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Water Quality Assessment for Irrigation Purposes in a Semi-Arid Region: Wadi Baghai (North East of Algeria)

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ABSTRACT

The region drained by wadi Baghai, North East of Algeria, characterized by a semi-arid climate, is the receiving environment for treated wastewater from Khenchela Wastewater Treatment Plant and the municipal untreated wastewater from the city of Baghai. This study aimed to monitor the water quality of Wadi Baghai using the physicochemical parameters (temperature, pH, dissolved oxygen, electrical conductivity, and major elements), pollution indicators such as chemical and biological oxygen demand (COD and BOD5), nitrogen matter, turbidity, total suspended solids, in addition to heavy metals. To evaluate its irrigation suitability, the sodium adsorption ratio, Kelly Ratio, soluble sodium percentage, permeability index, magnesium absorption ratio, cation ratio of structural stability, and irrigation water quality index were calculated. According to the results, the tested water did not exceed the agricultural reuse standards. The indices (SAR, Na%, KR, PI, MAR and CROSS) revealed that the water samples were suitable for irrigation. Similar results were recorded from IWQI with moderate to high restrictions. Classifications based on the riverside diagram illustrated that samples are classified as C3-S1 and C4-S1, therefore can be used for irrigation. Cluster analysis CA, based on the level of similarity, classified the sampling sites into two clusters: Cluster 1 (S1, S2), and Cluster 2 (S3).

INTRODUCTION

Water is an important natural resource and a vital component of the existence of life. Pollution of river systems is a major challenge for water resources **(Viswanathan *et al*., 2015)** since water quality is affected by several sources of pollution such as sewage discharge, industrial discharge and agricultural run-off **(Khatri & Tyagi, 2015)**. About 80% of the total sewage water in developing countries is directly dumped, without any treatment, into surface water of lakes and rivers **(Rehman *et al*., 2020)**. In many arid and semi-arid regions, natural freshwater resources are limited, whereas the demand is constantly increasing due to the industrial and population growth. The great challenge to meet water demands and manage its limited natural resources has led to the use of alternative irrigation sources **(Alrajhi *et al*., 2015)**. Water scarcity can mainly be supplemented by treated wastewater; this resource is abundant and always available **(Bourouache *et al*., 2019)**, which is typically discharged downstream from settlements and reused on a large scale in suburban agricultural irrigation **(Ababsa *et al*., 2020).** The reuse of wastewater results in minimizing environmental pollution and the demand for freshwater **(Rehman *et al*., 2020)**, and it is necessary to reduce the pressure on the groundwater **(Hajji *et al*., 2021)**. Despite the benefits of wastewater reuse, there may be significant risks on both users and environment **(Qadir *et al*., 2010)**. The use of unconventional water resources has increased in the Mediterranean region in recent decades in response to climate change-induced water scarcity and uneven rainfall **(Lonigro *et al*., 2015)**. According to global standards, where the critical threshold for water scarcity is 1000 m³/year/inhabitant, Algeria is a water-poor country **(Tamrabt, 2011)**. Water scarcity in Algeria has been exacerbated due to population growth, climate change, and rainfall. The country has implemented a new water resource management policy through the use of unconventional water resources **(Elmeddahi & Ragab, 2020)**. In this study, we focused on Wadi Baghai (Garaet El Taref Basin, Khenchela, North-East of Algeria), which is a typical example of a Mediterranean semi-arid river. It is an intermittent river that receives treated wastewater from the activated sludge wastewater treatment Plant of Khenchela city and untreated municipal wastewater of Baghai city. The main objective of this study was to assess the physicochemical quality of water of the wadi Baghai and its suitability for irrigation. Thus, a qualitative characterization through different parameters were conducted on water samples taken from different sites. Our study determined the analysis of pollution parameters (COD, BOD_5, nitrates, nitrites, ammonium, turbidity, total suspended solids and heavy metals. In addition, the current investigation addressed the irrigation water quality indices of Wadi Baghai waters, such as SAR, KR, Na%, PI, MAR, CROSS, and IWQI, widely used in the categorization of irrigation water quality in order to assess the suitability of surface waters for irrigation.

MATERIALS AND METHODS

Description of the study area

Our study was carried out at the level of Garaet El Taref Bassin (North-East of Algeria) which shelters Wadi Baghai (Fig.1), which forms an endorheic hydrographic system **(Naouel *et al*., 2018)**. In the gorge separating Ras Serdoun (1703 m) from the Tifekress (1722 m), Wadi Fringal rises fed by the spring of the same name receiving water from vast underground reservoirs and gushing intermittently. This Wadi cuts the plateau from the West to the East to the Chettaia Massif where it is oriented South-North crossing the urban area of Khenchela, and named as Wadi Boughougal, forming the main collector of urban wastewater in the city of Khenchela. It then bends to the northwest (after the TWW plant) under the name of Wadi Baghai and is lost in the Sebkha Et Tarf, which is bordered by a "Chott" area; El Melah (875 Ha) is one of the satellite chotts that merge with that of Gâraat EtTarf during the great floods; it is the point of discharge of the waters of Wadi Baghai.

The study area is characterized by a semi-arid climate. The lowest temperature is reached during January with a value of 7.22°C, while the maximum is 26.86°C in July and the annual pluviometry was estimated as 466.91mm/year (Meteorological station of Khenchela data from 1994 to 2018). Wastewater treatment plant is located in the North of the city of Khenchela, which was established in 2008. The effluent treatment channels include a water treatment system with pretreatments, biological treatment, and tertiary treatment, adding to a sludge treatment.

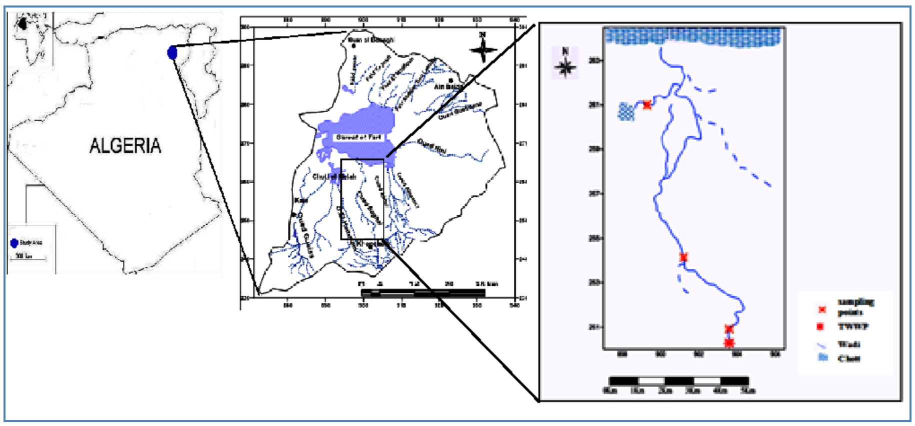

Fig. 1. Geographical location of the study area and sampling stations

Sample collection

To assess the physicochemical parameters, three sampling points were selected (S1: upstream at the point of discharge of treated wastewater; S2: point of discharge of domestic wastewater from the city of Baghai and S3: downstream near the chott). Water samples were taken until overflowing in polyethylene terephthalate bottles, washed with dilute nitric acid and rinsed with distilled water, and subsequently washed with the water at the site before filling the bottle with the water sample. The transport of the vials to the laboratory was carried out at a temperature of 4°C within 24 hours **(Rodier, 2009)**.

Methods of analysis

Water temperature, pH, electrical conductivity, and dissolved oxygen are the physical parameters measured *in situ* using a consort-type multiparameter. The analyses were carried out at the regional laboratory of the National Institute of Soils, Irrigation, and Drainage (Oum El Bouaghi, Algeria). Major cations (Ca^{+2}, Mg^{+2}, Na^{+}, and K^{+}) and metallic trace elements (Cu, Fe, Zn, and Mn) were determined using a flame atomic absorption spectrometer (Perkin Elmer A 200). Bicarbonates (HCO_3^{-}) and chlorides Cl^{-} were determined by volumetric methods. Sulfates (SO_4^{-2}), nitrates NO_3^{-}, nitrites NO_2^{-}, and ammonium NH_4^{+} were analyzed using a molecular absorption spectrophotometer (Genway 73). The COD is determined according to ISO 15705, closed reflux method using a DR 890 type DCOmeter. Total suspended solids (TSS) were identified by filtration according to AFNOR 2005 (T90-105). The biological oxygen demand (BOD_5) was determined by the manometric method using oxitop (*types Velp scientifica*). Turbidity is determined by a HANNA Instruments LP 2000 turbidimeter.

Indices calculation tools

Physicochemical parameters can be used to assess water quality and are directly associated with its use. However, the separate study of these parameters does not clearly define its quality **(De La Mora-Orozco *et al.*, 2017)**. To overcome this, the end use of specific water quality indices have been adopted to conduct effective water quality classifications, based on a set of water quality parameters that has been widely accepted as *information* for end-use. Sodium absorption ratio SAR, Kelly Ratio KR, soluble sodium percentage (SSP), permeability index (PI), magnesium adsorption ratio (MAR), and CROSS are the measures that are frequently employed to determine if water is suitable for irrigation (Table 1).

Table 1. Water Indices calculation tools

Index	Description
Sodium absorption ratio (SAR)	SAR is a measure used for agricultural irrigation activities, and its concentration reduces soil permeability and soil structure **(Richards, 1954)**. It is calculated from the relative concentrations of sodium, calcium, and magnesium (Eq. 1) in meq/l. $SAR = \frac{Na^+}{\sqrt{(Ca^{+2} + Mg^{+2})/2}}$ (1)
Kelly Ratio (KR)	KR is measured as the ratio of sodium ion concentration to calcium and magnesium ions **(Kelley, 1963)**. Eq. 2, where concentrations are given in meq/L, was used to calculate KR. $KR = \frac{Na^+}{(Ca^{+2} + Mg^{+2})}$ (2)
Soluble sodium percentage (SSP)	Soluble sodium percentage is used to determine the level of sodium in a water sample and classify irrigation water **(Rahimi *et al.*, 2018)**. This index is calculated as: $Na^+(\%) = \frac{(Na^+ + K^+)x100}{(Na^+ + Ca^{+2} + Mg^{+2} + K^+)}$ (3)
Permeability index (PI)	Soil permeability index was affected by Ca+2, Mg+2, Na+, and HCO3- ions in irrigation water **(Thapa *et al.*, 2017)**. It was calculated by using the formula (Eq. 4). $PI = \left(\frac{Na^+ + \sqrt{HCO3-}}{(Na^+ + Ca^{+2} + Mg^{+2})}\right)x100$ (4)
Magnesium adsorption ratio (MAR)	MAR, also called magnesium hazard (MH) **(Safiur Rahman *et al.*, 2017)** is another parameter for the assessment of water quality in agriculture and irrigation, which was determined by Eq. 5. $MAR = \frac{(Mg^{+2})}{(Ca^{+2} + Mg^{+2})})x100$ (5)
Cation ratio of structural stability (CROSS)	By combining SAR and potassium absorption ratio (PAR) with ratios of relative flocculating power as numerical coefficients of the K and Mg concentrations, CROSS was created and expressed in Eq. 6 **(Qadir *et al.*, 2021)**. $CROSS = \frac{Na^+ + 0,56K^+}{\sqrt{(Ca^{+2} + 0,60Mg^{+2})/2}}$ (6)

Irrigation water quality index (IWQI)

IWQI is a monitoring method innovated by **Meireles *et al*. (2010)**; ranging between 0 and 100 is not a dimensional index in this model. First of all, the parameters that play an important role in water quality for agricultural purposes must be identified (EC, Na, Cl, HCO3, and SAR) **(Abbasnia *et al*., 2019)**. The water quality index was calculated according to the following formula (Eq.7):

$$\text{IWQI} = \sum_{i=1}^{n} q_i w_i \qquad (7)$$

Where, IWQI: irrigation water quality index; n: number of parameters; wi refers to the normalized weight of the ith parameter and is related to the function of importance in explaining the global variability in water quality, which is shown in the study of Meireles *et al*. (2010**)**; qi: the quality of ith parameter from 0 to 100 and corresponding to function of its concentration.

$$q_i = q_{max} - \left(\frac{(xij - Xinf) * q_{imap}}{q_{amp}} \right) \quad (8)$$

Where,

q_{max}: the maximum value of qi for each class; *xij*: the observed value of each parameter; x*inf* refers to the lower limit value of the class to which the parameter belongs; *qimap* presents the class amplitude, and qamp is corresponding to the class amplitude to which the parameter belongs.

In this regard, the upper limit was considered to be the highest value determined in the analysis of the water samples which is required to evaluate the xamp of the last class of each parameter **(Meireles *et al*., 2010)**.

Cluster analysis

The application of different statistical techniques such as cluster analysis facilitates the interpretation of complex data matrices to understand better the water quality **(Gasmi *et al*., 2016)**, making it possible to develop a more effective sampling plan, which might lower expenses and the number of samples taken **(Bianchi *et al*., 2019)**. Furthermore, CA provides an intuitive similarity relationship between any sample and the entire data **(Karroum *et al*., 2019)**.

RESULTS AND DISCUSSIONS

Spatial-temporal variation of physicochemical parameters

The spatiotemporal variation of the different physicochemical parameters of the water at the different sites is shown in Fig. (2) and Table (2). The temperature of the water samples fluctuated from 11.6°C in May to 21.9°C in August. This variation is mainly conditioned by the temperature of the air, which reflects the divergence of water temperature values between hot and cold periods. Ambient temperature had a significant role in organic waste degradation powered by the presence of air, which promotes the self- purification of water **(Al-khateeb *et al.*, 2018)**. Temperature influences the solubility of gases, the determination of pH, and the dissociation of dissolved salts **(Rodier, 2009)**. The pH ranged from 7.5 to 8.5, which gives the water a slightly basic character; the pH of TWW is generally slightly alkaline. The same results were found by **Alaizari *et al.* (2020)** and **Alobaidy *et al.* (2010)** in the treated wastewater. This alkalinity can be explained by the lithological nature, the photosynthesis process, which absorbs CO_2 and consequently increases pH **(Abba *et al.*, 2021)**. It was noted that slightly alkaline water inhibits the toxicity of heavy metals in the form of carbonate or bicarbonate precipitates, making these heavy metals unavailable **(Ahipathy & Puttaiah, 2006)**. Irrigation water with a pH outside the normal range can cause nutrient imbalances or contain toxic ions **(Ayers & Westcot, 1985)**. The results showed that no spatial differences were observed in the temperature and pH of the water. On the other hand, EC values of 1675,33±102,08 µs.cm^{-1} at the point of discharge of TWW decrease along river paths, with the minimum of 1504 µs.cm^{-1} in S2 and a peak at Chott (2785±85,26µs.cm^{-1}), with a maximum of 2900µs.cm^{-1} in S3 in September. This indicates a moderate salinity level. While, EC values indicate the decomposition and mineralization of the organic matter **(Begum & Harikrishna, 2008)**. It is a good measure of salinity and it is significant in determining the suitability of water for irrigation **(Shakir *et al.*, 2017)**. Dissolved oxygen concentration at all three stations varied between 4,91± 1,31 mg/l in S1 and 6,13± 1,39mg/l in S3. The lowest mean concentration of DO was observed at S2 and the highest at S3. The slight increase in dissolved O_2 at the S3 level is due to the phenomenon of self-purification. Its value gives us information on the level of contamination, and consequently, the level of self-purification of a watercourse **(Makhoukh *et al.*, 2012)**.

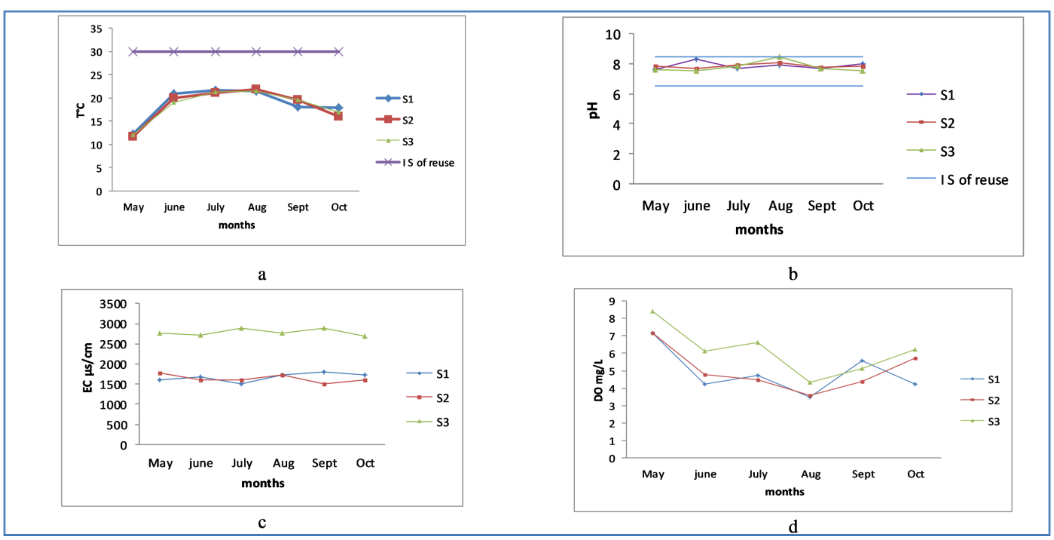

Fig. 2. Monthly variation of physical parameters of the water of Wadi Baghai intended for irrigation (a: temperature; b: pH; c: Electrical conductivity; d: Dissolved Oxygen)

For nitrogenous matter, there was a decrease in the concentration of nitrites in S3 compared to S1 and S2. Ammonium (NH_4^+) is the most toxic nitrogen-containing compound. It is the result of the mineralization of organic nitrogen, which is rapidly converted to nitrite and nitrate by oxidation **(Benariba *et al.*, 2022)**. The ammonium values decrease between S1 and S2 and increases again in S3 (Table 2.). **Ramdani and Laifa (2017),** announced that the Value of 3.04 mg/L of NH_4^+ could be explained by the ammonification process, favored by the temperature increase.On the other hand, The results of nitrates show an increase in station S2 (5,73±1,72mg/L) and then begins to decrease in S3 (2,67±1,2mg/L), nitrates concentrations are well below standards (50 mg/L). Treated wastewater provides a viable fertilizer supply. **Tampo *et al*. (2022)** found that treated wastewater is more suitable for irrigation purposes than groundwater.

The maximum BOD_5 value has been registered in S3, exceeding the Standards of water used in irrigation **(FAO, 1999)**, but there is a decrease when moving away from the TWWP and it increases again downstream; this is due to the domestic discharge from the city of Baghai. According to the results obtained, the COD values range from 49,82±14,56 mg O_2/l in S1 to 24,95±4,70mg O_2/l in S3. It is found that the high values of suspended solids coincide with the maximum levels of COD. the existence of suspended solids is caused by water flow or the discharge of wastewater that is heavily laden with particles **(Guemmaz and Neffar, 2019)**. By comparing the turbidity values between the sampling points, it was found that the water from the discharge point itself did not have high turbidity. Its water is generally greywater from domestic activities. Turbidity and TSS decrease during the wadi as a result of the reduction in flow and the distance from the points of discharge. High turbidity of surface water (case of wadis M'sila Algeria) explained by the discharge of sewage **(Ferahtia *et al.*, 2021)**.

Table 2. Pollution indicators at different stations (Mean ± standard deviation).

Parameters	**S1**	**S2**	**S3**
NO_2^-(mg/L)	0.02±0.01	0.02±0.01	0.01±0.01
NO_3^- (mg/L)	4.69±0.63	5.73±1.72	2.67±1.20
NH_4^+(mg/L)	4,83 ±1,81	2,48±1,56	3,48±2,91
COD (mg/L)	49.82±14.56	36.33±11.74	24.95±4.70
BOD5 (mg/L)	31.62±10.65	21.10±7.21	27.73±7.71
TSS (mg/L)	16.97±6.64	15.64±3.14	14.71±5.14
Turbidity (NTU)	88.43±6.14	70.77±15.89	48.78±8.91

Except Mn in S2, the three sampling stations record low levels of Fe, Cu and Zn, which do not exceed the reuse standards (fig.3). **Al-Hababheh *et al.* (2021)**, announced that no significant amounts of Cu and Mn were found in the TWW used for irrigation.

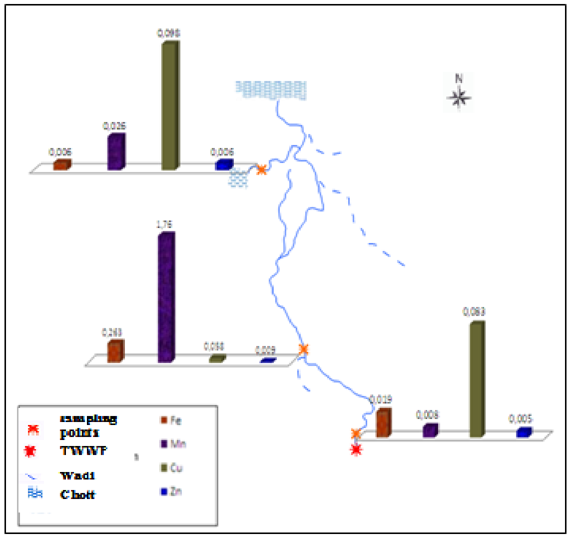

Fig. 3. Spatial variation of metallic trace elements in wadi Baghai.

1. Chemical classification of waters

Several methods can be used to determine the hydrogeochemical quality of water. To conclude the chemical facies of the waters of wadi Baghai, we plotted the concentrations of major elements on the Piper diagram (Fig.4). Two families of waters are observed; calcium and Magnesian chlorinated-sulfate waters for S1 and perchlorate calcium for S2 and S3 waters. Calcium is the dominant cation, These two families of water may reflect the effect of lithological heterogeneity or anthropic alteration.

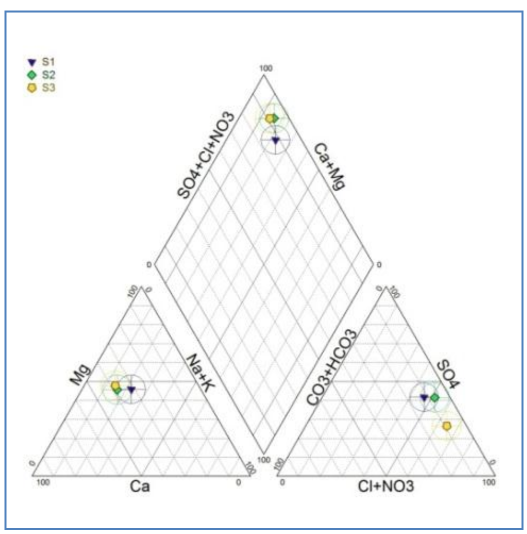

Fig. 4. Representation of Wadi Baghai water samples on Piper diagram.

2. *Water quality indices for irrigation*

It was found that SAR, Na%, KR and PI have their maximum values at sites S1 where they averaged, respectively, 1.15 meq/L (SAR), 22.59% (Na%), 0.25 meq/L (KR) and 29.57% (PI), decrease in S2 and S3. On the other hand, MAR increases in S2 and records its maximum in S3 (Table 3.).

Wastewater irrigated soils had higher SAR than freshwater irrigated soils. In one study, soil irrigated with treated wastewater increased 113.6% compared to soil irrigated with conventional water **(Zema et *al*., 2012)**. In general, there is a linear relationship between the increase in SAR and the proportion of sodium exchange **(Muyen et *al*., 2011)**. If the KR value is greater than 1, it is considered unsuitable for irrigation (El Bilali & Taleb, 2020). MAR is also considered a concomitant factor in the evaluation of irrigation water suitability as it can deteriorate the soil quality when its value in the water system exceeds 50 **(Islam et *al.*, 2018)**. Recent research has shown the negative effects of potassium (K) and Mg on the physical properties of the soil in addition to Na **(Qadir et *al.*, 2021).** In general, all the waters tested had values of the indices of suitability for irrigation in the acceptance range.

Table 3. Irrigation water quality indices of water of Wadi Baghai

	SAR	KR	% Na	PI	MAR	CROSS
S1	1.15	0.25	22.59	29.57	16.58	1.43
S2	0.85	0.17	16.13	20.95	19.64	1.04
S3	0.82	0.15	14.28	19.72	22.98	0.98

For Irrigation Water Quality Index IWQI, waters of S1 (**63.53)** and S3(**58.38)** were classified in Moderate restriction categories where water in this range would be better used for soils with moderate to high permeability values. Moderate leaching of salts is highly recommended to avoid soil degradation. And plants with moderate tolerance to salts maybe grow **(Meireles *et al*., 2010)**. S2 (**47.96)** was classified as High restriction (HR); This range of water can be used in soils with high permeability without compact layers. In this range, water is Suitable for irrigation of plants with moderate to high tolerance to salts with special salinity control practices, except for water with low Na, Cl, and HCO_3 values **(Meireles *et al*., 2010)**.

3. *Suitability of water of wadi Baghai for irrigation*

The combination of electrical conductivity (EC) and sodium absorption ratio (SAR) makes it possible to classify these waters according to the Riverside Diagram (Fig.5). The graphical representation of the samples shows that S1 and S2 are classified as C3, Satisfactory for most field crops, but salinity conditions will develop if leaching and drainage are not adequate, While S3 is classified as C4, normally not recommended unless tolerant crops are grown. Leaching and drainage are imperative **(Richards, 1954).**

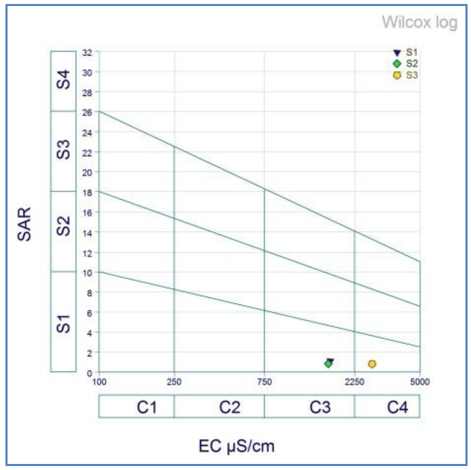

Fig. 5. Representation of water samples on Riverside diagram

4. Cluster analysis

The dendrogram using CA (Fig. 6) displayed information about the three sites studied grouped into 2 different clusters identified as cluster 1 and cluster 2. Group 1, comprising S1 (discharge of treated wastewater) and S2 (discharge of untreated wastewater from Baghai City), was characterized by the highest levels of nutrients, organic matter and Na, K, Fe, Mn, and Zn. Group 2 represented by S3 (The downstream of the Wadi near chott), was characterized by important values of EC, Mg, and Cu, reflecting that salinity in this site has natural causes.

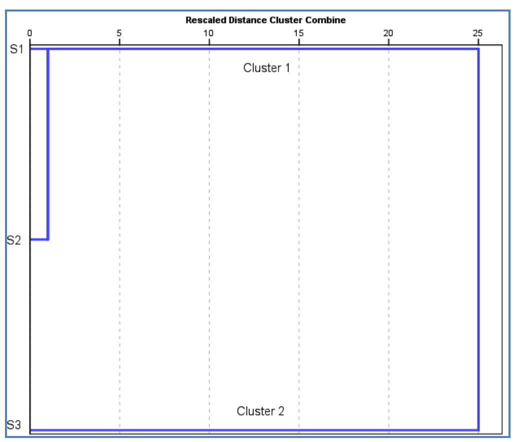

Fig. 6. Dendrogram resulting from the cluster analysis.

CONCLUSION

The monitoring of water quality by the physicochemical approach of the Wadi Baghai, which is part of the Garaet El Taref Basin, reveals a spatiotemporal variation between the different stations. This variation is influenced by the discharge of treated and untreated wastewater from the Khenchela TWW plant and Baghai city in S1 and S2 respectively. The water of Wadi Baghai is characterized by slightly alkaline water, and electrical conductivity >1500µS/cm, revealing moderate to high salinity levels. Regarding organic pollution parameters, COD results are relatively low, which shows the domestic origin of wastewater. BOD5 values, except S1, Regarding organic pollution parameters, COD results are relatively low, which shows the domestic origin of wastewater. BOD5 values, except S1, do not exceed standards of reuse. Spatially, the sites S1 and S2, the discharge points, record the highest averages of most of the parameters studied such as Nitrates and Nitrites, iron except salinity where we recorded its maximum at the level of S3 near chott. This differentiation is clearly apparent in the classification of cluster analysis on the one hand and in the Reverside diagram on the other. In the light of the results obtained and the indices calculated (SAR, Na%, KR, PI, MAR, CROSS and IWQI), the waters of wadi Baghai are suitable for irrigation, taking into consideration some restrictions concerning the soil and crops.

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