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ORIGINAL PAPER

Assessment of dam water quality for irrigation in the northeast of catchment Cheliff-Zahrez, Central Algeria

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Abstract
The aim of the present study was to appraise surface water quality for irrigation purposes. This research work concerns seven dams' water from higher and lower part of Cheliff agricultural area located in northeast to the larger catchment Cheliff-Zahrez, central Algeria. The following dams are investigated, namely Deurdeur, Ghrib, Harreza, Oued Fodda, Oued Mellouk, Sidi M'hamed Ben Taïba and Sidi Yakoub. Irrigation water quality evaluation was carried out by measuring and calculating physicochemical quality parameters monthly during three years: 2014, 2015 and 2016. For assessing the groundwater for irrigation suitability, parameters like pH, electrical conductivity, total dissolved solids, sodium adsorption ratio, pHc, adjusted sodium adsorption ratio, residual sodium carbonate, soluble sodium percentage, Kelly's ratio, USSL, Wilcox's diagram and permeability index suggest that the groundwater of the study area is moderately suitable for irrigation purposes. Based on USSL and Wilcox's diagram, it falls under excellent to unsuitable category indicating low salinity and high sodium water, which can be used for irrigation in almost all types of soil with little danger of exchangeable sodium. The Pearson correlation coefficient rate revealed strong correlation between several parameters. The water of Sidi M'hamed Ben Taïba dam has the best appropriateness for irrigation purpose compared to the other dams. Its water may be used in irrigation without limitation.

Keywords Surface water · Irrigation · Dams · Cheliff-Zahrez · Algeria · Quality parameters

1 Introduction

In Algeria, climate change has major consequences on the sustainable executive of lands and water. In arid and semiarid regions, domestic, industrial and irrigation water requirement increased considerably in recent decades. Imbalances among accessibility and demand, deprivation of surface and groundwater quality, inter-sectoral rivalry, inter-regional and worldwide conflicts regularly occur in water-scant regions, largely

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water in the Mediterranean region. Water is a vital constituent, but its quality is seriously in degradation for many years under the influence of various factors of pollution, chemical, organic and microbiological. These factors are chiefly caused by overcrowded population engendering the diversification of human economic activities. Use of pitiable quality groundwater has become predictable for irrigation to pay off hastily increasing water hassle in many arid and semiarid areas (Qadir et al. 2001; Selvam 2014).

The regular pH range for irrigation water is from 6.5 to 8.4; outside this interval, it may source a nutritional disproportion or toxicity (Ayers and Westcot 1985). The water irrigation with high salt contributes to modify arable land salt balance and accelerates its salinization. The quantity of salt accretion in the soil is associated with the quantity and quality of irrigation and drainage water (Mostafazadeh-Fard et al. 2008; Venkatramanan et al. 2016). Saline soil occurs not only ever since there is less rainfall accessible to leach and transfer the salts but also because of the immense evaporation rates attribute of arid climates, which have a propensity additional to deliberate the salts in soils and in surface waters (US Salinity Laboratory 1999). In addition to that, the water irrigation amount applied per hectare is too much because of climate change in this region (Mostafazadeh-Fard et al. 2008; Chung et al. 2018b; Selvam et al. 2014a, b). The total absorption of dissolved salts varies from a little parts per million (ppm) to several thousands. Most irrigation waters fall within the range of 100 to 1500 ppm, with a few as high as 5000 ppm., the elevated concentrations mortal used on the more tolerant crops (Wilcox 1948). Salinity affects the plant during the reduced water availability and increased water stress, which is reflected by the leaf water potential (Katerji et al. 2000). The assimilation of water by plants decreases when the osmotic pressure increases. The osmotic pressure depends to the salt content or salinity hazard (Rahman et al. 2012; Selvam et al. 2016, 2017; Singaraja et al. 2015). Soluble salt in the soil restricts the capability of the root structure to uptake water. It is well predictable that the salinity of an irrigation water and the SAR (sodium adsorption ratio) have an interactive effect on soil physical properties (Donald et al. 2006). According to Richards (1954), based on electrical conductivity (EC), irrigation water is classified in four classes: low, C1 ($EC < 250$ μ S/cm); medium, C2 (EC 250–750 μ S/cm); high, C3 (EC 750–2250 μ S/cm); and very high, C4 ($EC > 2250$ μ S/cm). However, based on sodium adsorption ratio (SAR), the classes are: low, S1 ($SAR < 10$); medium, S2 (SAR 10–18); high, S3 (SAR 18–26); and very high, S4 ($SAR > 26$). Another concept SAR accustomed sodium adsorption ratio (SAR_{adj}) is used for water containing an important quantity of carbonate (Ayers and Westcot 1976; Selvam 2015). The problems of permeability caused by calcium insufficiency or excess sodium may be assessed by the concept of adjusted SAR that takes on the account of the consequence of carbonate and bicarbonate on the aggressively through a formula of pHc which completes the old SAR method. The pHc value assesses water irrigation tendency to dissolve the soil limestone (Monition 1969; Singaraja et al. 2016; Venkatramanan et al. 2018a). Bower and Maasland (1963)'s anticipated approach used saturation index (SI), SI = (8.4—pHc to estimate carbonate precipitation as a function of $CaCO_3$ dissemination of the soil solution); pHc is the approximate pH of a non-sodic soil in equilibrium with $CaCO_3$. Residual sodium percentage (RSC) allows determining the hazardous effect of carbonate and bicarbonate on the irrigation water quality (Raju 2007; Sashikkumar et al. 2017a, b; Selvam et al. 2015). When the anions HCO_3^- and CO_3^- are in bigger proportion than cations calcium and magnesium and the RSC value is more than 2.5 meq/liter, the water is considered harmful, not appropriate for irrigation. In this situation, the calcium and the magnesium will be precipitated by bicarbonate anions and allow the increase in the sodium proportion in the soil. However, the water is probably safe with RSC value less than 1.25 meq/liter. For this reason, RSC is an important criterion that influences the suitability of water for irrigational uses (Wilcox 1958).

In order to establish the water capacity level for irrigation, problems in relation to its salt content should be considered (Hao et al. 2017; Landreau and Monition 1977: Saida et al. 2017; Venkatramanan et al. 2017a, b). Illustratively, sodium toxicity is often customized or reduced if adequate calcium is accessible in the soil (Ayers and Westcot 1985; Singaraja et al. 2016). Identifying and estimating the essential parameters which influence the quality of water assets help in implementing policies and strategies (Asadollahfardi et al. 2013; Venkatramanan et al. 2018b). The sodium has explicit harmful effects on soil physical properties, and it is defined separately. Soluble sodium percent (SSP) in irrigation water is also used to appraise its sodium hazard. Irrigation water with SSP value superior to 60 percent may result in accumulation of sodium that will source a harmful effect on soil properties (Bauder et al. 2014). The water index (PI) defined by Doneen (1964) indicates the combined effects of soil structure and irrigation water quality which may diminish the soil permeability. Soil permeability is exaggerated by long-term use of water characterized by a high concentration of soluble salt. Based on permeability index (PI), water is classified into three classes: class I ($PI > 75$), water is considered most suitable for irrigation, class II ($25 < PI < 75$), water is reasonably suitable for irrigation, and class III ($PI < 25$), water is considered unsuitable for irrigation (Doneen 1964). Kelly's ratio (KR) shows the concentration sodium deliberate beside calcium and magnesium of irrigation water. The waters with an index value greater than 1 are assessed as unbefitting for irrigation (Kelly 1940). The purpose of the present study is to appraise surface water quality for irrigation and its impact on soil properties in northeast to the larger catchment Cheliff-Zahrez where agriculture is the chief economic activity.

1.1 Study area

The study area is located between 35°36′11″ and 36°26′11″ north latitude, and 00°48′18 and 03°04′29″ east longitude. It is part of the larger catchment Cheliff-Zahrez (MRE 2009). The water quality study concerns seven dams: Deurdeur, Ghrib, Harreza, Oued Fodda, Oued Mellouk, Sidi M'hamed Ben Taïba and Sidi Yakoub indicated in the following map (Fig. 1). This area includes two important agricultural areas: upper and middle Cheliff by an agricultural surface of 62,386 ha, and main crops are cereals (mainly wheat and barley), citrus fruit, vegetables and grapes. The agriculture sector contributes 12% of Algeria's GDP (2016 estimates) and employs 20% of the population in rural areas. Algeria has 8.4 million hectares of arable land. To combat drought, the Ministry of Agriculture is developing projects to increase the amount of irrigated land by 2 million hectares by 2019. There is no major industry, but small industries are located in the study area. The present study area is one of the large settlements in the country where people are depending on agricultural activity (economic activities). In this regard, we have selected upper and middle Cheliff agricultural area.

The climate in this region is a semiarid type with an annual average rainfall less than 400 mm during these last decades, characterized by a long dry period situated between the middle April and middle October where crop irrigation is essential. Average annual temperatures decrease gradually from north to south with a minimum registered at Tissemsilt (14.2 °C) and a maximum at Cheliff (18.7 °C). Average monthly temperatures follow the same pattern, but the decline is faster in the cold season than in the hot season, because of

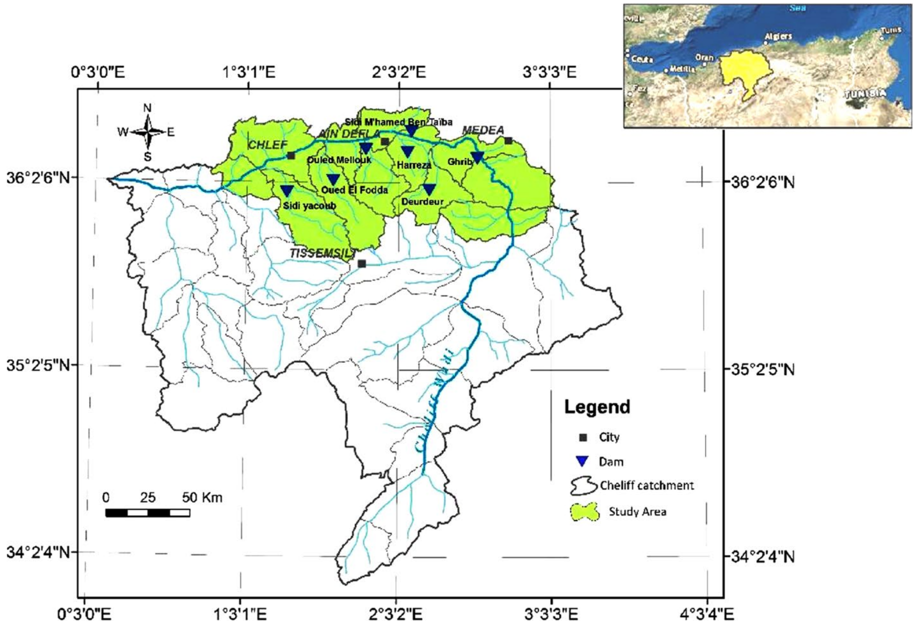

Fig. 1 Location map of the study area with dams

the particularly harsh effect of continentally winter and the regulating influence of the sea in summer. The hot season, months during which average monthly temperatures are higher than the annual average, extends from May to October, while the cold season lasts from November to April. The maximum temperatures of 27 to 28 °C are reached in August or July, and the minimum temperatures are in January and February (3 to 10 °C). The soil dominant texture is loamy and clayey (Merouche et al. 2014).

2 Materials and methods

2.1 Water sampling and analysis

A total of 252 water samples were collected by the National Agency of Hydraulic Resources. Of these, 12 samples were yearly taken from the each dam like Deurdeur, Ghrib, Harreza, Oued Fodda, Oued Mellouk, Sidi M'hamed Ben Taïba and Sidi Yakoub during three years: 2014, 2015 and 2016. The samples were taken at one meter water depth in the middle of dam. They were collected in high-density polyethylene bottles of one liter which are put in icebox and transported to the Université Djilali Bounaâma Khemis-Miliana water chemistry laboratory for analysis using Hanna HI98107P digital pH meter and Hanna HI98303P digital conductivity meter. The measure of the rest of chemical parameters in laboratory was based on the previous method (Rodier et al. 2009).

2.2 Analysis of physicochemical properties

Samples were analyzed in the laboratory for the physicochemical attributes like total major cations like calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}), potassium (K^{+}) and anions like bicarbonate (HCO_3^{-}), carbonate (CO_3^{2-}), chloride (Cl^{-}), nitrate (NO_3^{-}), sulfate (SO_4^{2-}) and phosphate (PO_4) in the laboratory using the standard methods given by the American Public Health Association (APHA 2005). These parameters are tabulated in Tables 2, 3 and 4. pH, EC and TDS were measured using portable water quality analyzers. Major cations (Ca, Mg, Na and K) were determined using ICP mass spectrometer while the anions were determined as follows: bicarbonate (HCO_3^{-}) and total hardness (TH) were analyzed by volumetric method, and sulfate (SO_4^{2-}) was estimated by the spectrophotometric technique, and nitrate (NO_3^{-}) was determined by ion chromatography. Chloride (Cl^{-}) was determined by volumetric titration using $AgNO_3$ and K_2Cr, $HCO_{3,}$ and carbonate (CO_3^{2-}) was determined by Portamess using HCl, phenolphthalein, methyl orange by titration method. Fluoride was estimated using an ion-selective electrode (ISE) with a pH/ISE meter (Orion 4-Star meter). All concentrations are expressed in milligrams per liter (mg/l), except pH and EC. The results were evaluated in accordance with the drinking water quality standards given by the Algeria National standard drinking quality (Algeria MWR 2015).

2.3 Irrigation water quality parameters

Use of poor water quality can create four types of problems, namely toxicity, water infiltration, salinity and hardness. To assess water quality for irrigation, there are four most popular criteria: TDS or EC, sodium adsorption ratio (SAR), chemical concentration of elements like Na^{+}, Cl^{-} and/or B^{-} and residual sodium. For current irrigation water quality assessment, the following parameters were considered.

According to Richards (1954), sodium adsorption ratio (SAR) is expressed as:

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

where all the ions are expressed in meq/L.

$SAR_{adj} = SAR\ [1 + (8.4 - PH_c]$, $PHc = (PK'_2 - pk'_c) + P\ (ca + Mg) + Palk$ where p represents the negative logarithm, K2 is the second dissociation equilibrium constant of carbonic acid and Kc is the solubility equilibrium constant for calcite.

Doneen (1962) expressed sodium percent (Na %) as:

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

where all the ions are expressed in meq/L.

Total hardness (TH) was calculated by the following equation (Raghunath 1987):

$$TH = (Ca + Mg) \times 50 \tag{3}$$

where TH is expressed in meq/L (ppm) and the concentrations of the constituents are expressed in meq/L.

The permeability index (PI), as developed by Doneen (1964), indicates the suitability of groundwater for irrigation. It is defined as follows:

$$PI = \frac{Na^{+} + \sqrt{HCO3}}{Ca^{2+} + Mg^{2+} + Na^{+}} \times 100 \tag{4}$$

where all the ions are expressed in meq/L.

Kelley's ratio (KR) (Kelly 1963) is described as:

$$KR = \frac{Na^{+}}{Ca^{2+} + Mg^{2+}} \tag{5}$$

where all the ions are expressed in meq/L.

Residual sodium carbonate (RSC) (Eaton 1950) is defined as:

$$RSC = [HCO_3^{-} + CO_3^{2-}] - [Ca^{2+} + Mg^{2}] \tag{6}$$

Total dissolved solids (TDS) were determined by multiplying the measured EC values (dS/m) by 640 (Brown et al. 1970).

The evaluation of irrigation water quality is completed by the calculation of the following index: soluble sodium percentage (SSP) (Todd 1980):

$$SSP = (Na^{+} + K^{+}) \times 100/(Ca^{2+} + Mg^{2+} + Na^{+} + k^{+}) \tag{7}$$

The graphical method USSL Richard's (1954) and Wilcox (1955) are used to show successively the classification and the correctness of water for irrigation purposes. USSL diagram represents SAR and electrical conductivity. It shows the classes of water quality: low, medium, high and very high. However, Wilcox's diagram represents the electrical conductivity and the percent sodium calculated. It depicts five water categories: excellent, good, permissible, doubtful and unsuitable. These diagrams were plotted using software Diagramme (Simler 2009).

2.4 Statistical analysis

Data were input by Microsoft office Excel 2007 and processed into graphs by Sigmaplot 10.0 (Systat Software, USA). Standard error of the samples was calculated. To quantitatively investigate the relationships among the dataset, Pearson correlation coefficient and multivariate statistics were performed in SPSS 14.0.

3 Results and discussion

Water samples were collected from seven different dams from the higher and Middle Cheliff agricultural area during three distinct years, 2014, 2015 and 2016. The annual average value of dam water quality parameters and analytic results for each parameter are summarized in Table 1.

Table 1 Annual average value of dam water chemical quality parameters and indexes

Parameter	National Standard in Algeria	Deurdeur	Ghrib	Harreza	Oued El Fodda	Oued Mellouk	Sidi M'hamed Ben Taïba	Sidi Yacoub
Ca^{2+} (mg/l)	200	85.63	192.38	147.75	94.78	91.22	55.15	113.78
Mg^{2+} (mg/l)	150	27.43	77.26	72.27	44.52	51.03	22.04	41.17
Na^{+} (mg/l)	200	184.56	262.28	182.67	91.18	122.58	24.36	169.65
K^{+} (mg/l)	20	5.07	8.98	6.31	3.28	3.63	3.25	3.97
Cl^{-} (mg/l)	500	331.83	432.95	378.24	117.80	215.61	35.42	267.42
SO_4^{2-} (mg/l)	400	161.29	619.96	405.44	331.10	294.61	94.00	357.78
NO_3^{-} (mg/l)	50	1.62	3.46	3.99	1.15	4.43	1.11	3.10
HCO_3^{-} (mg/l)	–	156.10	154.19	172.83	145.65	155.80	181.36	144.21
pH	6.5–8.5	8.06	8.04	8.03	8.03	8.03	8.14	7.98
EC (ds/m)	2800	1.72	3.05	2.37	1.38	1.60	0.62	1.90
TDS (mg/l)	1500	1101	1955	1520	885	1033	398	1218
SAR (meq/l)	–	4.46	4.04	3.08	1.95	2.57	0.71	3.51
pHc	–	7.39	7.08	7.09	7.26	7.27	7.42	7.41
SAR_{adj} (meq/l)	–	8.92	9.35	7.09	4.14	5.44	1.40	6.93
RSC (meq/l)	–	−4.01	−13.53	−10.58	−5.81	−6.26	−1.62	−6.76
SSP (%)	–	54.89	41.97	37.50	32.35	36.97	19.93	44.97
KR (meq/l)	–	1.23	0.71	0.59	0.47	0.58	0.23	0.82
PI (%)	–	65.58	47.29	44.94	44.35	48.10	49.19	53.95

3.1 pH

pH is the measure of the acidity of a solution of water. The pH scale commonly ranges from 0 to 14. The scale is not linear, but rather it is logarithmic. For example, a solution with a pH of 6 is ten times more acidic than a solution with a pH of 7. Pure water is said to be neutral, with a pH of 7. Water with a pH below 7.0 is considered acidic while water with pH greater than 7.0 is considered basic or alkaline. Analysis of dam surface water of this study area revealed that water is alkaline with pH ranging from 7.98 to 8.14 (Tables 2, 3, 4). The classification of groundwater on the basis of Algeria National standard drinking quality (Algeria MWR 2015) shows that all the dam waters are within permissible limits of irrigation water (6.5–8.5) (Ayers and Westcot 1985; FAO 1985). The slight alkalinity may be attributed to the dissolved atmospheric carbon dioxide resulting in the release of sodium and calcium, which progressively increases pH and alkalinity of the groundwater (Selvam et al. 2018).

3.2 Electric conductivity and TDS

All the water samples analyzed showed high mineralization, with EC higher than 2.8 mS/cm (Algeria MWR 2015) and the average of 0.65 mS/cm. These results could be explained either by the intensive use of artificial fertilizers (NPK) or the amount of salt carried by irrigation water. The salts accumulated in the soil are leached into water altering its physicochemical quality. Water samples collected between May and November had EC ranging between 0.7 and 1.2 mS/cm, which were classified within the class growing problem. Samples between November and April have EC within the same interval except for sites Sidi Yacoub and Harreza, where irrigation water represented a serious problem as EC > 1.8 mS/cm. There is a considerable increase in the ionic concentration which may be due to the leaching of salts from the soil and also by anthropogenic activities. The EC of the soils irrigated with water from BHD is higher. In fact, long-term irrigation adds large amounts of salts to a soil system. Our findings are consistent with those of previous reports (Chung et al. 2018a). The total dissolved solids (TDS) values of dam waters were below the Algeria National standard drinking quality permissible limit 1500 mg/l. High concentration of TDS can have an unfavorable effect on people and makes the water salty. Too high or too low TDS concentration can lower the effectiveness of wastewater treatment plants and industrial processes that use raw water. Lin Chou and Jhon Shih Lun (2018) studied hybrid zero-valent iron (Hzvi) media water treatment system for industrial wastewater treatment, in particular with applications involving extremely high TDS, dissolved Mn and Ni conditions. The concentration more than 1000 mg/L for TDS in water can cause scale buildup in distribution system, heaters, boilers and household appliances.

3.3 Variation of cations and anions

The tendency of the cations in all dams of the larger catchment Cheliff-Zahrez, central Algeria, is in the order of Na^+>Ca^{2+}>Mg^{2+}>K^+ with sodium as a dominant cation, and the tendency of anions is in the order of Cl- > SO_4^{2-}>HCO_3^-, with chloride as the dominant anion according to the Algeria National standard drinking quality 2015. The high concentration of sodium and chloride in the study area does not seem to arise from the above factors, but it may be caused by anthropogenic activities and due to the percolation of the saline water near river where the stagnant backwater facilitates the seepage thereby

Table 2 Deurdeur and Ghrib dam water quality in the years 2014, 2015, 2016

Dam	Year	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Cl (mg/l)	So_4^{2-} (mg/l)	HCo_3^- (mg/l)	Co_3^{2-} (mg/l)	pH	TDS
Deurdeur	2014	97.75	26.42	163.42	5.68	333.83	159.75	166.23	0.00	8.02	1082
Deurdeur	2015	83.63	23.32	151.83	4.38	303.83	135.25	150.09	0.00	8.14	1094
Deurdeur	2016	75.52	32.56	238.42	5.17	357.84	188.87	151.99	0.00	8.01	1126
Mean		85.63	27.43	184.56	5.07	331.83	161.29	156.10	0.00	8.06	1101
Ghrib	2014	211	79	276	9.95	519	637	161	0.00	7.9	2103
Ghrib	2015	192.66	68.32	234.75	7.79	395.25	590.79	152.50	0.00	8.22	1915
Ghrib	2016	173.22	84.83	276.08	9.21	384.20	632.60	149.25	0.00	7.99	1847
Mean		192.38	77.26	262.28	8.98	432.95	619.96	154.19	0.00	8.04	1955
RSC (meq/l)	NO_2	NH_4	M.Org	PO_4	SSP	KR	PI	SAR			
−4.36	0.06	0.11	6.45	0.11	50.56	1.00	61.69	3.83			
−3.66	0.14	0.08	6.95	0.06	52.29	1.08	64.20	3.78			
−4.00	0.05	0.13	7.48	0.04	61.80	1.60	70.86	5.78			
−4.01	0.08	0.11	6.96	0.07	54.89	1.23	65.58	4.46			
−14.48	0.065	0.138	6.8	0.103	41.72	0.70	46.79	4.12			
−12.83	0.20	0.18	7.31	0.10	40.44	0.67	46.17	3.71			
−13.28	0.08	0.16	7.38	0.05	43.76	0.76	48.92	4.28			
−13.53	0.12	0.16	7.17	0.08	41.97	0.71	47.29	4.04			

Table 3 Harreza and Oued El Fodda dam water quality in the years 2014, 2015, 2016

Dam	Year	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Cl (mg/l)	So_4^{2-} (mg/l)	Hco_3^- (mg/l)	Co_3^{2-} (mg/l)	pH	TDS
Harreza	2014	159.00	72.67	164.42	6.92	389.96	427.67	177.66	0.00	7.90	1537
Harreza	2015	153.60	62.36	162.25	5.33	361.00	352.67	174.36	0.00	8.24	1509
Harreza	2016	130.65	81.79	221.33	6.67	383.77	435.97	166.48	0.00	7.96	1513
Mean		147.75	72.27	182.67	6.31	378.24	405.44	172.83	0.00	8.03	1520
Oued El Fodda	2014	102.91	46.55	84.64	3.61	119.18	357.73	152.78	0.00	7.89	888
Oued El Fodda	2015	99.67	39.58	81.25	3.02	124.00	299.58	154.03	0.00	8.08	888
Oued El Fodda	2016	81.76	47.43	107.67	3.23	110.23	336.00	130.13	0.75	8.11	878
Mean		94.78	44.52	91.18	3.28	117.80	331.10	145.65	0.25	8.03	885
RSC	NO_2	NH_4	M.Org	PO_4	SSP	KR	PI	SAR			
−11.09	0.14	0.05	7.02	0.15	34.34	0.51	41.86	2.71			
−10.02	0.20	0.11	7.56	0.09	35.83	0.55	43.88	2.79			
−10.62	0.12	0.17	7.83	0.03	42.32	0.72	49.08	3.75			
−10.58	0.15	0.11	7.47	0.09	37.50	0.59	44.94	3.08			
−6.52	0.01	0.03	4.05	0.09	29.48	0.41	41.42	1.73			
−5.76	0.06	0.06	4.04	0.09	30.36	0.43	43.35	1.74			
−5.16	0.01	0.07	5.07	0.03	37.20	0.58	48.28	2.36			
−5.81	0.03	0.05	4.38	0.07	32.35	0.47	44.35	1.95			

Table 4 Oued Mellouk, Sidi M'hamed Ben Taïba and Sidi Yacoub dam water quality in the years 2014, 2015, 2016

Dam	Year	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	Cl (mg/l)	So_4^{2-} (mg/l)	Hco_3^- (mg/l)	Co_3^{2-} (mg/l)	pH	TDS
Oued Mellouk	2014	98.33	51.58	115.00	3.56	219.25	319.33	163.43	0.00	7.96	1030
Oued Mellouk	2015	116.67	40.13	110.25	3.18	223.00	250.00	171.56	0.00	8.14	1056
Oued Mellouk	2016	84.11	50.49	130.17	3.69	211.97	269.88	148.18	0.00	8.10	1013
Mean		91.22	51.03	122.58	3.63	215.61	294.61	155.80	0.00	8.03	1033
Sidi M'hamed Ben Taïba	2014	58.17	23	21	3.31	36	90	209.18	0	8.12	397
Sidi M'hamed Ben Taïba	2015	59.00	18.69	24.42	3.74	38.75	93.67	176.29	0.00	8.20	412
Sidi M'hamed Ben Taïba	2016	48.30	24.76	27.33	2.70	31.25	98.85	158.60	0.00	8.10	385
Mean		55.15	22.04	24.36	3.25	35.42	94.00	181.36	0.00	8.14	398
Sidi Yacoub	2014	120.27	45.82	145.55	3.95	249.18	368.36	156.10	0.00	7.95	1150
Sidi Yacoub	2015	120.42	37.79	167.50	3.50	282.33	332.00	150.47	0.00	8.10	1245
Sidi Yacoub	2016	100.66	39.91	195.92	4.44	270.73	372.96	126.07	0.00	7.89	1259
Mean		113.78	41.17	169.65	3.97	267.42	357.78	144.21	0.00	7.98	1218

RSC (meq/l)	NO_2	NH_4	M.Org	PO_4	SSP	KR	PI	SAR
−6.54	0.06	0.03	5.18	0.07	35.59	0.54	46.69	2.33
−6.36	0.36	0.09	5.91	0.11	34.69	0.52	46.32	2.25
−5.98	0.06	0.08	5.98	0.05	40.62	0.67	51.29	2.81
−6.26	0.06	0.06	5.58	0.06	36.97	0.58	48.10	2.57
−1.37	0.022	0.042	3.5	0.121	17.43	0.19	48.55	0.62
−1.62	0.08	0.03	2.62	0.08	20.43	0.24	49.59	0.72
−1.88	0.04	0.08	4.48	0.04	21.93	0.27	49.43	0.80
−1.62	0.05	0.05	3.53	0.08	19.93	0.23	49.19	0.71
−7.27	0.05	0.03	5.17	0.09	39.54	0.64	49.06	2.85
−6.70	0.12	0.09	5.68	0.07	44.57	0.79	53.81	3.44
−6.29	0.03	0.10	6.22	0.04	50.80	1.02	58.99	4.23

Table 4 (continued)

RSC (meq/l)	NO_2	NH_4	M.Org	PO_4	SSP	KR	PI	SAR
−6.76	0.06	0.07	5.69	0.07	44.97	0.82	53.95	3.51

increasing the sodium and chloride content in the groundwater near the downstream area. The leaching of saline residues of the soil by the action of rainwater during season may also contribute to the chemical composition of the water. In contrast to this, the predominant anion trend is in the order $HCO_3^- > Cl^- > SO_4^{2-}$ in the Harreza, Sidi M'hamed Ben Taïba and Sidi Yakoub, whereas the order in the stations Deurdeur, Ghrib, Oued Fodda, and Oued Mellouk is $HCO_3^- > SO_4^{2-} > Cl^-$with bicarbonate as the dominant anion Deurdeur, Ghrib, Harreza, Oued Fodda, Oued Mellouk, Sidi M'hamed Ben Taïba and Sidi Yakoub according to the Algeria National standard drinking quality 2015. Bicarbonate, formed by neutralization of CO_2, originated either by adsorption from the atmosphere or from the decomposition of organic matter in the recharge area. Weathering of silicates in the sediments of the study area also releases HCO_3^- into groundwater (Singaraja et al. 2016).

3.4 Salinity hazard

Electrical conductivity (EC) is the most important parameter in determining the suitability of water for irrigation use. Salinity hazard is the determination of the amount of salts in water and the risks it poses to soil when used for irrigation. The most influential irrigation water quality guideline is the salinity hazard. Water with high EC or TDS is toxic to plants and causes soil degradation and therefore must be controlled. According to Richards (1954), based on average value of electrical conductivity (EC) (Tables 1, 2, 3, 4), the irrigation water salinity hazard of dams: Deurdeur and Oued EL Fodda, is in high class (C3), but irrigation water of dams: Harreza, Ghrib, Oued Mellouk, Sidi Yakoub is in very high class (C4). However, the water samples from Sidi M'hamed Ben Taïba with EC = 0.71 mS/cm are in medium class (C2) which may be used in irrigation with none limitation (Bauder et al. 2014). Salinity hazard showed that few of water samples (13%) were of uncertain risk while the rest were inappropriate for irrigation.

3.5 Sodium adsorption ratio

The average values of sodium adsorption ratio vary from 0.71 meq/l in water Sidi M'hamed Ben Taïba dam to 4.46 meq/l in water Deurdeur dam. According to Richards (1954), the water of all the dams is in the low class because (SAR < 10).

The SAR and electrical conductivity values plotted on the Wilcox's diagram Richard's (1954) indicate that all of the groundwater samples belong to C4S4 category (Fig. 2). Water classification in this diagram is presented in two letters: the first letter which includes C1–C4 depicts water categories with raising salinity hazard, and the second letter which includes S1–S4 depicts water categories with raising peril of exchangeable sodium accumulation in irrigated soil.

The diagram showed three categories of water class: water Sidi M'hamed Ben Taïba in C2S1, water Deurdeur, Oued El Fodda and Oued Mellouk in C3S1, water Harreza and Ghrib in C4S1. Irrigation water of Sidi M'hamed Ben Taïba dam is the preeminent quality because of its low value of electrical conductivity and sodium adsorption ratio. However, irrigation water of Harreza and Ghrib dam C4S1 is considered particularly harmful according to USGS (2000) standard. These types of groundwater with very high salinity and sodium can be considered to have very poor quality, which can be used only for few plants with high salt tolerance.

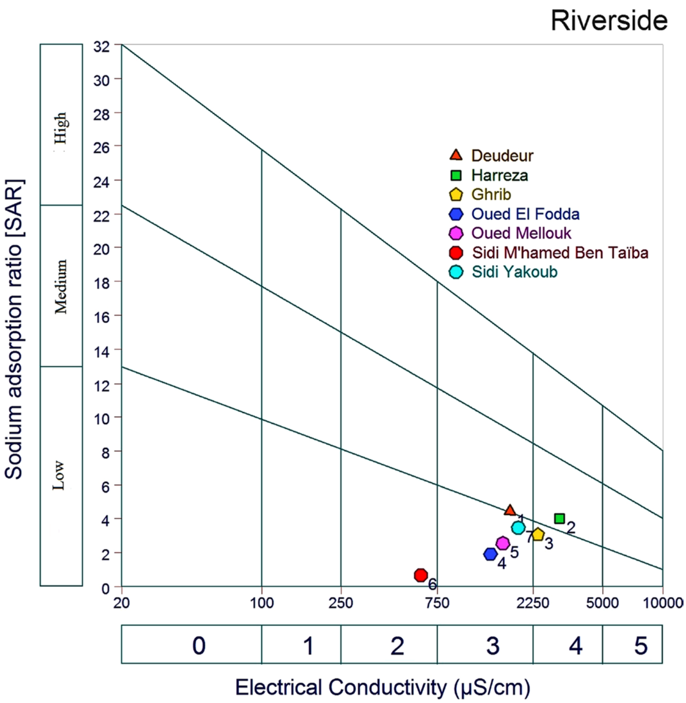

Fig. 2 Classification irrigation water quality of dams

3.6 pHc and accustomed sodium adsorption ratio

The pHc varies between 7.08 and 7.42, is less than 8.4 and is less than the water pH. It thus permits an accumulation of bicarbonate in soil surface. Bicarbonate reacts with soil calcium and magnesium to form unsolvable compounds leading to accumulation of sodium in the soil via substitution. If this situation persists for a long term, high sodium levels with low calcium levels soil particles get dispersed and thus reduced water infiltration in the soil (Ayers and Westcot 1985).

3.7 Residual sodium carbonate

The residual sodium carbonate (RSC) is a superior index of the sodicity hazard of irrigation water. Irrigation water having RSC values greater than 5 meq/l has been considered harmful to the growth of plants, while waters with RSC values above 2.5 meq/l are unsuitable for irrigation. The RSC average values obtained in all studied dam waters vary between −1.62 and −13.52 meq/l and were less than 1.25 meq/l. Based on average RSC values, the water is measured suitable for irrigation (Wilcox 1958).

3.8 Percent sodium

A graphical method based on electrical conductivity and percent sodium is used to better understand categories of appropriateness of water for irrigation use (Wilcox 1955). Na^+ is an important cation which in excess deteriorates the soil structure and reduces crop yield (Ayers and Westcot 1985). High Na^+ concentration in irrigation water tends to be absorbed by clay particles displacing Mg^{2+} and Ca^{2+} ions. This exchange process of Na^+ in water for Ca^{2+} and Mg^{2+} in soil reduces the permeability and eventually results in soil with poor internal drainage. The Na % is calculated using the formula given below according to Wilcox's classification.

The data of dam water plotted on the diagram (Fig. 2) show four class categories for irrigation: excellent (Sidi M'hamed Ben Taïba), good (Oued El Fodda, Oued Mellouk and Sidi Yakoub), permissible (Deurdeur), doubtful (Ghrib) and unsuitable (Harreza). The high percentage of sodium (60%>) in the irrigation water has negative effects on soil, as described above (Wilcox 1955).

3.9 Soluble sodium percent

The soluble sodium percentage (SSP) is also broadly utilized for assessing the appropriateness of water quality restriction for irrigation (Wilcox 1948). The SSP average value of Sidi M'hamed water dam is <20% (Table 1) that fell under class that permits low quantity of restriction on use for irrigation. The SSP of water samples from Ghrib, Oued El Fodda and Oued Mellouk is in the range that fall under class II (20 to 40%) where degrees of constraint for irrigation are used (Fig. 3). However, this degree of restraint is high for water samples from Harreza, Deurdeur and Sidi Yakoub that fall under class III (40–80%) (Ayers and Westcot 1985).

3.10 Kelly's ratio

Sodium measured against calcium and magnesium was considered by (Kelly 1963) to classify waters for irrigation. Kelly's ratio greater than 1 indicates an excess level of Na^+ in water. Therefore, water with the Kelly's ratio less than 1 is suitable for irrigation, while

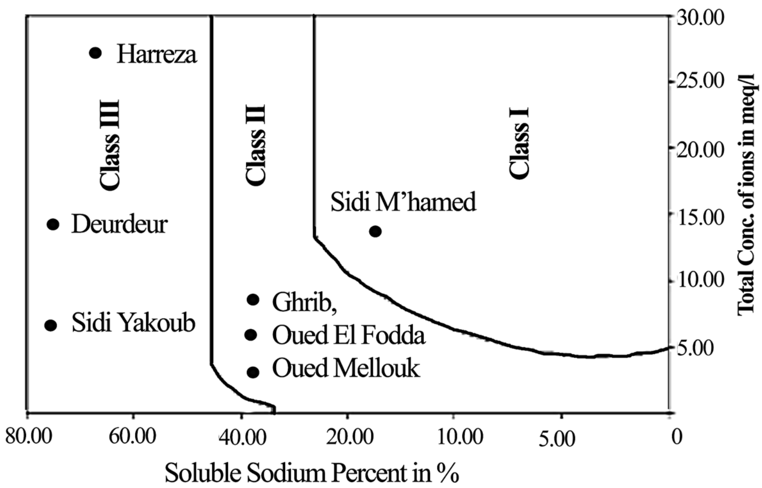

Fig. 3 Suitability of irrigation water: SSP plot

those with a ratio more than 3 are unsuitable for irrigation. Kelly's ratio (KR) also allows assessing the appropriateness of water for irrigation purposes (Kelly 1963). The average value obtained is equal to 1.23 for water dam Deurdeur more than one. However, the average values vary between 0.23 and 0.82 for the rest of the dam waters (Table 1). Based on these results, all the dam waters are suitable for irrigation except Deurdeur dam water.

3.11 Permeability index

The calculation of PI values also indicated the suitability of groundwater for irrigation, as the soil permeability is effected by long-term use of irrigation water, as influenced by Na^{+}, Ca^{2+}, Mg^{2+} and HCO^{-3} contents of the soil (Selvam et al. 2018). According to permeability indices, the groundwater may be divided into Class I, Class II and Class III types of Doneen's chart (1964) as shown in Fig. 4. Class I and Class II water types are suitable for irrigation with 75% or more of maximum permeability and Class III type of water with 25% of maximum permeability. The average permeability index values for all dams vary between 44.35 (Ghrib) and 65.58% (Deurdeur) (Table 1). According to PI values, the

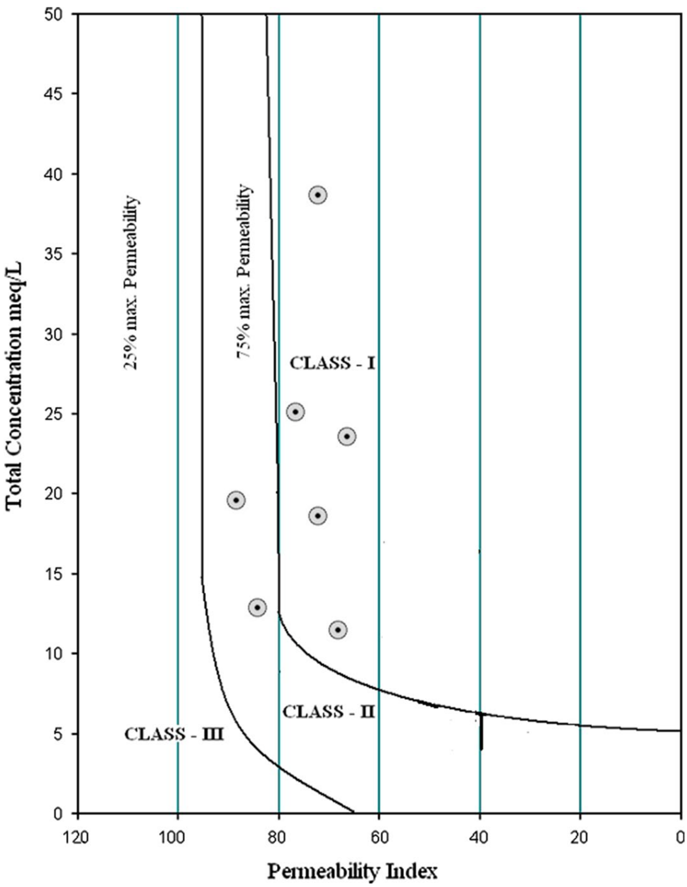

Fig. 4 Doneen's chart of permeability index for the study area

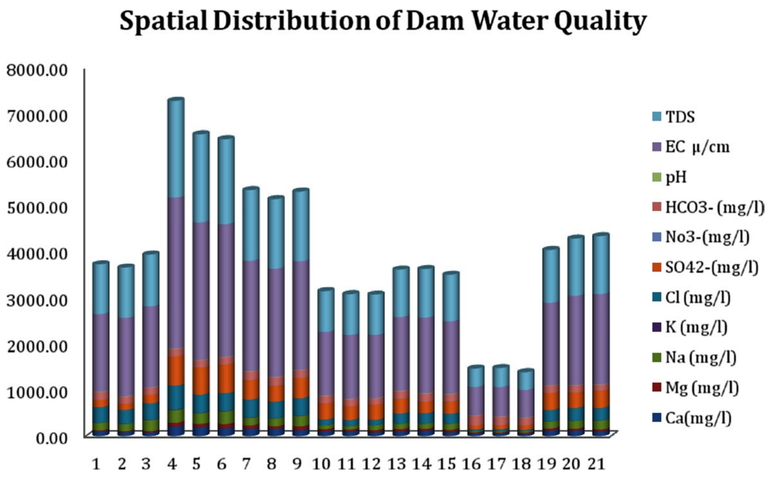

Fig. 5 Spatial bar diagram of major water quality parameters

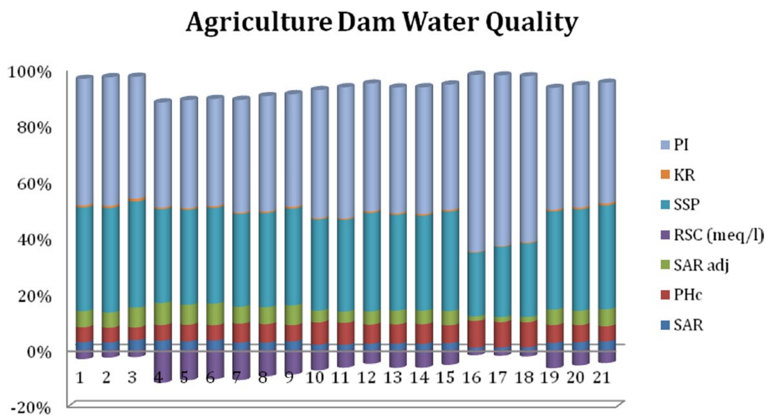

Fig. 6 Spatial bar diagram of agricultural water quality parameters

groundwater samples fall in Class I and II category in all the dams; it is indicating water is moderately suitable for irrigation purposes in the study area (Figs. 5, 6).

3.12 Pearson correlation

The Pearson correlation coefficient is calculated to establish the correlation between two variables. Correlation coefficient values of electrical conductivity (EC) with Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, SO_4^{2-} indicate that the salinity of the water has diverse origins (Table 5). We notice that the residual sodium carbonate is inversely proportional to calcium and magnesium concentrations. The sodium is significantly correlated with soluble sodium percentage (SSP), sodium adsorption ratio (SAR), adjusted sodium adsorption ratio (SAR_{adj}) and Kelly's ratio (KR).

Table 5 Pearson coefficient between water quality parameters

	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Cl^{-}	SO_4^{2-}	SAR	SAR_{adj}	RSC	EC	SSP	KR	PI
Ca^{2+}	1												
Mg^{2+}	0.849**	1											
Na^{+}	0.755**	0.692**	1										
K^{+}	0.838**	0.765**	0.826**	1									
Cl^{-}	0.813**	0.686**	0.933**	0.834**	1								
SO_4^{2-}	0.910**	0.912**	0.750**	0.769**	0.683**	1							
SAR	0.463*	0.389	0.915**	0.592**	0.828**	0.460*	1						
SAR_{adj}	0.590**	0.531*	0.965**	0.709**	0.894**	0.581**	0.983**	1					
RSC	−0.970**	−0.947**	−0.779**	−0.835**	−0.799**	−0.957**	−0.481*	−0.615**	1				
EC	0.944**	0.839**	0.918**	0.868**	0.933**	0.889**	0.712**	0.809**	−0.945**	1			
SSP	0.250	0.160	0.769**	0.360	0.691**	0.249	0.952**	0.894**	−0.263	0.531*	1		
KR	0.094	0.014	0.678**	0.280	0.586**	0.086	0.915**	0.836**	−0.099	0.384	0.968**	1	
PI	−0.363	−0.457*	0.264	−0.045	0.174	−0.394	0.594**	0.464*	0.391	−0.091	0.721**	0.834**	1

*, **Correlation is successively significant at 0.05 and 0.01 level

3.13 Possible remediation techniques

Remediation techniques play an important role in cleaning up the contaminants in groundwater. Remediation refers to the process of environmental cleanup of contaminated sites and the techniques to reduce or eliminate contamination from groundwater. Remediation pathways include transfer of contaminants alone or with contaminated groundwater to other place for the final treatment, confinement and destruction of contaminants in place. Technical principles for remediation can be divided into physical, chemical and biological processes. Frequently used techniques are containment, pump and treat, extraction, stabilization/solidification, precipitation, vitrification, thermal desorption and bioremediation. Nevertheless, the continuous monitoring and the analysis of monitoring data are still required to conserve groundwater around this area.

4 Conclusion

The dam water in the higher and Middle Cheliff agricultural area located in northeast to the larger catchment Cheliff-Zahrez, central Algeria, was evaluated for their chemical composition and suitability for agricultural uses. The investigation indicates that pH of all dam waters is alkaline considered permissible for irrigation purposes. However, based on electrical conductivity (EC) values, the dam water is classified into different classes between medium class (C2) and very high class (C4) of salinity hazard. Dam water of Sidi M'hamed Ben Taïba may be used for irrigation without limitation, but other dam's water present high levels of salinity hazard; using that in irrigation at the long term may increase considerable the soil osmotic pressure and prevent thus the absorption of the water by plants. Based on sodium adsorption ratio and electrical conductivity, waters of these dams are classified in three categories: the water Sidi M'hamed Ben Taïba in C2S1, water Deurdeur, Oued El Fodda and Oued Mellouk in C3S1, water Harreza and Ghrib in C4S1. The water of Sidi M'hamed Ben Taïba dam is the most suitable quality for irrigation use. However, waters of Harreza and Ghrib dam are considered particularly harmful for irrigation.

In the long tenure, the high levels of bicarbonate concentration by reacting with soil calcium and magnesium to form insoluble compounds reduced water infiltration in the soil. At the same time, the residual sodium is negative for water from all dams. It indicates that waters are rich in calcium and magnesium comparatively to bicarbonate and carbonate, measured suitable for irrigation. Based on sodium percent, the water dams are classified on four categories for suitability to irrigation: excellent (Sidi M'hamed Ben Taïba), good (Oued El Fodda, Oued Mellouk and Sidi Yakoub), permissible (Deurdeur), doubtful (Ghrib) and unsuitable (Harreza). The soluble sodium percentage also shows that water of Sidi M'hamed Ben Taïba dam has the best appropriateness for irrigation compared with waters of the other dams because it permits low degree of limitation on use for irrigation. The average permeability index values classify the water of the all dams as reasonably suitable for irrigation. Finally, it can be concluded using the water of these dams in irrigation, except that from Sidi M'hamed Ben Taïba dam, requires to make in parallel an agricultural drainage in order to prevent an unnecessary accumulation of wastages into the soil.

Further, this research appears it will integrate the real mechanism of the physicochemical parameters interactions with groundwater modeling. In future, the continuous environmental monitoring includes determination through recent models such as time series analysis, artificial neural network and fuzzy GIS which are essential for identifying and preventing pollution in this area.

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References

Algeria MWR, CEDARE, Demmak. A. (2015). Algeria state of the water reporting, monitoring and evaluation operational framework and guidelines. Monitoring & Evaluation for water in North Africa (MEWINA) Project, Ministry of water resources, Algeria MWR, Water Resources Management Program-CEDARE.

American Public Health Association (APHA). (1995). American Water Works Association (AWWA), Water Pollution Control Federation. Standard methods for the examination of water and wastewater, 16th edn. Washington, DC, p 1268.

Asadollahfardi, G., Hemati, A., Moradinejad, S., & Asadollahfardi, R. (2013). Sodium adsorption ratio (sar) prediction of Thechalghazi river using artificial neural network (ann) Iran. *Current World Environment, 8*(2), 169–178.

Ayers, R. S., & Westcot, D. W. (1976). *Water quality for agriculture. Irrigation and drainage paper 29*. Rome: FAO.

Ayers, R. S., & Westcot, D. W. (1985). *Water quality for agriculture*. FAO Irrigation and drainage paper 29 http://www.fao.org/docrep/003/T0234E/T0234E00.htm#TOC.

Bauder, T. A., Waskom, R. M., & Davis, J. G. (2014). *Irrigation water quality criteria* (Fact Sheet No. 0.506). Retrieved from Colorado State University Extension. http://www.ext.colostate.edu/pubs/crops/00506.pdf.

Bower, C. A., & Maasland, M. (1963). Sodium hazards of Punjab groundwater. *West Pakistan Engineering Congress Proceeding, 50,* 49–56.

Brown, E., Skougstad, M. W., & Fishman, M. J. (1970). *In techniques of water resources investigations of US Geological Survey*. Washington, DC: Book 5 US Government Printing Office.

Chou, L., & Lun, J. S. (2018). *Impact of high total dissolved solids, manganese and nickel ions on the hybrid zero-valent iron treatment system*. Master's thesis, Texas A & M University.

Chung, S. Y., Venkatramanan, S., Park, K. H., Son, J. H., & Selvam, S. (2018a). Source and remediation for heavy metals of soils at an iron mine of Ulsan City, Korea. *Arabian Journal of Geosciences, 11*(24), 769–790.

Chung, S. Y., Venkatramanan, S., Selvam, S., & Kim, T. H. (2018b). Time series analyses of hydrological parameter variations and their correlations at a coastal area in Busan, South Korea. *Hydrogeology Journal*. https://doi.org/10.1007/s10040-018-1739-9.

Donald, D. B., Cessna, A. J., Sverko, E., & Glozier, N. E. (2006). Pesticides in surface drinking-water supplies of the Northern Great Plains. *Environmental Health Perspectives*, *115*, 1183–1191.

Doneen, L. D. (1962). The influence of crop and soil on percolating water. Proceedings of the 1961 Biennial Conference on Groundwater Recharge, 156–163.

Doneen, L. D. (1964). *Notes on water quality in agriculture*. Water Science and Engineering, Paper 4001, Department of Water Sciences and Engineering, University of California, Davis.

Eaton, F. M. (1950). Significance of carbonate in irrigation waters. *Soil Science, 95,* 123–133.

FAO. (1985). *Criteria for water quality interpretation*. Roma: FAO.

Hao, J., Zhang, Y., Jia, Y., Wang, H., Niu, C., Gan, Y., et al. (2017). Assessing groundwater vulnerability and its inconsistency with groundwater quality, based on a modified DRASTIC model: A case study in Chaoyang District of Beijing City. *Arabian Journal of Geosciences, 10*(6), 144. https://doi.org/10.1007/s12517-017-2885-4.

Katerji, N., Hoorn, J. W., van Hamdy, A., & Mastrorilli, M. (2000). Salt tolerance classification of crops according to soil salinity and to water stress day index. *Agricultural Water Management, 43,* 99–109.

Kelly, W. P. (1940). Permissible composition and concentration of irrigated waters. *Proceedings of the American Society of Civil Engineers*, *66*, 607–613.

Kelly, W. P. (1963). Use of saline irrigation water. *Soil Science, 95*(4), 385–390.

Landreau, A., & Monition, L. (1977). Nouvelle évaluation de la qualité de l'eau pour l'irrigation. Rapport BRGM inédit 77 SGL 628 HYD.

Merouche, A., Debaeke, P., Messahel, M., & Kelkouli, M. (2014). Response of durum wheat varieties to water in semi-arid Algeria. *African Jounal of Agricultural Research, 9*(38), 2879–2892.

Monition, L. (1969). Données sur l'utilisation des eaux selon leur qualité chimique. Rapport BRGM 69 SGL 121 HYD.

Mostafazadeh-Fard, B., Heidarpour, M., Aghakhani, A., & Feizi, M. (2008). Effects of leaching on soil desalinization for wheat crop in an arid region. *Plant, Soil and Environment, 54*(1), 20–29.

MRE. (2009). *Plan directeur d'aménagement des ressources en eaux de la région hydrographique chéliff Zahrez*. Alger: Rapport de synthèse.

Qadir, M., Ghafoor, A., & Murtaza, G. (2001). Use of sa-line-sodic waters through phytoremediation of calcareous saline-sodic soils. *Agricultural Water Management, 50,* 197–210.

Raghunath, H. M. (1987). *Groundwater* (2nd edn., p. 561). New Delhi: Wiley Eastern Ltd.

Rahman, T. M., Rahman, S. H., & Majumder, R. K. (2012). Groundwater quality for irrigation of deep aquifer in southwestern zone of Bangladesh. *Songklarakerin Journal of Science and Technology, 34*(3), 345–352.

Raju, N. J. (2007). Hydrogeochemical parameters for assessment of groundwater quality in the upper Gunjanaeru River basin, Cuddapah district, Andhra Pradesh, south India. *Environmental Geology, 52,* 1067–1074.

Richards, L. A. (Ed.). (1954). Diagnosis and improvements of saline and alkali soils. US Department of Agriculture Handbook 60, p 160.

Rodier, J., Legube, B., Merlet, M., & Brunet, R. (2009). L'analyse de l'eau. Ed. Dunod, Paris, p. 1600.

Saida, S., Tarik, H., Abdellah, A., Farid, H., & Hakim, B. (2017). Assessment of groundwater vulnerability to nitrate based on the optimised DRASTIC models in the GIS environment (Case of Sidi Rached Basin, Algeria). *Geosciences, 7*(2), 20. https://doi.org/10.3390/geosciences7020020.

Sashikkumar, M. C., Selvam, S., Karthikeyan, N., Ramanamurthy, J., Venkatramanan, S., & Singaraja, C. (2017a). Remote sensing for recognition and monitoring of vegetation affected by soil properties. *Journal Geological Society of India, 90,* 609–615.

Sashikkumar, M. C., Selvam, S., Lenin Kalyanasundaram, V., & Colins Johnny, J. (2017b). GIS based groundwater modeling study to assess the effect of artificial recharge: A case study from Kodaganar River Basin, Dindigul District, Tamil Nadu. *Journal Geological Society of India, 89,* 57–64.

Selvam, S. (2014). Irrigational feasibility of groundwater and evaluation of hydrochemistry facies in the SIPCOT industrial area, South Tamilnadu, India: A GIS approach. *Water Quality, Exposure and Health, 1,* 1. https://doi.org/10.1007/s12403-014-0146-2.

Selvam, S. (2015). A preliminary investigation of lithogenic and anthropogenic influence over fluoride ion chemistry in the groundwater of the southern coastal city, Tamilnadu, India. *Environmental Monitoring and Assessment, 187,* 106. https://doi.org/10.1007/s10661-015-4326-8.

Selvam, S., Magesh, N. S., Sivasubramanian, P., Soundranayagam, John Prince, Manimaran, G., & Seshunarayana, T. (2014a). Deciphering of groundwater potential zones in Tuticorin, Tamilnadu, using remote sensing and GIS techniques. *Journal of the Geological Society of India, 85*(5), 597–608.

Selvam, S., Manimaran, G., Sivasubramanian, P., Balasubramanian, N., & Seshunarayana, T. (2014b). GIS-based evaluation of Water Quality Index of groundwater resources around Tuticorin coastal city, south India. *Environmental Earth Sciences, 71,* 2847–2867. https://doi.org/10.1007/s12665-013-2662-y.

Selvam, S., Singaraja, C., Venkatramanan, S., & Chung, S. Y. (2018). Geochemical appraisal of groundwater quality in Ottapidaram Taluk, Thoothukudi District, Tamil Nadu using graphical and numerical method. *Journal of the Geological Society of India, 92,* 313–320.

Selvam, S., Venkatramanan, S., Chung, S. Y., & Singaraja, C. (2016). Identification of groundwater contamination sources in Dindugal district of Tamil Nadu, India using GIS and multivariate statistical analyses. *Arabian Journal of Geosciences, 9,* 407. https://doi.org/10.1007/s12517-016-2417-7.

Selvam, S., Venkatramanan, S., & Singaraja, C. (2015). A GIS based assessment of water quality pollution indices for heavy metal contamination in Tuticorin corporation, Tamil Nadu, India. *Arabian Journal of Geosciences, 1,* 1. https://doi.org/10.1007/s12517-015-1968-3.

Selvam, S., Venkatramanan, S., Sivasubramanian, P., Chung, S. Y., & Singaraja, C. (2017). Geochemical characteristics and evaluation of minor and trace elements pollution in groundwater of Tuticorin City, Tamil Nadu, India using geospatial techniques. *Journal of the Geological Society of India, 90*(1), 62–68.

Simler, R. (2009). Diagrammes software. http://www.lha.univ-avignon.fr/LHA-Logiciels.htm.

Singaraja, C., Chidambaram, S., Jacob, Noble, Selvam, S., & Prasanna, M. V. (2016). Tidal effects on groundwater dynamics in shallow coastal aquifers—southeast coast of Tamilnadu, India. *Arabian Journal of Geosciences, 9,* 467.

Singaraja, C., Chidambaram, S., Srinivasamoorthy, K., Anandhan, P., & Selvam, S. (2015). A study on assessment of credible sources of heavy metal pollution vulnerability in groundwater of Thoothukudi Districts, Tamilnadu, India. *Water Quality, Exposure and Health, 1,* 1. https://doi.org/10.1007/s12403-015-0162-x.

Todd, D. K. (1980). *Ground water hydorlogy* (2nd ed., pp. 10–138). New York: Wiley.

US Salinity Laboratory. (1999). *Diagnosis and improvement of saline and Alkali soils. USDA Agriculture Handbook 60* (p. 160). Washington, DC: Etats-Unis, US Government Printing Office.

Venkatramanan, S., Chung, S. Y., Kim, T. H., Kim, B., & Selvam, S. (2016). Geostatistical techniques to evaluate groundwater contamination and its sources in Miryang City. *Korea Environmental Earth Science, 75,* 994. https://doi.org/10.1007/s12665-016-5813-0.

Venkatramanan, S., Chung, S. Y., Ramkumar, T., & Selvam, S. (2018a). Ecological risk assessment of selected heavy metals in the surface sediments of three estuaries in the southeastern coast of India. *Environmental Earth Sciences, 77*(4), 116. https://doi.org/10.1007/s12665-018-7294-9.

Venkatramanan, S., Chung, S. Y., Selvam, S., Lee, S. Y., & Elzain, H. M. (2017a). Factors controlling groundwater quality in the Yeonjegu District of Busan City, Korea, using the hydrogeochemical processes and fuzzy GIS. *Environmental Science and Pollution Research, 24,* 23679–23693.

Venkatramanan, S., Chung, S. Y., Selvam, S., Lee, S. Y., & Elzain, H. E. (2018b). Factors controlling groundwater quality in the Yeonjegu District of Busan City, Korea, using the hydrogeochemical processes and fuzzy GIS. *Environmental Science and Pollution Research, 1,* 1. https://doi.org/10.1007/s11356-017-9990-5.

Venkatramanan, S., Chung, S. Y., Selvam, S., Son, J. H., & Kim, Y. J. (2017b). Interrelationship between geochemical elements of sediment and groundwater at Samrak Park Delta of Nakdong River Basin in Korea: multivariate statistical analyses and artificial neural network approaches. *Environmental Earth Sciences, 76,* 456. https://doi.org/10.1007/s12665-017-6795-2.

Wilcox, L. V. (1948). *The quality of water for agricultural use*. US Dept Agriculture Tech. Bull. 962, US Washington, DC.

Wilcox, L. V. (1955). *Classification and use of irrigation waters*. USDA circular no. 969, p. 19.

Wilcox, L. V. (1958). *Determining the quality of irrigation water*. US Dept. of Agric. Agr. Inform. Bull. 194.

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