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Apply Indices And Statistical Methods To Assess Water Suitability For Irrigation In Wadi Djedra And Tributaries, North-East Algeria

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Abstract: The region under study is marked by agricultural activity, where farming is the primary occupation of its inhabitants. This study aims to determine the suitability of surface waters in the watershed of DjedraWadi and its tributaries for irrigation. Hydrochemical analysis was conducted at seven stations over four sampling campaigns extending from November 2020 to December 2021. These analyses included pH, electrical conductivity, TDS, major element concentrations, nutrients, and five trace metal elements (Mn, Zn, Pb, Cr, and Cd). The suitability of these waters for irrigation was also assessed based on water quality indices such as sodium adsorption ratio (SAR), residual sodium carbonate (RSC), permeability index (PI), sodium percentage (Na %), Kelley ratio (KR), magnesium hazard (MH), and potential salinity (PS). High levels of electrical conductivity, HCO_3^-, NO_3^-, and Cl^- recorded may influence the yield and quality of certain vegetable crops and fruit trees. Statistical analysis enabled us to identify the group of stations whose waters may contribute to decreased permeability, which could lead to long-term deterioration of soil structure.
Key words: Wadi, Irrigation, watershed, suitability, quality index.

1. INTRODUCTION

The constant increase in human population, climate change, and intensification of agriculture exerts significant pressure on water resources, posing a major challenge in providing enough food to meet current demand (Misra,2014). The agricultural nature of our study region, characterized by significant agricultural activities, requires enormous quantities of water. It is therefore necessary for this water to have appropriate properties suitable for crop irrigation.
Our objective is to determine the suitability of the waters of the Djedra Wadi and its tributaries (Akiba and Hammam Wadis) for irrigation and to assess their influence on crops as well as soil structure. We considered four periods in our calculations, namely November 2020, February, June, and December 2021.
To achieve the desired objectives of this study, water quality indices were used to assess water quality for irrigation purposes.

2. MATERIALS AND METHODS

2.1 Presentation of the study area

The watershed of the Djedra Wadis in the extreme northeast of Algeria, between latitudes 7°51' and 8°03'E and longitudes 36°18' and 36°23'N (Figure. 1). It is characterized by a Mediterranean climate. The average annual precipitation for 2020 and 2021 was 764.65 and 597.37 mm, respectively. The temperature varies between 9.9 °C (in January) and 32.4 °C (in July). It is part of the Medjerda basin, where it covers an area of 127 km2. Hydrographically, this area is characterized by an incredibly significant network that will supply the Oued Djedra dam, where construction works are nearing completion. The Djedra wadi like other wadis in the eastern part of northern Algeria in accordance with the food regime relates to the type with pluvial floods in the humid period, from December to April, and with the very weak flow during the dry period from May to August. With the interannual average flow rate of around 1.6 m3/s, the monthly average flow rates are from 0 to 23.3m3/s. Runoff volumes during the dry period, from May to August, are on average around 9%.

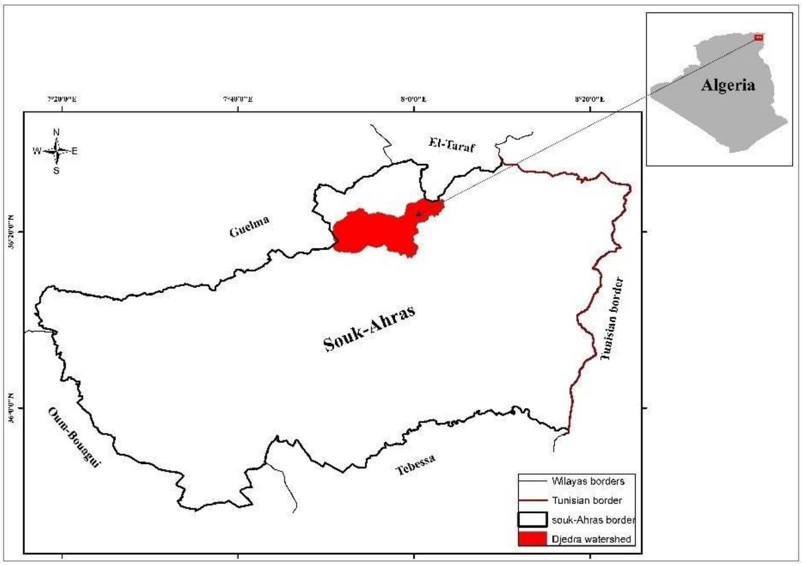

Figure. 1: location of the study area

From a geological perspective, the Djedra watershed is part of the external domain of the Maghrebides chain. It consists of a marine formation ranging in age from Turonian to Paleocene and a lower Miocene clay-sandstone cover. It is composed of marls and marly limestone from the Turonian to Santonian. The Campanian and Maastrichtian periods are characterized by two limestone bars, with the Campanian-Maastrichtian transition occurring through a series of marly limestones. The Cretaceous-Tertiary transition is represented by marly facies, with the Eocene being absent (Chabbi,2017). In the Triassic diapir upstream of the Oued Djedra, yellow clayey marls and greenish sandy marls predominate. Within the marly clays, sandstones and gypsum occur as intercalations and lenses. The gypsum is often saccharoidal, crystalline, and amorphous, rarely fibrous(Figure. 2). (David, 1956).

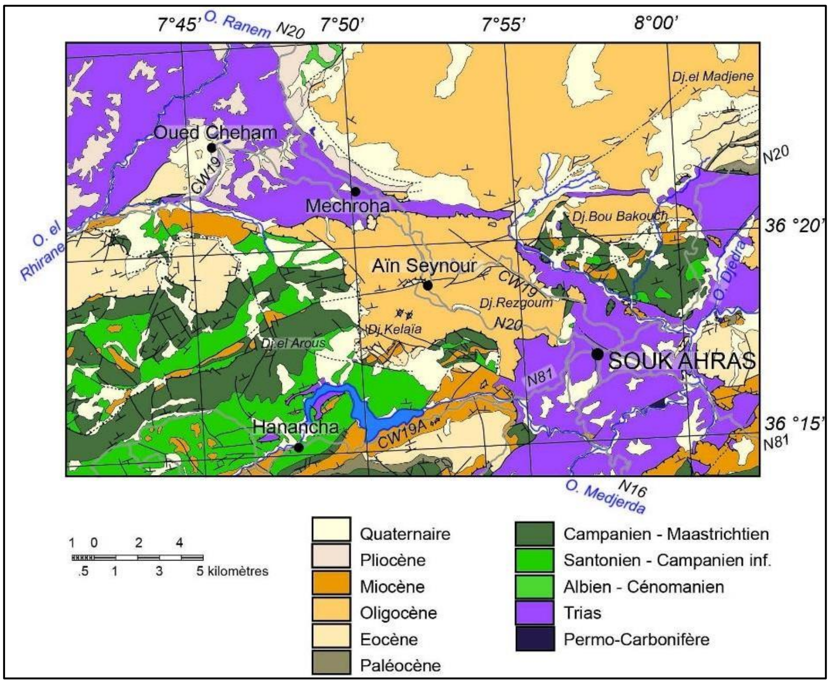

Fig. 2 : geological map of the study area.

2.2 Sampling

The assessment of the suitability for irrigation of the surface waters of the Djedra Wadi watershed, which receives various discharges, was based on a spatiotemporal sampling protocol covering four seasons, with samples taken at seven different stations (Figure. 3):

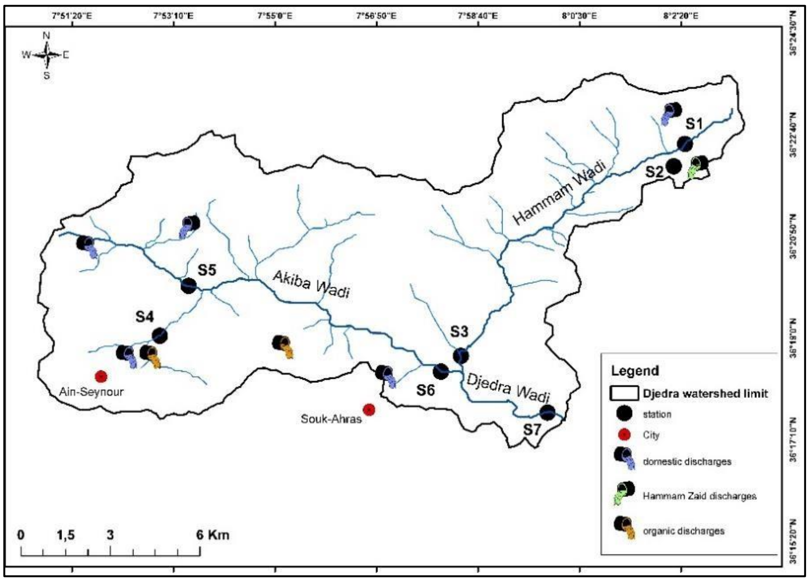

Figure.3: Location of sampling stations

S1: Downstream of the Hammam Wadi, it is taken as a reference station.
S2: Receives discharges from Hammam Ouled Zaid (thermal waters).
S3: Downstream of the Hammam Wadi just before joining Oued Akiba.
S4: Receives urban wastewater from the city of Ain-Seynour and discharges from livestock farms.
S5: This site was chosen as a reference upstream of the Akiba Wadi.
S6: Located downstream of Akiba Wadi, it receives effluents resulting from agricultural practices (livestock manure, fertilizers, and pesticides) and also wastewater from part of the northern side of the city of Souk Ahras.
S7: Downstream of the Djedra Wadi, it is considered the balance station of the Djedra watershed. The coordinates of the sampling points are given in table 1.

During sampling, care was taken to adhere to standard sample preparation rules (filtration at 0.45 µm and acidification to pH <2), bottle preparation, labeling, and sample storage (at 4°C) (AFNOR/T91E). Figure. 02 illustrates the locations of the sampling sites of the studied waters.

Table 1. coordinates of the sampling points

Sites	Longitude	Latitude
S1	8.014967°	36.363677°
S2	8.012782°	36.360932°
S3	7.972567°	36.308580°
S4	7.885352°	36.321415°
S5	7.888897°	36.333218°
S6	7 .966438°	6.306819°
S7	7.990154°	36.292978°

2.3 Methodology

Assessing the suitability of water for irrigation generally involves several steps and methodologies to ensure a comprehensive analysis of water quality. For our case we began a spatiotemporal study of 21 parameters, including pH, temperature, total dissolved solids, electrical conductivity, dissolved oxygen, major elements, nutrients and five metallic trace elements. Different indices of water quality for irrigation were also determined, the formulas for calculating the indices used in this study, as well as the classification of water for irrigation according to these are summarized in table 2.

The pH, temperature (T), electrical conductivity (EC), and dissolved oxygen (DO) are measured in situ using a WTW multi-parameter device (multi 340 i/SET). All parameters were analyzed according to standard methods for water and wastewater analysis as outlined by (Rodier et al., 2009). Total dissolved solids (TDS) are determined according to Standard NF T 90-029, Ca^{2+}, Cl^{-}, Mg^{2+}, CO_3^{-}, and HCO_3^{-} are analyzed by titration, while PO_4^{3-}, NO_3^{-}, NH_4^{+}, and SO_4^{2-} are figured out by the colorimetric method using a multi-parameter spectrophotometer of the SECOMAN Uviline 9400 type. The analysis of the five trace metal elements was performed using an atomic absorption spectrometer (novAA 350, Germany), and finally, Na^{+} and K^{+} are determined by the same device but in emission mode. R-studio software was used for multivariate data analysis, while ArcGIS software was utilized to create maps.

Table 2. Calculation formulas and classifications of irrigation water quality indices.

Indices	Formula*	Range	Water class	References
SAR	$SAR = \frac{Na^+}{\sqrt{(Ca^{2+} + Mg^{2+})/2}}$	<10 10 – 18 18 – 26 <26	Excellent Good Doubtful Unsuitable	(Richards, 1954)
Na%	$Na(\%) = \frac{Na^+ + K^+}{2Ca^{2+} + Mg^{2+} + Na^+ + K^+} \times 100$	< 10 20 - 40 40 - 60 60 – 80 > 80	Excellent Good Permissible Doubtful Unsuitable	(Wilcox, 1948)
RSC	$RSC = (HCO_3^- + CO_3^{2-}) - (Ca^{2+} + Mg^{2+})$	< 1,25 1,25 - 2,5 > 2,5	Good Doubtful Unsuitable	(Eaton, 1950)
PI	$PI = \frac{(Na^+ + \sqrt{HCO_3^-}}{Ca^{2+} + Mg^{2+} + Na^+} \times 100$	> 75 25 - 75 < 25	Excellent Good Poor	(Doneen, 1964)
PS	$PS = Cl^- + (0,5 \times SO_4^{2-})$	< 5 5 - 10 > 10	Excellent to good Goodtoharmful Harmful to unsuitable	(Doneen, 1964)
KR	$KR = \frac{Na^+}{Ca^{2+} + Mg^{2+}}$	< 1 > 1	Good Unsuitable	(Kelley, 1963)
MH	$MH(\%) = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} \times 100$	< 50 > 50	Suitable Unsuitable	(Raghunath,1987)

* (Ion concentrations are expressed in milliequivalent per Liter (meq/L).

3. RESULTS AND DISCUSSION

3.1. Hydrochemical characteristics

The analysis of the physicochemical parameters of the waters of Djedra Wadi and its tributaries, overall shows relative heterogeneity. The minimum, maximum and average values with standard errors of these parameters for the waters studied are presented in Table 3.

Table3. Descriptive statistics of parameters for the waters studied.

Parameter	unit	Min	Max	Avearage ± S. Error	Guideline value [1]
T	°C	9.70	31.20	17.39 ± 1,12	-
pH	-	6.87	8.33	7.74 ± 0.08	6,5 – 8,4
CE	µs/cm	304.0	2750	1102.3 ± 132.64	0 –3000
TDS	mg/L	636	1268	942.8 ± 34.84	0 – 2000
Ca^{2+}	mg/L	82.1	205.40	133.4 ± 7.6	0 – 150
Mg^{2+}	mg/L	9.85	26.50	16.27 ± 0.95	0 – 30
Na^{+}	mg/L	32.40	135.60	70.81 ± 4.78	0 – 70 [2]
K^{+}	mg/L	1.320	7.31	3.46 ± 0.3	0 – 10
HCO_3^{-}	mg/L	91.5	248.60	184.4 ± 6.22	0 – 244
CO_3^{-}	mg/L	0	4,80	0.43 ± 0.24	0 – 3
Cl^{-}	mg/L	93.2	284	178.1 ± 13.59	0 – 345 [3]
SO_4^{2-}	mg/L	192.0	439.20	317.0 ± 11.59	0 – 300
NO_3^{-}	mg/L	16.21	67.80	36.8 ± 2.52	0 – 30
NH_4^{+}	mg/L	0.06	3.80	1.1 ± 0.18	0 – 10
PO_4^{3-}	mg/L	0.19	1.40	0.54 ± 0.05	0 – 5
DO	mg/L	4.30	9.20	9,82 ± 0,27	-
Cd	mg/L	0.001	0.01	0.003 ± 0.0005	0.01
Cr	mg/L	0	0.003	0.001 ± 0.0001	0.1
Pb	mg/L	0	0.05	0.01 ± 0.002	5.0
Zn	mg/L	0.001	0.06	0,02 ± 0.004	2.0
Mn	mg/L	0.02	0.24	0.14± 0.012	0.2

[1]Adapted from Spectrum Analytic Inc. Washington court House, Ohio 4316.

[2] this value for sprinkler irrigation, for surface irrigation we take the SAR to determine the effect of Sodium.

[3]In case of sprinkler irrigation, values greater than 100 mg L^{-1} can affect plant foliage.

The pH values range from 6.87 to 8.33, showing a slightly alkaline pH, with an average value of 7.74, showing good water quality in terms of pH. The EC varies from 304 to 2750 µS/cm with an average value of 1102.3 µS/cm. These results suggest the presence of varying degrees of mineralization (Ayers and Westcot, 1994). EC concentrations gradually increase from upstream to downstream, with the highest levels recorded at stations serving as discharge points (S2, S6 and S7). Based on these EC levels, it was observed that 21.4% of the analyzed samples could reduce the productivity of some crops such as potatoes and corn by 10%. Additionally, these results indicated that 35.7% of the samples could reduce the yield of less tolerant crops, such as onions and dry beans, by 10%(Donald and George, 2007).The abundance of the main cations was in the following descending order: Ca^{2+}>Na^{+}> Mg^{2+}> K^{+} for all sites except for station S2 where the concentration of Ca^{2+} and that of Na^{+} are almost the same. Calcium is the dominant cation in almost all sites, with a content varying between 82.1 and 205.4 mg L-1, and an average value of 133.4 mg L-1.For the anions, the contents showed the following decreasing order: SO_4^{2-}>HCO_3^- >Cl^->NO_3^->PO_4^{3-}, for the waters of stations S1,S2,S6 and S7, and SO_4^{2-}>Cl^->HCO_3^->NO_3^->PO_4^{3-}, for those of sites S3, S4 and S5.

The high concentrations of calcium and sulfates are due to the direct effect of the geology of the region which is Triassic (David,1956). Regarding the major elements, all measured parameters meet the standard guidelines for water quality for agriculture. Metallic trace element concentrations occurred in the following order: Mn > Cu > Zn >Pb > Ni > Cd > Cr. Except for the manganese values recorded at stations S2, S4 and S7 during the low flow period, and which exceeded the guide values on water quality for irrigation, we can say in general that the concentrations of trace metal elements recorded are low and indicate the absence of significant effects on the suitability of irrigation water, and they are mainly within the acceptable limits for irrigation (Ayers and Westcot, 1994). These results obtained are closer to those observed in the surface waters of the northern Nile delta, in Egypt, reported by (Elsayed et al., 2020), but remain lower than those measured in Seybousse river, in the in the Northeastern Algeria, according to a study carried out by (Derradji et al., 2004).

3.2. Quality indices

The analytical results of these indices, as well as their statistical description, are given in Table 4.

Table 4. Statistical description of water quality indices in the Djedra watershed

index	Min	Max	Avearage ± S*e*
SAR	1,18	4,19	2,2 ± 0,15
RSC	-8,43	-2,03	-4,78 ± 0,37
Na%	17,39	43,02	28,3 ± 1,40
MH	8,22	27,67	17,29 ± 0,95
KR	0,2	0,74	0,4 ± 0,03
PS	4,02	13,44	7,48 ± 0,46
PI	31,64	59,97	44,6 ± 1,54

According to the SAR index (Table. 4) (Figure. 4), all analyzed samples belonged to the excellent category, showing that the waters of the Djedra Wadi watershed are suitable for all types of soils. The high concentrations of Na^+ in surface water, compared to the concentrations of Ca^{2+} and Mg^{2+}, react with the soil and decrease its permeability, contributing to soil structure deterioration (Sundaray et al., 2009; Todd, 1980). According to the Na% values, 7.14% of the samples belonged to the Excellent class, however, most water samples are in a good class for irrigation (82.15%), and the remaining samples (10.71%) fall within an acceptable suitability for irrigation.

The alkalinity content plays a key role in determining the suitability of water for irrigation. The excessive concentration of CO_3^{2-} and HCO_3^- ions in surface waters at levels higher than the concentrations of Ca^{2+} + Mg^{2+} ions cause the precipitation of Ca^{2+} and Mg^{2+} ions and influences the unsuitability for irrigation (Sudhakar et al., 2013; Keesari et al., 2009). The results obtained from this index place all samples (100%) in the good class, indicating that the collected samples have been classified as safe for irrigation purposes in terms of RSC.

The permeability index (PI) is commonly used to assess the significant long-term impact of irrigation water with high concentrations of Na^+, Mg^{2+}, $Ca^{2+}$and HCO_3^-ions on soil permeability (Ravikumar et al., 2011). According to the classification by (Doneen, 1964), all samples fall into Class II (25 < PI < 75) (Fig. 4), which considers that the surface water samples from these sites were not of excellent quality but rather good (moderately suitable) for long-term agricultural irrigation with minimal effects on soil properties, requiring some precautions regarding soil permeability.

One of the most important parameters for assessing the quality of irrigation water is the magnesium hazard ratio (MH). Ca^{2+} and Mg^{2+} are generally in balance in most watercourses. Waters with high concentrations of Mg^{2+} would exchange with Na^+ in the soil, leading to soil alkalinization and reducing crop yield (Zhao et al., 2021; Anim-Gyampo et al., 2019). The values recorded for this index are below 50 meq/L (Figure. 4), indicating that all analyzed samples are suitable for irrigation. This means that the use of these waters for irrigation does not lead to long-term magnesium-induced soil alkalinization.

The Kelley ratio is an essential index used to assess the suitability of waters for irrigation purposes in terms of main cations (Na^{+}, Mg^{2+} and Ca^{2+}). In light of the values recorded for this index, we can see that all the samples analyzed had values lower than 1(Figure. 4), which can allow this water to be used for irrigation without any risk in terms of this index.

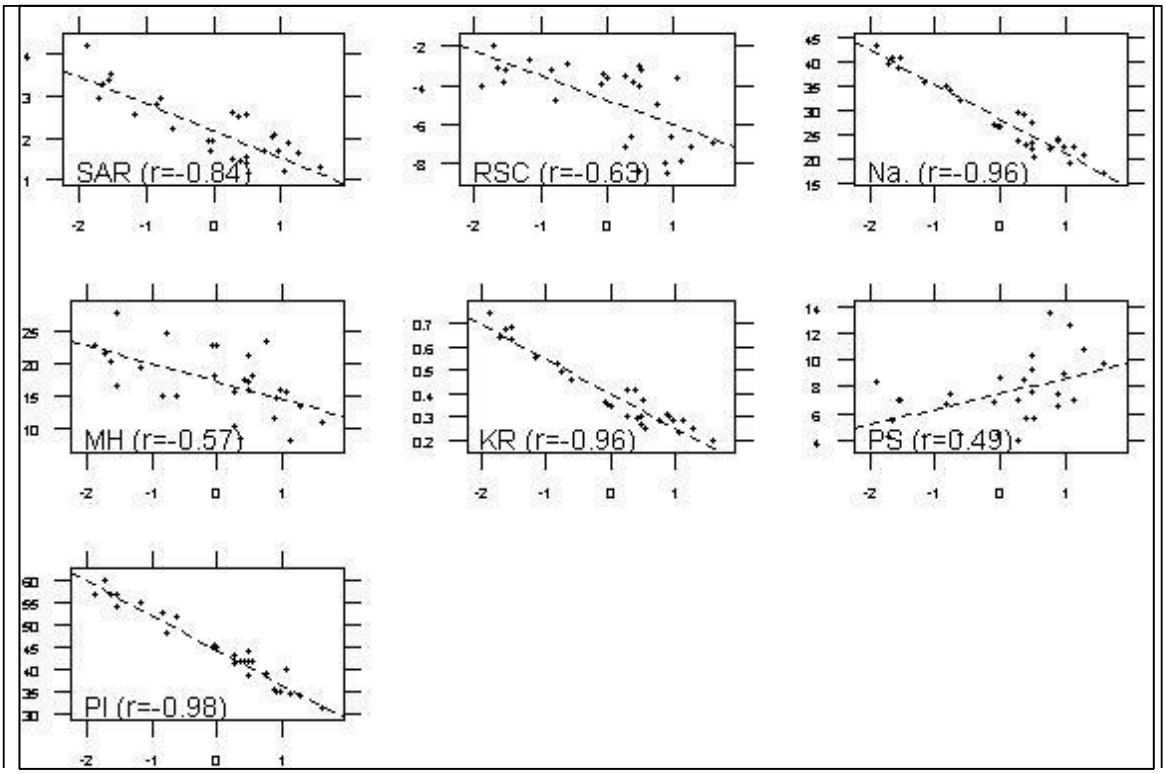

Figure. 4:the indexes value relative to the sample scores with the squared correlation with the first principal component.

3.3. Multivariate Analysis for Data(Thioulouse et al., 2018)

First, we apply a standardized PCA to the data table encompassing the results of the physico-chemical parameters during the four sampling periods (Fig. 5). The correlation circle shows that the first axis, which summarizes 54.48 % of the information, corresponds to a pollution gradient, with high pollution on the right and absence of pollution on the left. This pollution directly affects the quality of these waters for irrigation. According to the recorded bicarbonate levels, we found that 42.9% of the studied waters could lead to the formation of limestone deposits on the roots, which can be particularly detrimental to many tree species. The high concentrations of nitrates indicated that 39.9% of the analyzed samples could disrupt the production of fruits such as grapes, apricots, and citrus fruits due to excessive growth stimulation, delayed maturity, or poor quality. Regarding the effects of chlorides, we also observed that 64.3% of the samples could cause leaf damage to crop such as peppers, potatoes, and corn, especially in periods of low flow, particularly in the case of sprinkler irrigation.

The second axis, which expresses 16.72% of the total inertia, is a dissolved oxygen gradient and signals the absence of pollution. The analysis of the factor map of the sites with their sampling periods indicates that pollution manifests itself during the month of June and especially for sites S2, S4, S6 and S7.

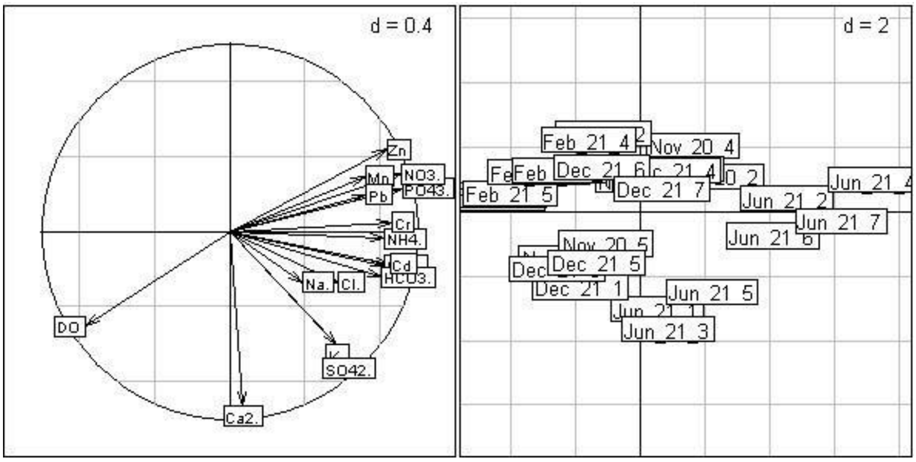

Figure. 5:Correlation matrix PCA of physicochemical parameters data table.
Left: parameter correlation circle, **right**: factorial map of sites and their sampling periods.

The interpretation is easier on the figure (Figure. 6), where the stations are grouped using a star and a polygon for each river. It is easy to observe that the sites of Akiba Wadi and Djedra Wadi are more polluted than the others (as they are located to the right of the figure). The most samples taken from Hammam Wadi are less polluted, and the samples taken in the Feb_21 period (which are located to the left of the figures) are actually comparable for all three rivers.

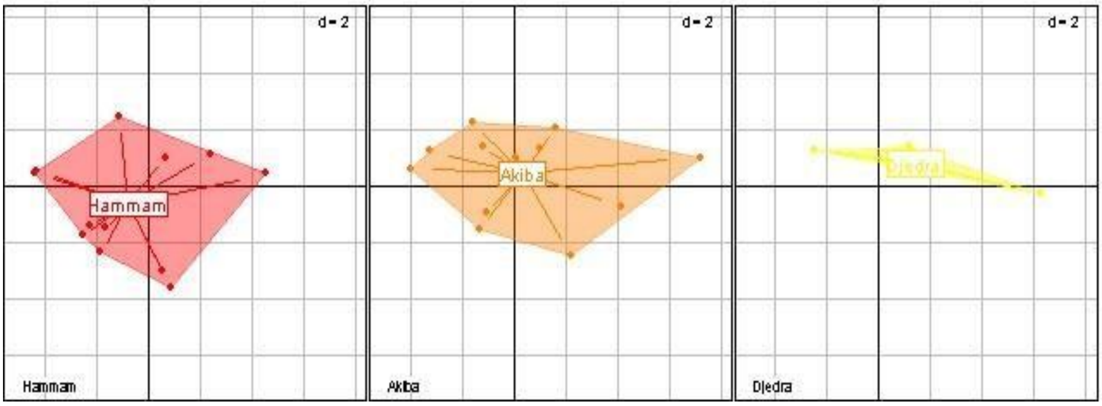

Figure. 6:PCA Wadis factorial map, with samples grouped for each Wadi.

3.4. Between-Class Analysis(BCA):(Culhane et al., 2002).

The inter-class analysis allows us to separate groups of sites based on a set of variables, in our case, the water quality indices. This technique provides a composite plot consisting of six elementary graphs. The first two axes of the analysis express 80.99% of the total inertia of the dataset(64.07% for the first axis and 16.92% for the second); this means that 80.99% of the total variability of the cloud of individuals (or variables) is represented in this plane. Figures (Figure. 7A) (loadings) and (Figure. 7B) (columns) both present the seven water quality indices. The significant similarity between these two figures demonstrates the coherence of our analysis. The main figure is the one in the top right (Figure. 7D), showing the row scores of the initial data table ($ls data frame). The four sampling periods for each site are grouped by a star and an ellipse. Two groups of stations can be distinguished, the first consists of S2 and S7, with the latter characterized by the highest values in SAR, KR, and Na%. The long-term application of these waters can lead to decreased permeability, resulting in soil structure deterioration (Suarez et al., 2006). The second group encompasses stations S4, S5, and S6, characterized by high PS values, indicating a dominance of chloride and sulfate in this group of stations.

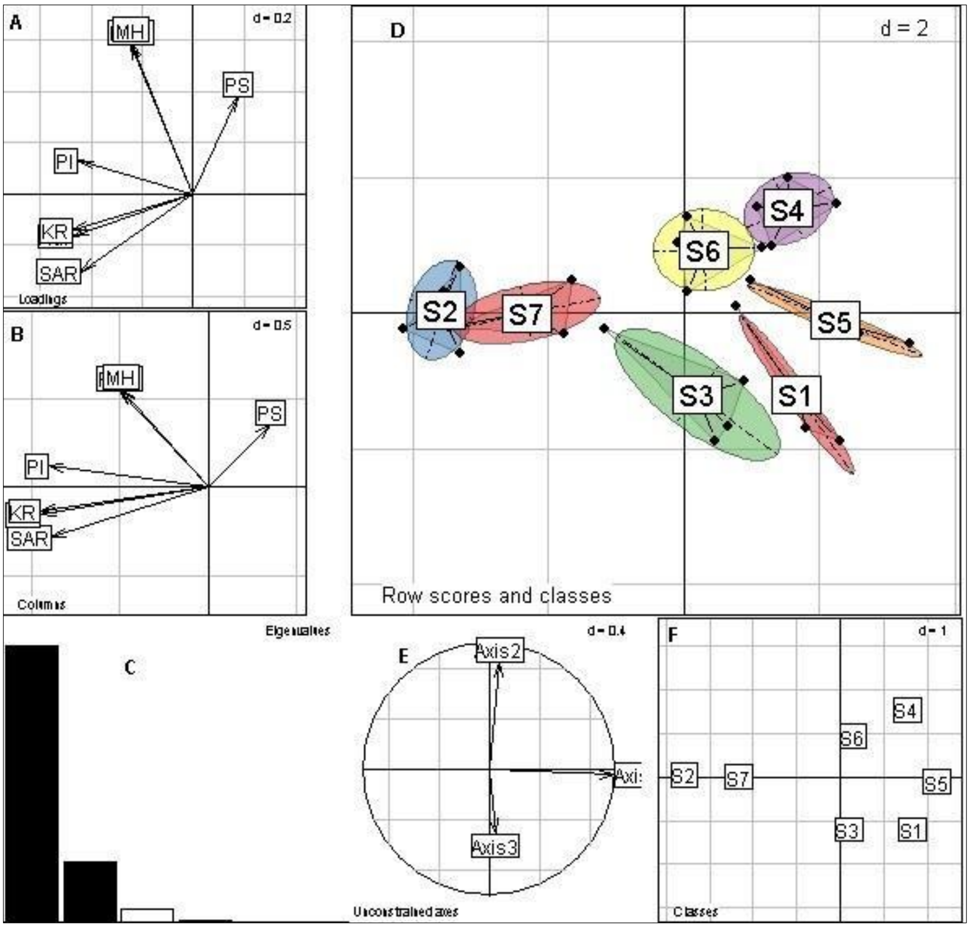

Figure.7:A:Loadings, gives the coefficients of the linear combination that maximise the between-class inertia ($c1 data frame). **B**:Columns shows the scores of the variables ($co data frame). **C**: Eigenvalues barchart. **D**: Row scores and classes: shows the row scores of the first data table ($ls data frame). **E**: Unconstrained axes: shows the projection of the first three axes of the initial analysisonto the Between-Class Analysis. **F**: Classes: shows the scores for the groups of the Between-Class Analysis ($li data frame).

This statistical analysis allowed us to develop a summary map of the suitability of water for irrigation for different sites (Figure. 8).

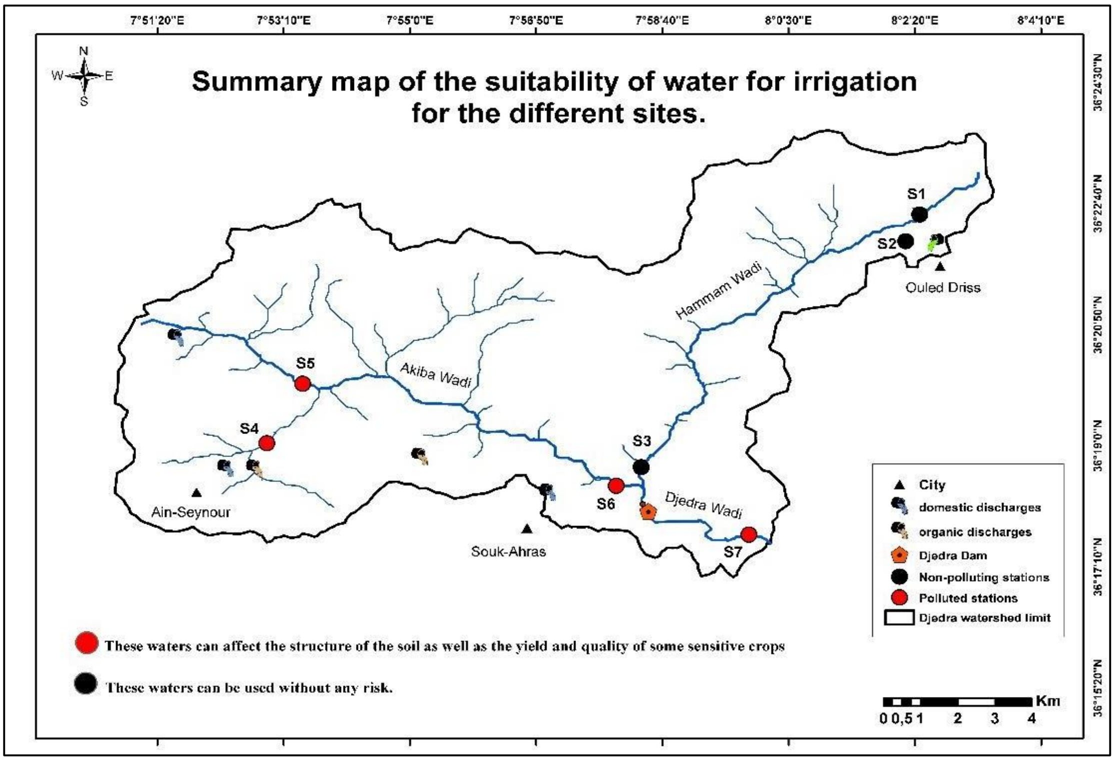

Figure. 8: Summary map of the suitability of water for irrigation for the different sites.

4. CONCLUSION

The expected objective of this study was to evaluate the suitability of the waters in this region for irrigation. Therefore, we conducted a hydrochemical analysis based on 28 samples distributed over Oued Djedra and its two tributaries. The results revealed relatively variable physicochemical characteristics. The abundance of major cations was in the following order: Ca^{2+}> Na^{+}> Mg^{2+}> K^{+} for all sampling sites. Regarding the major anions, the abundance was in the following order: SO_4^{2-}>HCO_3^{-}>Cl^{-}>NO_3^{-}> $PO_4^{3-}$for samples from stations S1, S2, S6, and S7, and in the order: SO_4^{2-}>Cl^{-}>HCO_3^{-}>NO_3^{-}>PO_4^{3-} for the waters from stations S3, S4, and S5.

The elevated levels of HCO_3^{-}, $NO_3^{-}$and Cl^{-} can affect the yield and quality of some sensitive crops and fruits such as peppers, tomatoes, corn, grapes, and apricots. Through statistical analysis, we were able to identify the most polluted stations, located at Oued Akiba and Oued Djedra. With the same analysis, we were able to distinguish two groups of stations. The first consists of S2 and S7, with the latter characterized by the highest values in SAR, KR, and Na%. The long-term application of these waters can lead to decreased permeability, resulting in soil structure deterioration. The second group encompasses stations S4, S5, and S6, characterized by high PS values, indicating a dominance of chloride and sulfate in this group of stations.

This study can contribute to and assist farmers and water resource managers in making informed and appropriate decisions to maximize crop productivity while preserving soil and environmental health.

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