Evaluation of Groundwater Quality and Its Suitability for Drinking and Agricultural Purposes Using Self-Organizing Maps

L. Belkhiri, L. Mouni, A. Tiri, T.S. Narany

***Abstract*—**In the present study, the self-organizing map (SOM) clustering technique was applied to identify homogeneous clusters of hydrochemical parameters in El Milia plain, Algeria, to assess the quality of groundwater for potable and agricultural purposes. The visualization of SOM-analysis indicated that 35 groundwater samples collected in the study area were classified into three clusters, which showed progressive increase in electrical conductivity from cluster one to cluster three. Samples belonging to cluster one are mostly located in the recharge zone showing hard fresh water type, however, water type gradually changed to hard-brackish type in the discharge zone, including clusters two and three. Ionic ratio studies indicated the role of carbonate rock dissolution in increases on groundwater hardness, especially in cluster one. However, evaporation and evapotranspiration are the main processes increasing salinity in cluster two and three.

***Keywords*—**Drinking water, groundwater quality, irrigation water, self-organizing maps.

I. Introduction

THE groundwater is one of the most important sources for both drinking and agricultural purposes in El Milia plain, north of Algeria [1]. The fact of exploiting less surface water, inceases the dependence on groundwater which leads to more pollution, hence the rise of water treatment costs [2]. Groundwater quality is largely influenced by the natural processes and anthropogenic activities in this area. This recent research has focused on the evolution of groundwater quality and devoted to studying the effect of natural processes and anthropogenic activities on the current situation of groundwater quality in El Milia plain. Therefore, the specific objectives of the study are to investigate the hydrochemical characteristics of groundwater samples in El Milia in order to determine the sources responsible for deterioration of groundwater quality and to evaluate the suitability of the groundwater for drinking and agricultural purposes.

II. Study Area

The study area is conducted at El Milia plain, located in the north of Algeria. El Milia plain is situated at a few kilometers from the Mediterranean Sea and between the eastern longitude of 6010'-6020'E and northern latitude of 36040'-36047'N (Fig. 1). The studied area is situated in this alluvial aquifer that shows a heterogeneous continental detrital sedimentation. In the hydrogeological study, 35 wells were selected during the third week of April 2015 and all of them used for the domestic and agricultural purposes.

III. Methodology

A. Samples

In this study, 35 representative sampling wells were selected in such a way that they represented different geological formations and anthropogenic activities at varying topography of the study area (Fig. 1). Groundwater samples were collected in April 2015 using standard sampling procedures [3]. The physical parameters such as electrical conductivity (EC) and pH were measured in situ using a multi-parameter WTW (P3 MultiLine pH/LF-SET). However, the chemical parameters such as calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), chloride (Cl), sulfate (SO_4), bicarbonate (HCO_3), nitrate (NO_3) and nitrite (NO_2) were analyzed in the laboratory.

B. Self-Organizing Method

In this study, all calculations concerning SOM were performed by SOM Toolbox 2.0 developed by Helsinki University of Technology [4] from MATLAB R2016a, and this method was selected as a suitable data analysis tool to help determine the spatial variation of groundwater samples.

IV. Results and Discussion

Following K-means clustering of the SOM output, the groundwater samples are grouped into three clusters (Fig. 2 and Table I). The electrical conductivity progressively increased from the first cluster to the last one. Generally, the order of enrichment in most hydrochemical constituents is such that cluster 3 > cluster 2 > cluster 1. The sampling wells 1, 2, 3, 4, 12, 14, 18, 19, 20, 21, 22, 23, and 35 made the first cluster (Cluster 1), which corresponds to 37% of all the sample wells. This cluster has the lowest average concentrations of the physicochemical parameters, and represents by the order of dominance of cations and anions following Ca > Mg > Na > K and Cl > HCO3 > SO4 > NO3, respectively. These are generally fresh water types and are suitable for most domestic uses in the area based on the

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concentrations of the individual ions, and the EC values. The second cluster (Cluster 2) is represented by the sampling wells 11, 29, 30, 31, 32, 33 and 34, and it contains 20% of the groundwater samples. The average EC value in this cluster is 935µS/cm, suggesting that the samples generally represent moderate salinization. The water samples from this cluster are characterized by high concentrations of Ca, Mg, Cl, HCO3 and SO4. The last cluster (Cluster 3), involved 5, 6, 7, 8, 9, 10, 13, 15, 16, 17, 24, 25, 26, 27 and 28 wells corresponds to 43% of total samples. This cluster has an average EC of 1,009 µS/cm, which is relatively high and represents a clear situation, whereby the quality of groundwater in the basin is influenced by the dissolution of carbonate and evaporite minerals in the aquifer.

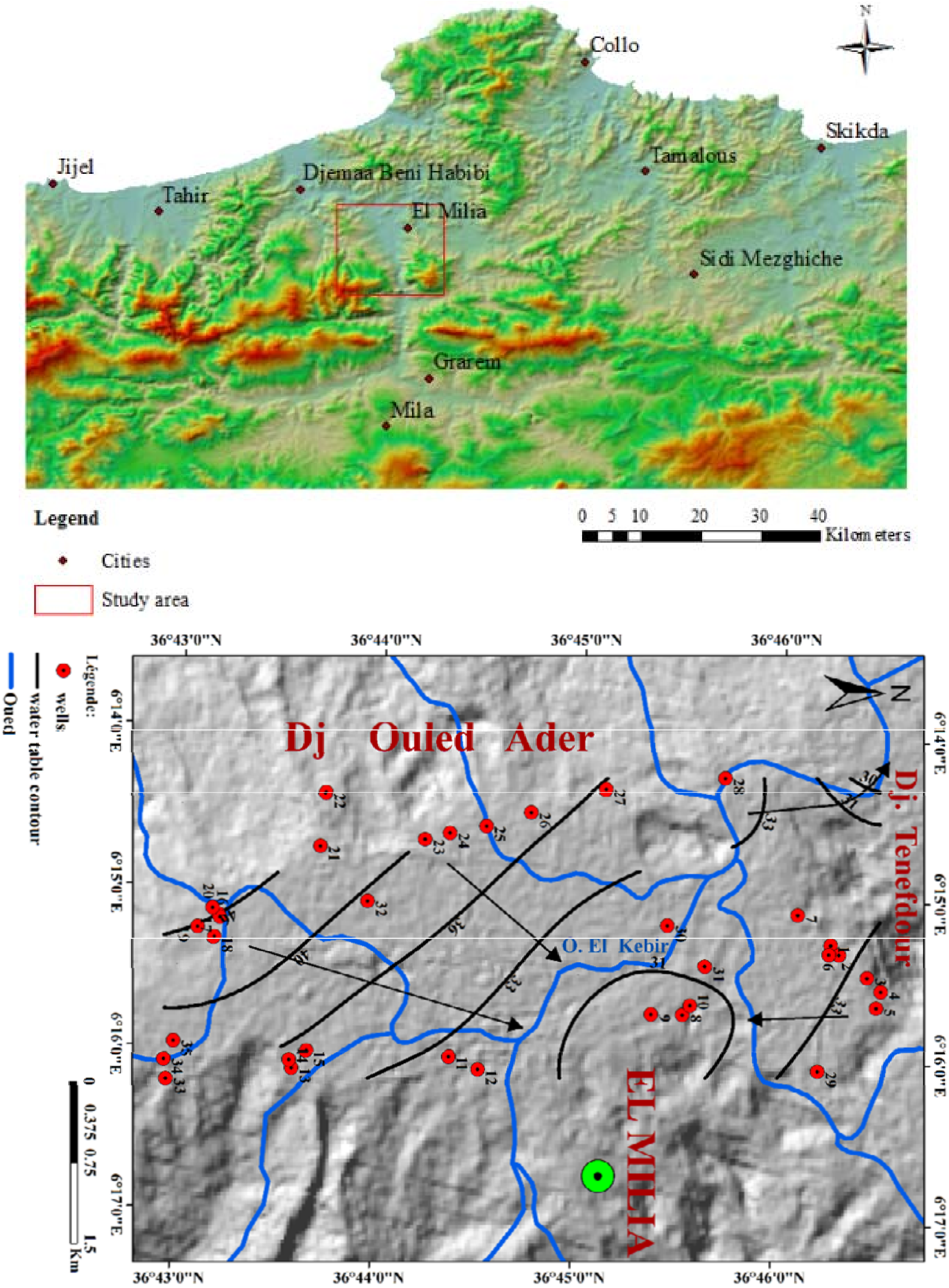

Fig. 1 Location of the study area

Piper diagram clearly indicate that the groundwater type change from mixed Ca-Mg-Cl to Ca-Cl in groundwater samples (Fig. 3). However, a detailed investigation using piper domains indexes reveals that average of GQIPiper.mix is 60.8, 58.8, and 61.7 in cluster 1, cluster 2, and cluster 3, respectively, which indicate no evidence of seawater intrusion in the groundwater samples. The average of GQIPiper.dom is 24, 23.8, and 24.8 in cluster 1, cluster 2, and cluster 3, respectively, which clearly indicate to secondary saline water, represented by Ca-Cl type. Regarding to the Fig. 3, the majority of samples in all three clusters (61.5% of cluster 1, 57% of cluster 2, and 53% of cluster 3) show Ca-Cl water type (domain V). The rest of samples indicate the Ca-Mg-Cl type (domain IV), except the samples 10 in cluster 3, which represents Ca-HCO3 water type (domain I).

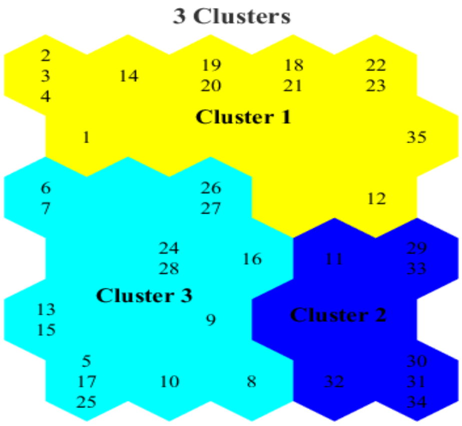

Fig. 2 Clustering of samples using SOM method

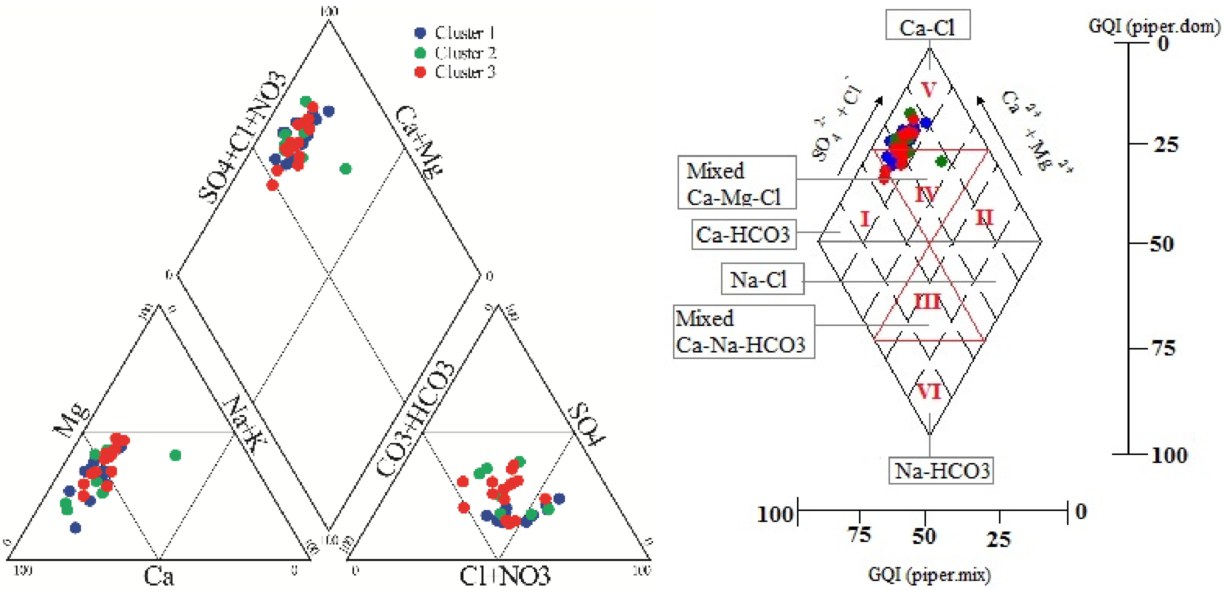

Fig. 3 Representation of groundwater samples on Piper diagram

The computed water quality index (WQI) values range from 45 to 72, 71 to 134 and 70 to 97 for cluster 1, cluster 2 and cluster 3, respectively. EC, SO4 and NO2 show strong correlation with the WQI. Ca and HCO3 show good correlation with WQI. This index shows a correlation of less than 0.5 for the other parameters. The results of WQI indicate that 77%, 57% and 100% of the groundwater samples were good water quality in the three clusters, respectively, while 23% and 43% in the first and second cluster were in the category of excellent and poor water quality, respectively (Table II). This may be due to effective leaching of ions, over exploitation of groundwater, direct discharge of effluents, and agricultural impact [5], [6].

In this study, groundwater quality was evaluated to determine its suitability for irrigation purposes by determining the main parameters including EC, sodium percent (Na%) and sodium adsorption ratio (SAR).

The concentration of sodium, calcium, and magnesium, and sodium in water can influence the normal infiltration rate of the water. The alkali/sodium hazard to crop is measured by sodium adsorption ratio (SAR). SAR is defined by [7]:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{(Ca^{2+} + Mg^{2+})}{2}}} \quad (1)$$

where all concentrations are expressed in meq/l.

The classification of groundwater samples demonstrates that SAR values of less than 10 indicate excellent water quality, 10-18: good water, and >18 doubtful to unsuitable water for irrigation purposes. A high concentration of SAR leads to the development of an alkaline soil, which will be hard and compact when dry and increasingly impervious to water penetration [8]. In the study area, SAR results obtained for all samples were less than 10 meq/l (ranged from 0.27 meq/l to 1.03 meq/l with an average value of 0.67 meq/l).

The analytical data plotted on the US salinity diagram [9] illustrates that most of the groundwater samples fall in the field of C2-S1 (all samples belong to cluster 1) and C3-S1 (all samples belong to cluster 2 and cluster 3) (Fig. 4), indicating medium to high salinity and low sodium water, which can be used for irrigation on almost all types of soil with little danger of exchangeable sodium. However, water samples belong to the C3–S1 group, representing the high salinity/low sodium type, which is detrimental to crops.

TABLE I
DESCRIPTIVE STATISTICS OF PHYSICOCHEMICAL PARAMETERS IN THE THREE CLUSTERS

	Cluster 1				
	Min	Max	Mean	SD	Cv
T	17.19	18	17.63	0.27	1.53
pH	6	6.87	6.67	0.25	3.68
EC	228	830	543	175	32
Ca	48	117	82	21	26
Mg	11.02	43.71	31.33	10.44	33.33
Na	12.47	26.47	21.02	4.26	20.29
K	1.78	3.78	3	0.61	20.29
Cl	88	248.5	145.28	47.46	32.66
SO_4	61.39	121.13	88.43	17.76	20.09
HCO_3	97.6	261.08	193.61	52.16	26.94
NO_3	0.02	38.56	23.16	10.8	46.62
NO_2	0.013	32.12	2.544	8.887	349.304
	Cluster 2				
	Min	Max	Mean	SD	Cv
T	16.84	17.53	17.38	0.27	1.54
pH	6.7	7.5	6.94	0.36	5.12
EC	730	1100	935	164	18
Ca	16	198	108	60	55
Mg	16.8	58.92	35.11	14.51	41.34
Na	21.22	29.25	24.59	2.62	10.67
K	3.03	4.18	3.51	0.37	10.67
Cl	110.05	255.6	194.24	51.68	26.61
SO_4	106	270	181.02	68.38	37.77
HCO_3	183	390.4	276.59	76.32	27.59
NO_3	0.02	19.37	2.81	7.3	260.19
NO_2	0.102	47.54	26.2	16.304	62.229
	Cluster 3				
	Min	Max	Mean	SD	Cv
T	17.5	18	17.6	0.21	1.18
pH	6.27	6.88	6.77	0.18	2.7
EC	745	1411	1009	187	18
Ca	74	127	101	19	19
Mg	30.26	61.32	43.72	9.33	21.33
Na	22.32	38.14	27.64	4.47	16.19
K	3.19	5.45	3.95	0.64	16.19
Cl	63.9	216.55	133.63	49.92	37.36
SO_4	91.07	187.72	132.82	30.1	22.66
HCO_3	135	524.6	244.51	111.39	45.55
NO_3	19.56	47.54	33.39	9.36	28.04
NO_2	0.012	0.092	0.061	0.028	45.726

TABLE II
CLASSIFICATION OF GROUNDWATER BASED ON WQI

Range	Type of water	Cluster 1	Cluster 2	Cluster 3
<50	Excellent water	23	0	0
50–100.1	Good water	77	57	100
100–200.1	Poor water	0	43	0
200–300.1	Very poor water	0	0	0
>300	Water unsuitable for drinking purposes	0	0	0

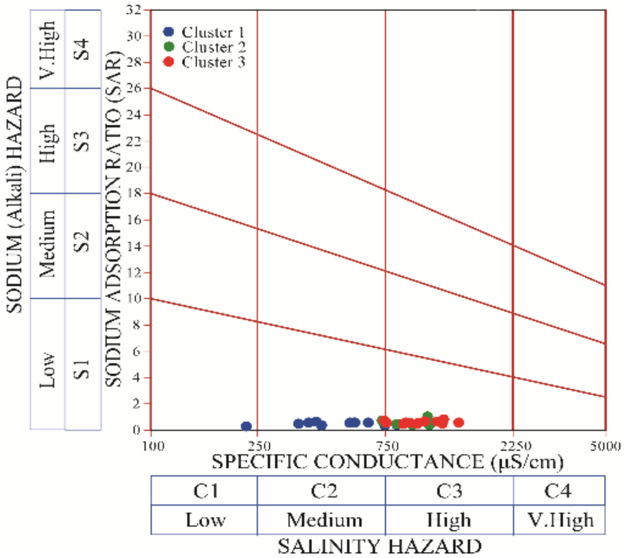

Fig. 4 Suitability of groundwater for irrigation based on salinity and SAR

The concentration of the sodium in irrigation water is also known as the sodium percentage (Na%). The sodium percentage has been used to classify the chemical composition of the groundwater. Excess sodium in water will change the soil structure and reduce soil permeability. The sodium percentage can be calculated as [10]:

$$Na\% = \frac{\left(Na^{+} + K^{+}\right) \times 100}{Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}} \tag{2}$$

Percentage of sodium calculated for groundwater in the study region is plotted against specific conductance in Wilcox diagram (Fig. 5). Fig. 5 shows that 12 samples (cluster 1) are excellent to good; 23 samples (cluster 2 and cluster 3) are good to permissible for agricultural activities.

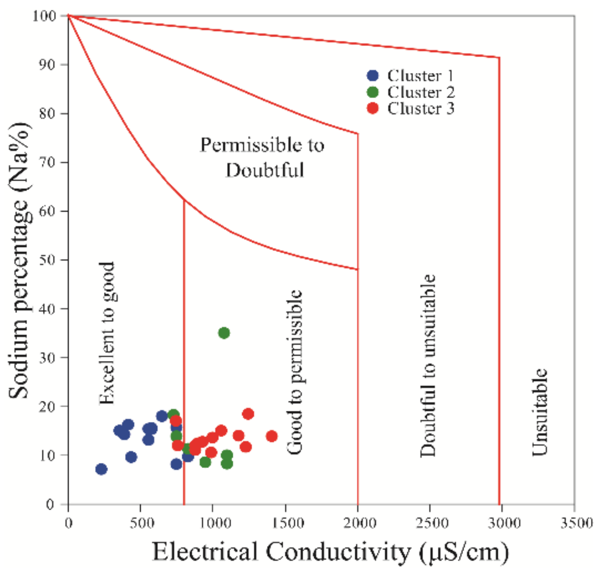

Fig. 5 Suitability of groundwater for irrigation based on EC (µS/cm) and Na %

V. Conclusion

The quality of groundwater in El Milia plain was evaluated using hydrochemistry data for drinking and agricultural suitability. Self-organizing map algorithm was applied in the expletory data analysis of a 35 groundwater samples and classify data into three clusters from cluster one, lowest electrical conductivity values to cluster three, the highest EC values. The results showed that samples in cluster one related to recharge zone, which characterized with hard-fresh water type.

Based on the WQI results, cluster one has best better quality for drinking purposes compared to cluster 3 and cluster 2. However, samples belonging to cluster 2 showed low quality for drinking water. Moreover, cluster one showed excellent quality for agricultural proposes. Meanwhile, cluster 3 and cluster 2 represent good to permissible water type, which indicate groundwater resources require adequate planning and management to the preserve water quality for agricultural activities in the future.

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