2	1180.1
Ain Nechaa	1226.9	131.7	90.0	61.5
Ain Oued Erbiba	610.1	24.6	14.3	8.3
Ain Bassin Dzair	1156.3	762.5	709.7	660.5
Ain Bouzizi	2441.7	5625.4	6693.7	7964.9

These analyses and figures (Fig. 7 and Fig. 8), although simplified, highlight the perennial nature of the Seraidi springs, characterized by low to very low recession coefficients. While spring flow rates are reduced during the dry period, they continue to provide a reliable water supply for local residents and those in need of fresh water. Figures 7 and 8 illustrate the evolution of flow rates and estimated reserves during low-flow periods, offering insights into their temporal and spatial variations in relation to the hydrogeological setting of the study area. For instance, at Ain Chifa (AC), The discharge rate (Fig. 7) shows a gradual decline over time, reaching its lowest value once, in late October, after decreasing through late September and mid-October. This behavior reflects the aquifer's recharge capacity and its connection to the geological formations supporting the spring. In contrast, Ain Bassin Dzair (ABDZ) exhibits consistently lower discharge rates than Ain Chifa (AC), likely due to spatial variability influenced by differences in geological context and aquifer properties. These differences may stem from variations in lithology, permeability, or structural features.

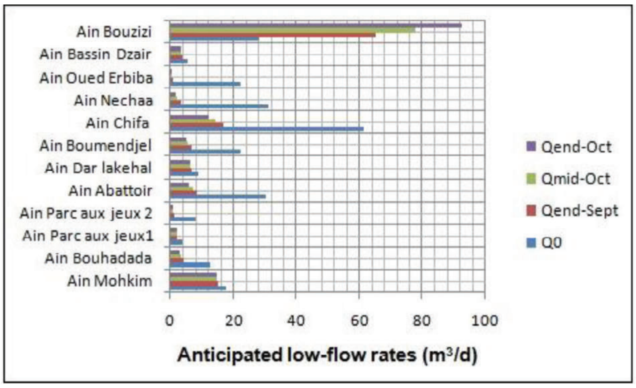

Fig. 7 - Flow rate evolution throughout low-flow period (May-October2018).

Fig. 7 - Evoluzione temporale della portata delle sorgenti durante il periodo di magra (Maggio-Ottobre 2018).

Figure 8 further emphasizes this variability by presenting the temporal and spatial distribution of estimated reserves. At Ain Abattoir (AA), the reserves are notably higher than those at Ain bouhadada (AB), underscoring the spatial disparities likely shaped by the underlying hydrogeological conditions. Temporally, all sources display a decline in reserves, with values consistently below the initial storage (S_0) by the end of September, middle of October, and end of October. This analysis underscores how variations in aquifer recharge and geological characteristics across the study area impact the flow rates and storage dynamics of the springs, providing a comprehensive interpretation of the results.

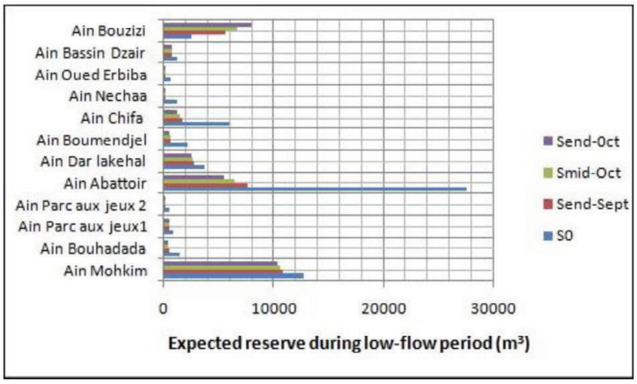

Fig. 8 - Reserve evolution throughout low-flow period (May-October 2018).

Fig. 8 - Evoluzione temporale del volume immagazzinato nell'acquifero durante il periodo di magra (Maggio-Ottobre 2018).

Exploration of physicochemical parameters

The analysis of physical parameters is elaborated in Table 6. Temperature and pH show minimal variations across different springs, with coefficients of variation (CV) at 5% and 3%, respectively. The mean values are approximately 16.9°C and 6.7, respectively, meeting the World Health Organization (WHO) standards. Therefore, Seraidi spring waters are considered fresh and slightly acidic.

Electrical conductivity ranges from 222 to 774 µS/cm at 25°C (Fig. 9), remaining within potability standards.

Tab. 6 - Results of Seraidi spring waters physico-chemical analyses (May-October 2018).

Tab. 6 - Risultati delle analisi fisico-chimiche delle acque delle sorgenti del Seraidi (Maggio-Ottobre 2018).

Spring name	pH	T (°C)	EC (µs/cm) at 25 °C	Salinity (mg/L)	Turbidity (NTU)
Ain Mohkim	6.91	16.5	458	209.2	1.7
Ain Bouhadada	6.5	17.5	568.4	273.9	1.1
Ain Parc aux jeux1	6.8	16.9	701.4	339.9	1.2
Ain Parc aux jeux 2	6.3	16.9	646.3	312.3	1.2
Ain Abattoir	6.7	16	749.9	363.9	1.2
Ain Dar lakehal	6.7	15.2	405.1	193.2	1.3
Ain boumendjel	6.5	15.2	645.2	311.2	1.5
Ain Chifa	6.5	16.7	524.3	251.8	5.2
Ain Nechaa	6.7	17.7	221.5	105.8	3.3
Ain oued Erbiba	6.7	16.7	286.2	136.2	1.3
Ain Bassin Dzair	6.8	16.7	773.5	375.6	1.1
Ain Bouzizi	6.4	17.2	302.5	144.1	1.8
Minimum	6.3	15.2	221.5	105.8	1.1
Maximum	6.91	17.7	773.5	375.6	5.2
Mean	6.6	16.6	523.5	251.4	1.8
Standard deviation	0.2	0.8	188.8	92.9	1.2
CV%	3%	5%	36%	37%	67%

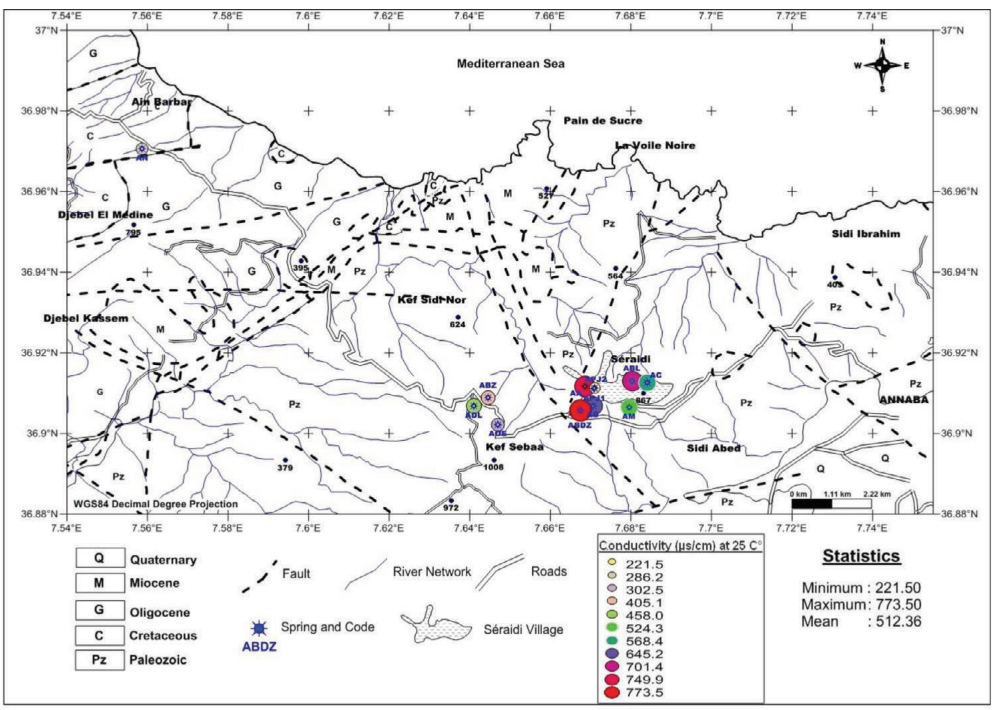

Fig. 9 - Map of electrical conductivity (µs/cm) of studied springs (May-October 2018).

Fig. 9 - Carta della conducibilità elettrica (µs/cm) delle sorgenti studiate (Maggio-Ottobre 2018).

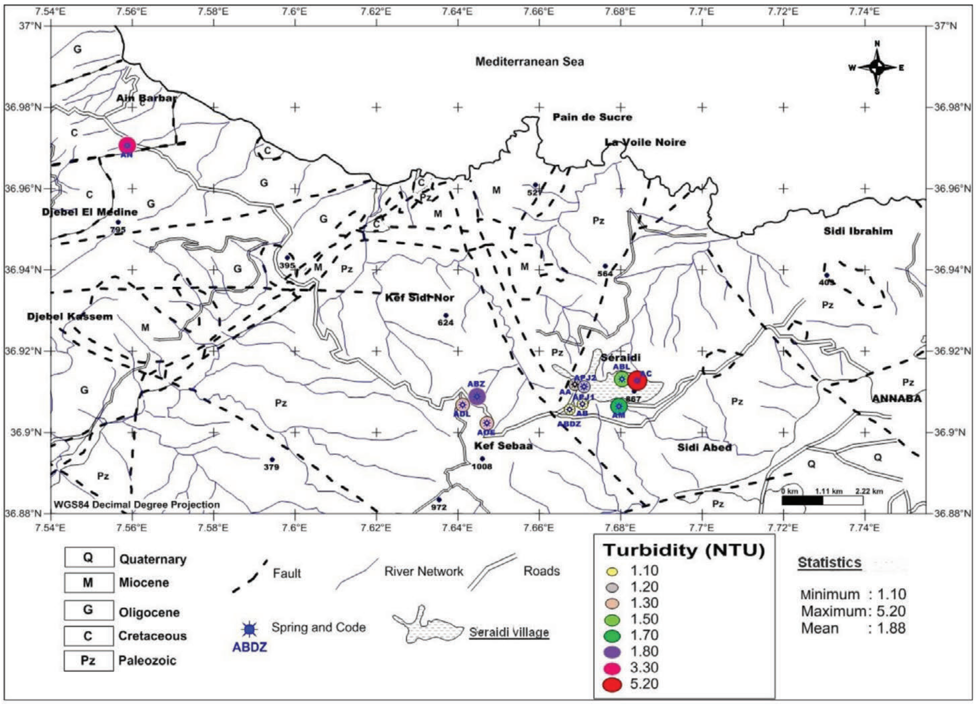

Fig. 10 - Map of turbidity of the studied springs (May-October 2018).

Fig. 10 - Carta della torbidità delle sorgenti studiate (Maggio-Ottobre 2018).

Furthermore, these spring waters demonstrate slight to moderate mineralization. Total Dissolved Solids (TDS) concentrations, as reported by Benouara (2016), range from 123 mg/L to 701 mg/L, with a mean value of approximately 455 mg/L. These concentrations remain within the WHO (2004) recommended acceptable range of 500–1000 mg/L. The salinity values during the period (May–October 2018) ranged from 105.8 mg/L in Ain Nechaa (AN) to 375.8 mg/L in Ain Bassin Dzair (ABDZ). According to the World Health Organization (WHO), the recommended salinity limit for drinking water is 250 mg/L. The salinity level at Ain Nechaa (AN) is within acceptable limits, as it falls below the WHO guideline. However, the salinity level at Ain Bassin Dzair (ABDZ) exceeds the recommended limit, which may affect the water's taste and suitability for human consumption. Since this water is intended for consumption, treatment or further evaluation may be necessary to ensure its safety and quality.

Seraidi spring waters are also distinguished by their clarity and absence of suspended matter, with turbidity values ranging between 1 and 5 NTU (Fig. 10).

Water Quality Assessment

The results of the analysis conducted on twelve samples at the Annaba Horizon Laboratory in October 2018, targeting nine specific elements and chemical compounds, are presented in Table 7.

Dissolved Oxygen

The dissolved oxygen concentration is a critical indicator, providing valuable information about microbial contamination. At atmospheric pressure, oxygen reaches equilibrium at 8.8 mg/L, representing full saturation (100%). Undersaturation in water indicates microbial activity consuming oxygen, often due to the presence of degradable organic matter. In the examined springs, dissolved oxygen levels range between 7 and 9 mg/L, signaling well-aerated water, fully saturated with oxygen and absence of microbial contamination.

Nitrogen compounds

NO_3^- and NO_2^- serve as reliable indicators of excessive nitrogen inputs from fertilizers, animal manure, and poorly maintained sewage systems. NO_3^- content ranges from 28 mg/L at Ain Bouhadada (AB) to 37 mg/L at Ain Boumendjel (ABL), all within the acceptable standards set by the WHO in 2011 (50 mg/L). In contrast, NO_2^- levels vary from 0.11 mg/L at Ain Mohkim (AM) to 0.55 mg/L at Ain Abattoir (AA) (Fig. 11), exceeding the WHO standards established in 2011 (0.1 mg/L) across all studied spring waters. This increase is attributed to the use of synthetic fertilizers and manures, combined with intensive agricultural and livestock practices.

NH_4^+ in water generally signals an incomplete degradation process of organic matter. It originates from the reaction of iron-containing minerals with NO_3^-. Thus, its presence indicates water pollution caused by agricultural, domestic, or industrial organic waste.

NH_4^+ concentrations range from 0.15 mg/L at sources such as Ain Nechaa (AN), Ain Oued Eribiba (AOE), and Ain Bassin Dzair (ABDZ) to 0.19 mg/L at Ain Bouzizi (ABZ). These values are all below the Algerian potability standard of 0.5 mg/L and the WHO acceptable drinking water standard for groundwater, also 0.5 mg/L.

Phosphates

PO_4^{3-} originates from various sources, including agricultural fertilizers, industrial detergents, and human

Tab. 7 - Concentration of elements and compounds in the analyzed waters springs (2018).
Tab. 7 - Concentrazione degli elementi e dei composti chimici nelle acque analizzate (2018).

Spring name	NO_3^- (mg/L)	NO_2^- (mg/L)	NH_4^+ (mg/L)	PO_4^{3-} (mg/L)	Ni^{2+} (mg/L)	Al^{3+} (mg/L)	Fe^{3+} (mg/L)	Mn^{2+} (mg/L)	Cu^{2+} (mg/L)	DO (mg/L)
Ain Mohkim	29	0.11	0.18	0.99	0.002	0.05	0.01	0.1	0.0013	9.04
Ain Bouhadada	28	0.23	0.17	0.7	0.35	0.05	0.08	0.1	0.0001	8.4
Ain Parc aux jeux1	32	0.22	0.17	0.68	0.005	0.08	<0.01	0.1	0.0033	9.2
Ain l'Abattoir	29	0.55	0.17	1	0.001	0.07	0.04	0.2	0.0001	7.8
Ain Dar lakehal	30	0.25	0.16	1	0.001	0.05	0.03	0.2	0.0032	9
Ain boumendjel	37	0.35	0.16	0.93	0.004	0.11	0.09	0.1	0.0019	9.1
Ain Chifa	29	0.19	0.17	0.91	0.11	0.04	0.02	0.2	0.0018	8.4
Ain Nechaa	28	0.26	0.15	0.47	0.004	0.13	0.06	0.1	0.0006	7.3
Ain ouedErbiba	32	0.32	0.15	1.68	0.001	0.05	0.02	0.1	0.0007	8.2
Ain BassinDzair	36	0.26	0.15	1.31	0.1	0.04	0.01	0.1	0.0001	8.7
Ain Bouzizi	35	0.4	0.19	0.76	0.001	0.08	0.03	0.1	0.0031	8.5
Minimum	26	0.11	0.15	0.47	0.001	0.04	0.01	0.1	0.0001	9.2
Mean	30.9	0.3	0.2	0.9	0.049	0.067	0.038	0.1	0.0014	8.55
Maximum	37	0.55	0.19	1.68	0.35	0.13	0.09	0.2	0.0033	9.2
Standard deviation	3.50	0.11	0.01	0.33	0.10	0.03	0.03	0.05	0.0013	0.57
CV%	11.33	39.03	7.48	36.23	212.14	43.06	71.07	36.70	90.81	6.70

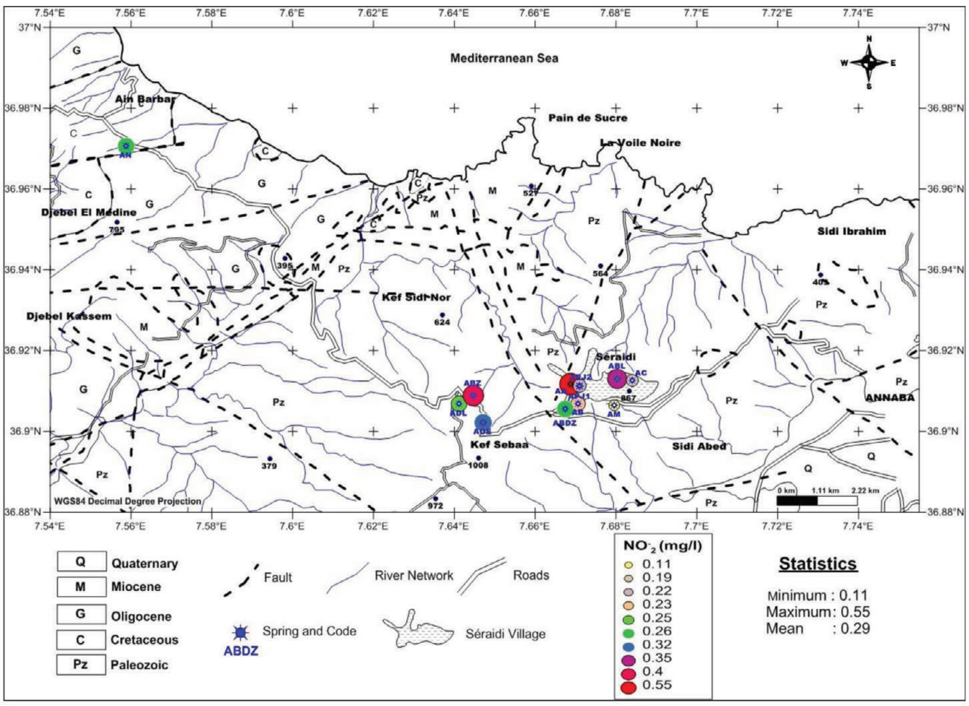

Fig. 11 - Map of nitrites concentrations in the studied springs (May-October 2018).

Fig. 11 - Carta della concentrazione di nitriti delle sorgenti studiate (Maggio-Ottobre 2018).

waste. The findings reveal minimal PO_4^{3-} concentrations, ranging from 0.47 mg/L at Ain Nechaa (AN) to 1.68 mg/L at Ain oued Eribiba (AOE) (Fig. 12). These levels consistently fall well below the WHO standard of 5 mg/L.

Trace Elements and Heavy Metal Concentrations in Spring Waters

In this study, trace elements predominantly consist of heavy metals, which are renowned for their toxic properties and anthropogenic origins. The examined heavy metals include Ni^{2+}, Al^{3+}, Fe^{3+}, Mn^{2+}, and Cu^{2+}. While previous studies reported zero concentrations for Ni^{2+} and Cu^{2+} (Majour, 2010), our recent research reveals a slight increase in the concentrations of these two elements, as Ni^{2+} reaches a value of 0.35 mg/L in certain spring, which warrants attention.

Ni^{2+} concentrations ranged from 0.001 mg/L at Ain Abattoir (AA), Ain Dar Lakehal (ADL), Ain Oued Eribiba (AOE), and Ain Bouzizi (ABZ) to 0.35 mg/L at Ain Bouhadada (AB) (Fig. 13).

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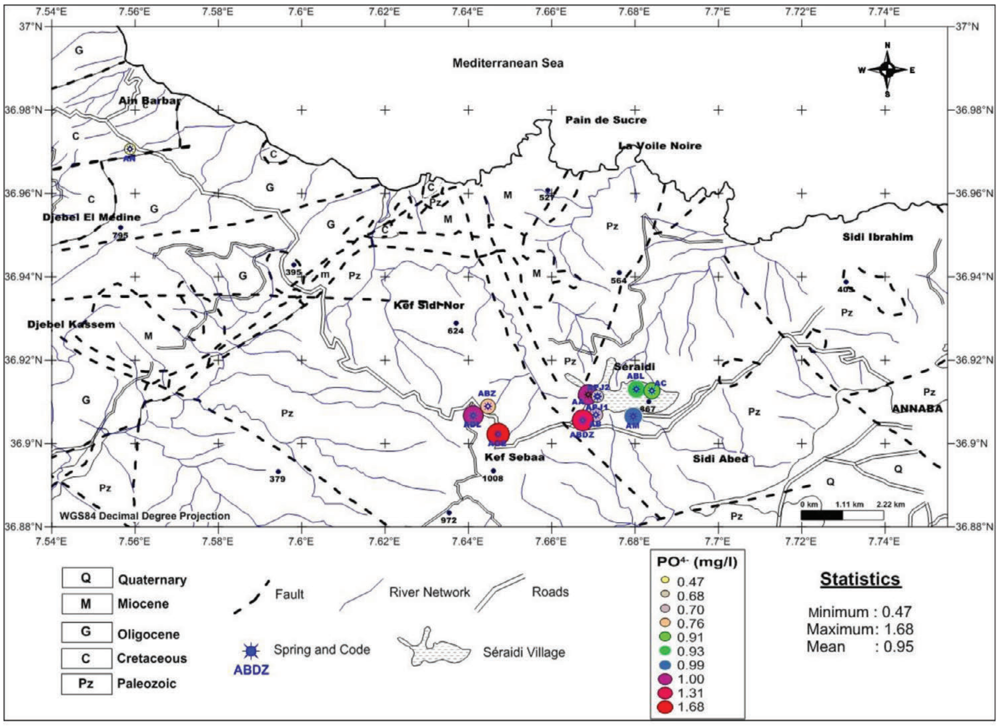

Fig. 12 - Map of phosphates concentrations in the studied springs (May-October 2018).

Fig. 12 - Carta della concentrazione di fosfati delle sorgenti studiate (Maggio-Ottobre 2018).

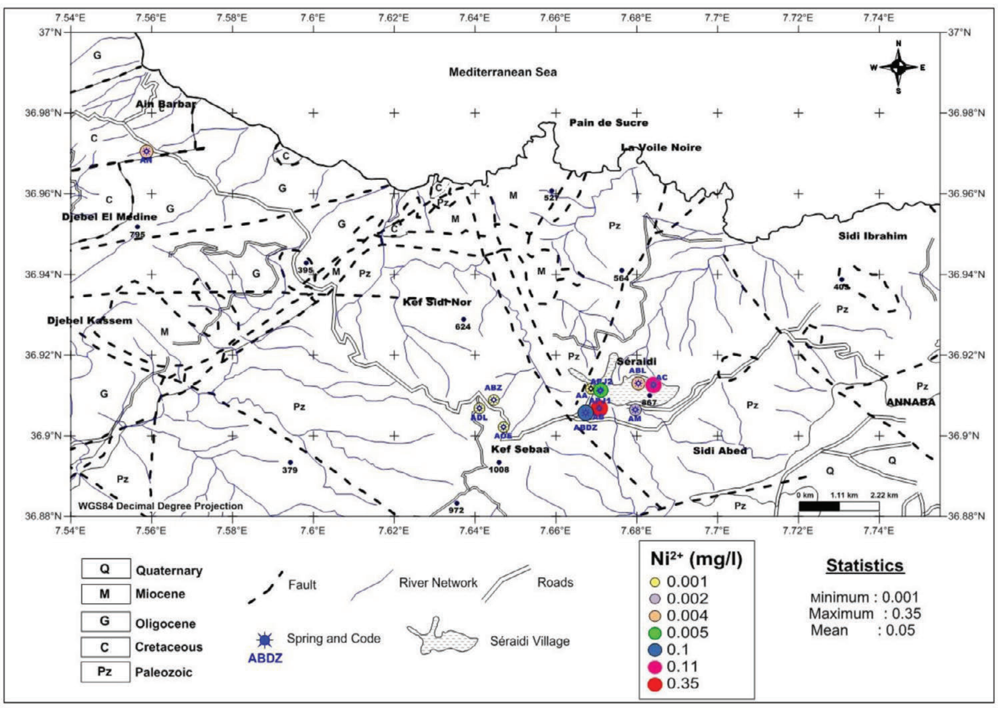

Fig. 13 - Map of nickel concentrations in the studied springs (May-October 2018).

Fig. 13 - Carta della concentrazione di nickel delle sorgenti studiate (Maggio-Ottobre 2018).

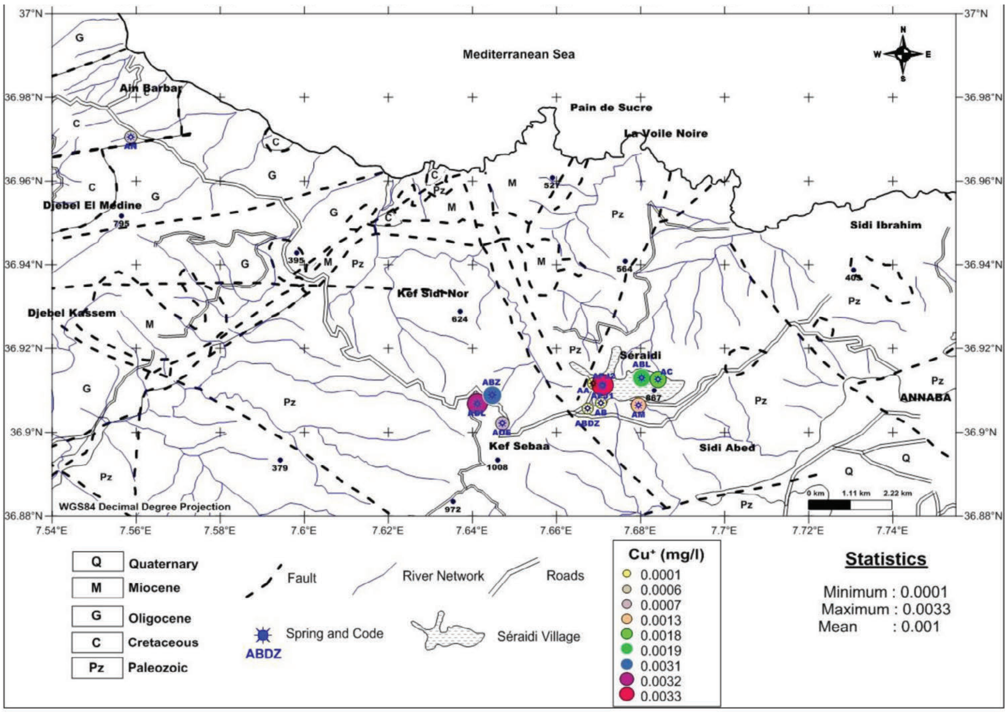

Fig. 14 - Map of copper concentrations in the studied springs (May-October 2018).

Fig. 14 - Carta della concentrazione di rame delle sorgenti studiate (Maggio-Ottobre 2018).

Similarly, Cu^{2+} concentrations varied from 0.0001 mg/L at Ain Bouhadada (AB), Ain Abattoir (AA), and Ain Bassin Dzair (ABDZ) to 0.0033 mg/L at Ain Parc aux jeux1(APJ1) (Fig. 14).

Fe^{3+} concentrations range from 0.01 mg/L at Ain Mohkim (AM) and Ain Bassin Dzair (ABDZ) to 0.09 mg/L at Ain Boumendjel (ABL), influenced by the surrounding rock type (Majour, 2010) (Fig. 15). Al^{3+} levels vary between 0.04 mg/L at Ain Chifa (AC) and Ain Bassin Dzair (ABDZ) to 0.13 mg/L at Ain Nechaa (AN) (Fig. 16), while Mn^{2+} ranges from 0.1 mg/L at springs like Ain Mohkim (AM) and Ain Bouhadada (AB) to 0.2 mg/L at Ain Abattoir (AA) and Ain Dar Lakehal (ADL) (Fig. 17).

These variations result from water infiltrating rock fractures, breaking down silicate minerals such as micas and feldspars, and releasing potassium, iron, aluminum, and manganese. Marble also contributes calcium and magnesium.

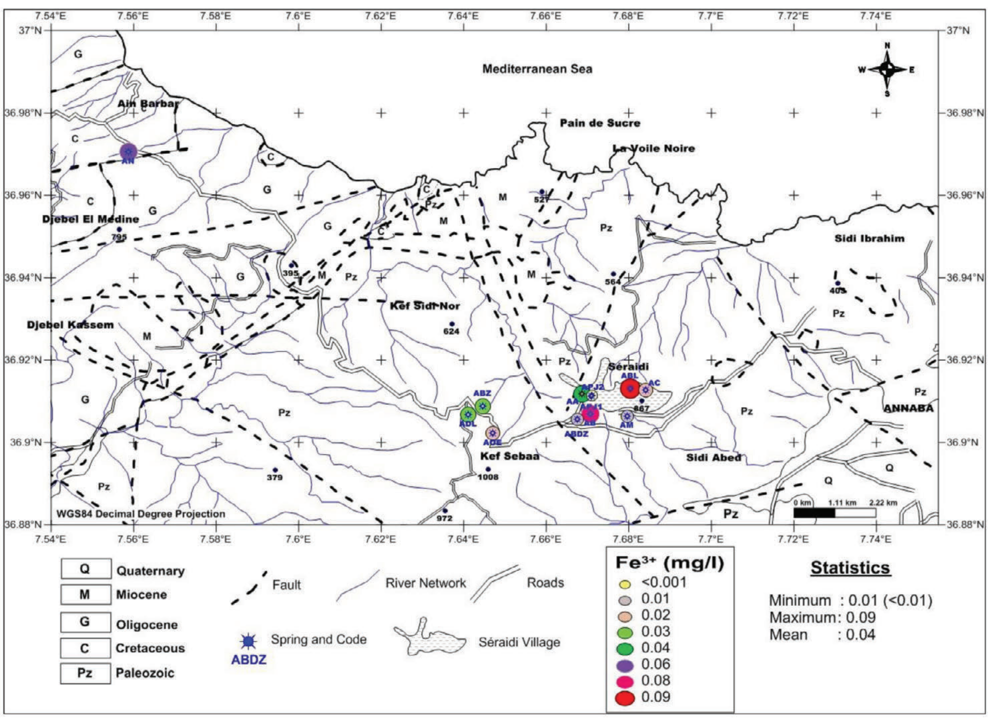

Fig. 15 - Map of iron concentrations in the studied springs(May-October 2018).

Fig. 15 - Carta della concentrazione di ferro delle sorgenti studiate (Maggio-Ottobre 2018).

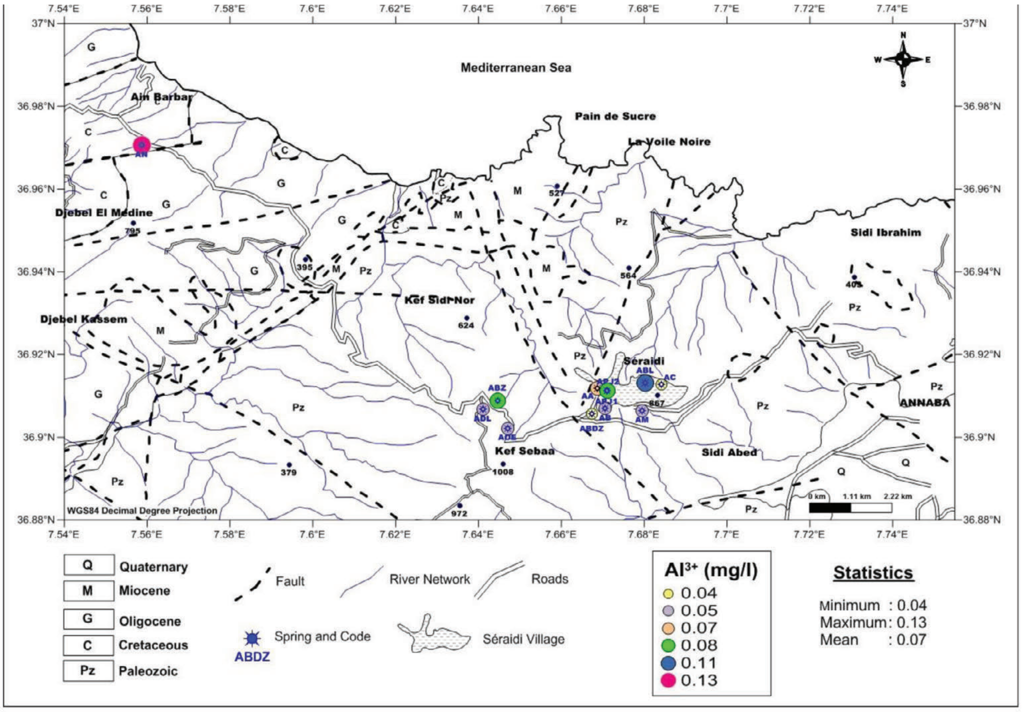

Fig. 16 - Map of aluminum concentrations in the studied springs (May-October 2018).

Fig. 16 - Carta della concentrazione di alluminio delle sorgenti studiate (Maggio-Ottobre 2018).

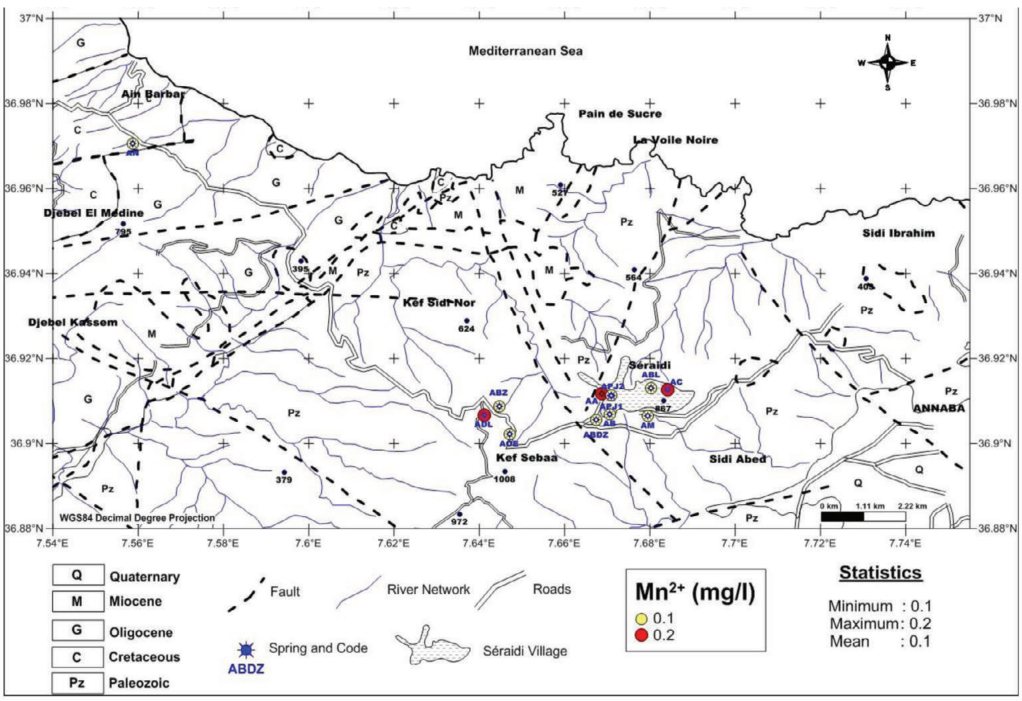

Fig. 17 - Map of manganese concentrations in the studied springs (May-October 2018).

Fig. 17 - Carta della concentrazione di manganese delle sorgenti studiate (Maggio-Ottobre 2018).

Additionally, soil leaching during high-water periods and the hydrolysis of acidic rocks play roles in mineralization.

While the spring waters are generally of good quality, with magnesium and calcium chlorides as the dominant minerals, their shallow groundwater makes them highly vulnerable to pollution from human activities. These pollutants include nitrates, nitrites, orthophosphates, and nickel.

In certain areas, the concentrations of specific heavy metals occasionally exceed the drinking water standards established by Algeria and the WHO. For instance, Ni^{2+} concentrations were recorded at 0.35 mg/L in Ain Bouhadada (AB), 0.11 mg/L in Ain Chifa (AC), and 0.1 mg/L in Ain Bassin Dzair (ABDZ) Therefore, rigorous monitoring is necessary to prevent potentially irreversible pollution of the natural environment.

Conclusions

The population frequently relies on the Seraidi springs, making it crucial to study them during the dry season to accurately forecast water reserves in the surrounding reservoirs. This analysis facilitates improved management of the springs and promotes their sustainable development.

The decline in water quality can likely be attributed to anthropogenic pollution stemming from population growth associated with rural-to-urban migration in the 1990s. This phenomenon led to the establishment of informal settlements within the catchment areas of the water springs.

The primary objective of this study was to monitor the hydrological behavior of the Seraidi springs during low-water periods, with particular emphasis on the depletion phase, which poses significant risks to the availability of high-quality water. The Maillet exponential decreasing model was employed to characterize the low-water behavior and depletion patterns of the Seraidi springs.

The results generally reveal low values of the recession coefficient for most of the studied springs, indicating substantial support from the fractured aquifer formations in the region. This support is influenced by the interaction between the aquifer's hydraulic head and fault conductance, with faults facilitating water movement from confined aquifers to the surface. Higher fault conductance enables greater flow, which is essential for understanding spring behavior and ensuring the sustainability of spring water resources. The hydraulic head within the aquifer creates the necessary pressure for flow, while fault conductance determines the ease with which water moves through fault zones.

Using the Maillet model, we estimated low-water flows and the volume of groundwater reserves at the end of September, middle of October, and the end of October. These findings underscore the critical role of both the aquifer's characteristics and fault systems in maintaining spring discharge rates. However, the persistent increase in heavy metal concentrations in the spring waters is a concerning issue that may pose significant health risks. Consequently, monitoring these elements is essential to avert any irreversible effects. The water quality of the Seraidi springs is sufficiently high to be developed as a freshwater source, provided that contamination is effectively managed. The most effective strategy for controlling unwanted chemicals, such as nitrogen compounds and trace elements, and preventing bacterial outbreaks in the spring water is the implementation of measures to prevent contamination. These measures include proper management of local agricultural practices, strategic placement of pit latrines and septic tanks, control of sewage leaks, and meticulous application and storage of fertilizers and animal manure. This study has enhanced our understanding of the hydrogeological characteristics of the area, including how groundwater moves and interacts with the surrounding geology. These findings can help manage local water resources more effectively, especially in predicting droughts and making better use of aquifers. The results can also inform local water management policies, promoting sustainable practices for future generations.

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Author contributions

Collection of data: Dr. Guechi Salima, Pr. Beloulou Laroussi.
Data processing: Guechi Salima, Pr. Beloulou Laroussi .
Interpretation of results: Guechi Salima.
Writing - Original Draft Preparation: Guechi Salima.
Writing - Review and Editing: Guechi Salima.
Visualization: Guechi Salima.
Supervision: Pr Beloulou Laroussi.
Project Administration: Guechi Salima. Beloulou Laroussi
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