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Evaluation of quality of water from wells and boreholes located in some irrigated perimeters of N'Djamena city: Case of sites of Digangali, Moursal, Sabangali and Walia

K. Edith[1, 2 *], I. M. Alhabib[1], T. Léontine[1], B. Djimako[3], D. M. Jean-Claude[4]

[1]Geology Department, Faculty of Science and Technology, University of Doba, Chad
[2]Geology Department, Faculty of Exact and Applied Sciences, Chad
[3]Mechanical Engineering Department, Normal School Superior of Technical Education of Sarh, Chad
[4]Geology Department, Faculty of Science and Technology, University of Moundou, Chad
**Corresponding author, djimako.b5@gmail.com*
***Corresponding author, edith.kadjangaba@gmail.com*

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**Corresponding author, djimako.b5@gmail.com*
***Corresponding author, edith.kadjangaba@gmail.com;*

Abstract

Objective of this study is to assess chemical quality and pollution status of groundwater used in irrigated areas located along rivers of N'Djamena city, and to assess their suitability for irrigation purposes. Thirteen groundwater samples, nine wells and four boreholes were collected at four sites. To carry out this study, we considered 14 parameters: pH, T°, EC, HCO_3^-, Cl^-, Na^+, K^+, Ca^{2+}, Mg^{2+}, SO_4^{2-}, NO_3^- , NO_2^-, NH_4^+ and PO_4^{3-}. Values of analytical parameters were compared to standards admitted by [1] for drinking water and to guide values of [2] for irrigation water. In addition, we proceeded to calculation of some parameters of water for agriculture. Results of this study show that most of major ions have values in accordance with ([1], [2]) standards except for K^+, NO_3^-, NO_2^- NH_4^+ and PO_4^{3-} ions which present levels that exceed the ([1],[2]) guide values in some water points. The high concentrations of some elements in analyzed waters underline presence of pollution index in these waters. 100% of our water points are suitable for irrigation, according to Corrosivity Ratio values. For Kelly ratio, 23% of waters are unsuitable and for sodium percentage, 15% of waters are good, 77% are acceptable and 8% are unsuitable for irrigation. In Wilcox chart almost all waters are of excellent to good quality, with exception of one water point which is of acceptable quality. In Riverside diagram, 84% of waters belong to C2S1 class, which corresponds to waters of medium salinity, thus with a low risk of alkalinization, and 16% of these waters belong to C3S1 class, which represents highly mineralized waters with a low risk of soil salinization. In [23], 54% of waters belong to class II, representing waters of an intermediate quality class and are likely to be used for irrigation, with certain precautions. Other 46% of waters are Class I, representing water unsuitable for irrigation.

1. Introduction

The earth's surface is covered with 70% water, but out of this total, fresh water represents only 2.53% (a volume of 35 million km^3). This one is not totally mobilizable, but it is necessary to all forms of life [1,2]. Moreover, it constitutes an element of promotion of health of individuals and the socioeconomic development of human communities [3]. However, when not properly protected, it can become a source of problems for all those who consume it. Of small percentage of freshwater available, groundwater accounts for only 0.63%, and it must be of good quality. Cities in sub-Saharan regions are experiencing rapid population growth and urbanization. This urban growth is partly due to natural population growth, but it is mainly linked to rural exodus. N'Djamena city, capital of Chad, has not been left out, and for about four (4) decades, it has not stopped growing rapidly. Indeed, population of N'Djamena which was 531,000 inhabitants in 1993 increased to 800,000 inhabitants in 2000. INSEED (2022) estimated the population of N'Djamena at 1,454,671 inhabitants with a current population growth rate of about 3.53% per year. Based on this data, it is not excluded that N'Djamena population will reach approximately 2,122,000 inhabitants in 2030 according to the projections. This rapid population growth has negative repercussions on environment, available natural resources, including water, and food. In order to solve the problem of unemployment, a certain segment of population, including many young people, are increasingly involved in market gardening. The irrigated areas of N'Djamena city are located along Chari and Logone rivers. They are mainly dedicated to cultivation of market garden produce to supply the city with fresh produce.

Irrigated agriculture is considered a main cause of increase in concentrations of plant protection products in receiving environment and is main emitter of nitrogen pollution [4]. The accumulation of these products in groundwater can alter water quality and thus reduce its use by consumers.

To meet increasing demand for food products, the study area is undergoing intensification of agricultural practices. In order to obtain a good yield, market gardeners use fertilizers (NPK and Urea) associated with household waste and phytosanitary products (pesticides and herbicides) to treat the crops. However, due to lack of training, market gardeners do not master techniques of market garden production [5]. As a result, each market gardener treats the crops in his own way and doses of pesticides are not respected. The use of products certainly has a positive effect on agricultural yields but is not without consequences insofar as it will degrade quality of water and soil. The degradation of water quality is often done in a progressive manner and when it is not followed it can grow to the point of making water unsuitable for any purpose for a long period [6].

N'Djamena population makes extensive use of groundwater for its drinking water supply, and any agricultural pollution that originates at level of banks of watercourses is likely to be heard and to contribute to generalized degradation of water table, as noted in previous studies carried out in the study area ([7]; [8]; [9]; [10]). Although role of irrigation in degradation of groundwater quality in N'Djamena has not been specifically studied, it is known that agriculture has a negative impact on groundwater quality, particularly because of infiltration of chemical inputs into soil.

It should be noted that in agricultural areas, this same water is used for crop irrigation and human consumption. The quality of water therefore affects to a large extent human health and economy of localities. It is important to monitor groundwater quality because same water we contaminate through our practices can have serious effects on both human health when we consume it and on soil structure and crop yields when it is used for irrigation. Indeed, the consumption of unsafe water can cause waterborne diseases, just as use of poor-quality water for irrigation can lead to a decrease in plant growth and crop yields, and can influence crop productivity and physical condition of the soil ([11]; [12]). Thus, knowledge of hydrochemical characteristics is essential to understand suitability of water for various purposes [13] and ensure sustainability of good quality water. It is in this context that this study was conducted, with main objective of assessing the quality of groundwater in irrigated areas of N'Djamena city in order to show the impact of irrigation on quality of these waters.

1.1 Presentation of the study area

N'Djamena city (study area) is located in western Chad on border with Cameroon between 12°06'59" North and 15°04'20" East. It covers an area of 15,000 ha, 10,000 of which are urbanized and 5,000 of which are non-urbanized or in process of being urbanized. Administratively recognized as a commune, N'Djamena is divided into ten (10) districts, three (3) of which were selected for our study.

The irrigated areas selected are those of Moursal, Sabangali, Digangali and Walia districts, which are located between the 3rd, 6th and 9th arrondissements (Figure 1). It is, on whole, slightly flat. The climate is Sahelian, and is characterized by an alternating rainy and dry season of varying duration depending on year. Average annual rainfall recorded over a 30-year period from 1985 to 2015 is 574.6 mm.

The average monthly temperatures recorded over same period range from 23.7 to 33.8°C and average monthly evaporation is around 243.3 mm. The city is bordered in its entire southern part by Chari River, which is joined by its main tributary, Logone. These two main rivers have their sources in Central African Republic and in Adamaoua plateau in Cameroon ([14]; [15]). The subsoil of N'Djamena city contains a system of quaternary aquifers that supply the city with drinking water. The piezometric surface of surface water table is relatively close to surface at level of river banks, but it deepens as one moves away from banks. In agricultural sector, market gardening occupies an important place in human nutrition [16]. It ensures food security for populations while improving their socio-economic conditions. In order to cope with never-ending economic crisis, urban agriculture has developed very quickly in urban perimeter of N'Djaména city, mainly on banks of rivers. Indeed, field surveys have identified about twenty agricultural production sites throughout N'Djaména city, but this study focuses on four sites.

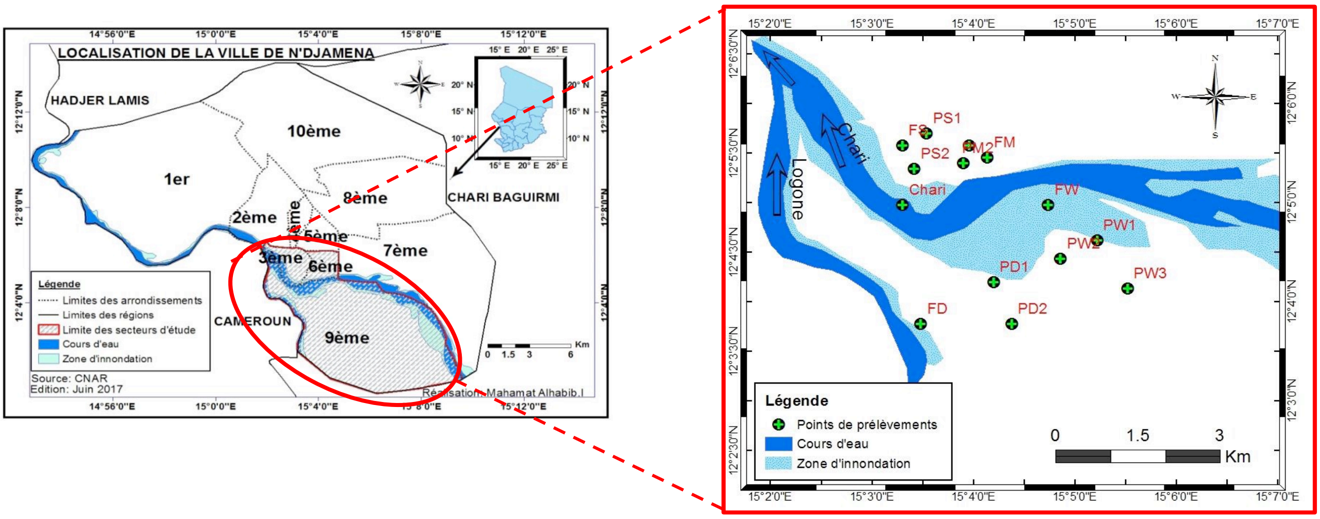


Figure 1: Location map of the study area and sampled points

2. Methodology Material and methods

The field campaign took place from May 20 to 25, 2017. A total of thirteen (13) groundwater samples were collected (09 wells and 04bores). Water points were located by a Garmin type GPS. Sensitive parameters such as temperature, electrical conductivity (EC) and pH were measured in field using a multi-parameter device brand wtw multi 350i. Water for laboratory was collected in 1L polyethylene bottles. The latter were previously rinsed at least three times with water to be sampled and the bottles were filled to brim before being hermetically sealed. A few drops of acid were added to samples for cation analysis. Samples were then placed in a cooler to be maintained at a temperature of 4°C before being transported to laboratory. Chemical analyses were carried out at the Water and Environment Laboratory (LABEEN) of Faculty of Exact and Applied Sciences (University of N'Djamena). HCO_3^- and Cl^- ions were determined by volumetric method while Na^+, K^+, $Ca2^+$, Mg^{2+}, SO_4^{2-}, NO_3^-, NO_2^-, NH_4^+ and PO_4^{3-} ions were determined with DR7100 Photometer. We checked reliability of our results by calculating ionic balance of each water point and values are within ±3%.

3. Results and Discussion

To assess quality of groundwater, values of analyzed parameters were compared to standards admitted by World Health Organization [1] for drinking water and to guide values of Food and Agriculture Organization [2] for irrigation water (Table 1).

Table 1: Summary of physico-chemical parameters of groundwater in irrigated areas (May 2017).

Parameters	Units	Minimum	Maximum	Mean	Standard deviation	CV(%)	OMS(2011)	FAO(2003)
T°	°C	27,5	32,5	30,8	1,6	5,3		
pH		6,4	7,4	7,0	0,3	3,9	6,5-8,5	6,5-8,5
C25°C	µs/cm	308 ,0	1223,0	667,6	293,5	44,0	2500	0-3000
Ca^{2+}		15,0	83,0	47,8	25,6	53,6	100	0-400
Mg^{2+}		8,0	59,0	30,0	17,4	58,0	50	0-60
Na^{+}		20,5	151,0	90,6	51,3	56,6	200	0-290
K^{+}		2,1	24,0	8,1	6,5	80,0	12	0-2
HCO_3^-		115,0	644,9	318,9	157,4	49,3	-	-
Cl^-		1,6	106,6	41,0	35,3	86,2	250,00	0-1000
		23,0	147,9	75,8	46,8	61,7	250,00	0-960
		1,6	135,9	66,8	53,3	79,9	50	0-10
		00	1,5	0,3	0,5	142,0	0,1	
		00	0,5	0,3	02	66,4	0,5	0-5
		00	4,1	1 ,1	1,5	136,5	0,5	0-2

The results of analyses show that pH values of waters vary between 6.4 (FW) and 7.4 (PD2) with an average of 7.0. These values are all within range of values defined by ([1], [2]). The conductivity values vary between 308 (FS) and 1223 µS/cm (PS1) with an average of667.6µS/cm. This variation in conductivity thus indicates the presence of several mineralization processes taking place in different parts of study area. On other hand, average conductivity of well water (804.66 µS/cm) is higher than those of boreholes 359.25µS/cm), this is explained by fact that wells are more exposed to influence of pollution. Water temperatures vary between 27.5°C (FS) and 32.5°C (PS1) with an average of 30.8°C. For majority of ions put into solution by natural processes, such as silicate hydrolysis and base exchange, ion contents in water are in accordance with ([1], [2]) standards. With exception of potassium, which has values exceeding WHO standard (12 mg/L), in four (04) water points (PD1 PM1 PM2 and PS1) and that of FAO (0 - 2 mg/L) in all sampled waters.

The potassium comes mostly from alteration of clay formations of quaternary alluviums, however the fact of having values higher than standards admitted by WHO, one can say that potassium has partly as source dissolution of chemical fertilizers (NPK).

The nitrogen and phosphate pollution indicator parameters such as NO_3^-, NO_2^-, NH_4^+ and PO_4^{3-} present very variable values. They can question quality of water. For these parameters, some points have values that exceed the guide values of the ([1], [2]). Thus, for nitrates, there are seven (07) water points (PD1, PD2, PM1, PM2, PS1, PS2 and WP) that have values higher than WHO standard (50 mg/L) and most of samples except for points FD, FM and FS have values higher than that defined by FAO (10 mg/L). For nitrite, considering standard set by WHO for drinking water which is 0.1 mg/L, there are also seven (07) water points (PD1, PD2, PM1, PM2, PS1, PW3 and WP) that have values higher than this standard. For values of ammonium, three (03) water points (PD1, FM and

PS1,) have values higher than WHO standard (0.5 mg/L) while totality of values remain in range of values defined by [2]. Finally, for phosphates, six (06) of water points (FD, PD1, FM, FS, PS1, and WP) have values higher than WHO standard (0.5 mg/L) and three (03) water points (FM, PS1 and WP) have values higher than FAO standard (0 - 2mg/L).

Nitrates in water can come from a variety of sources, both natural and anthropogenic. In urban areas, and especially in sub-Saharan regions, high nitrate levels in water are often linked to domestic and urban discharges, which contribute locally to groundwater contamination, to influence of latrines and to influence of animal waste around water points. But in our case, in addition to these possible sources, we can add use of chemical or organic nitrogenous fertilizers for fertilization in order to obtain a good yield. Nitrites, which represent least oxygenated and least stable form in nitrogen cycle, are generated by decomposition of organic matter associated with degradation of fertilizers. The high levels correspond to reduction of nitrates by sulfite-reducing anaerobes. They can also be linked to bacterial oxidation of ammonia [17]. The presence of Ammonium in water usually reflects an incomplete degradation process of organic matter, is often related to presence of nitrate and nitrite.

Ammonium is product of final reduction of nitrogenous organic substances and inorganic matter in water and soil. It also comes from excretion of living organisms and from reduction and biodegradation of waste. It is considered an excellent indicator of water pollution by organic discharges of agricultural, domestic or industrial origin. The origin of phosphates in water would be related to urban discharges or to dissolution of chemical fertilizers (NPK), which is case for study area. Excessive phosphate values indicate pollution caused by agricultural practices in irrigated area, following use of phosphates in form of chemical fertilizers or pesticides.

The Piper diagram (using software "Diagrams" [18]. was used to identify water facies. Projection of chemical analysis results on this diagram shows a variability of chemical facies. Four groups of waters can be distinguished (Figure 2).

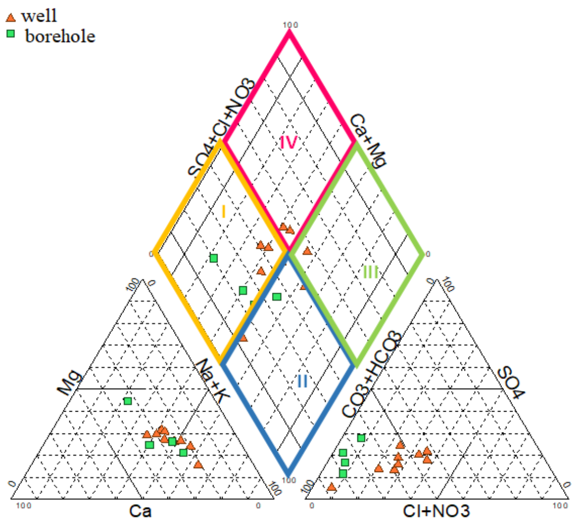


Figure 2: Piper diagram

At the level of group I, we can differentiate two sub-groups corresponding to two distinct types of water:

Ca-Mg-Na+K-HCO3-Cl-NO3 type, which includes PM1, PM2 and PW2 points, which represents about 23% of total waters analyzed. The presence of nitrates in these waters suggests that these points are anthropogenically influenced.

Ca-Mg-Na+K-HCO3 type, which includes points FM, FW, FS and PS1, representing about 31% of total waters analyzed. This type of water and those of group II (Na+K-HCO3) which includes points PW3, WP and FD, that is to say approximately 23% of totality of analyzed waters come from a natural mineralization, that is to say hydrolysis of silicates and basic cationic exchanges.

In group III, we have Na+K-HCO3-Cl-NO3 type waters represented by one water point (PS2) and in group IV, we have Ca-Na+K-HCO3-Cl-NO3 type waters represented by two water points (PD1, PD2). This represents about 8% and 15% respectively. In these two (02) groups, we note presence of relatively mineralized water. Apart from presence of Nitrates and Chloride, we note that quantities of sulfate relatively important. To complete the information, quality of irrigation water was evaluated based on following criteria: dry residue (RS(mg / L) = 0, 7CE (µS/ cm); osmotic pressure (π (atm.) = 0, 00036 CE); sodium percentage (% Na = $Na^+ + K^+/ (Ca^{2+} + Mg^{2+} + Na^+ + K^+) \times 100$), Kelly ratio(KR (meq/L) = $Na^+/(Ca^{2+} + Mg^{2+})$), corrosiveness ratio (CR (mg/L) = $[(Cl^- / 35.5) + 2 (SO_4^{2-} /96)] / 2(HCO_3^- + CO_3^{2-} /100)$), residual Sodium Carbonate (CSR (meq/L) = $(CO_3^{2-} + HCO_3^-) - (Ca^{2+} + Mg^{2+})$) and Sodium Absorption Rate (SAR = $Na^+/(Ca^{2+} +Mg^{2+})1/2$). These equations were proposed by [19] for RS and π; by Richards et al (1954) for CSR and SAR, by [20] for % Na, by [21] for CR and by Kelly (1963) for KR. The results obtained are in Table 2. To have additional information, in addition to these parameters, we also used, ([22]; [23]).

Table 2: The various water quality parameters used for irrigation (May 2017).

Name of samples	RS(mg /L)	π(atm)	SP	%Na	KR	RSC	SAR	CR
FD	219,10	0,11	0,55	54,81	1,17	0,48	1,59	0,42
PD2	564,20	0,29	3,42	44,79	0,79	-1,42	2,37	0,68
PD1	628,60	0,32	4,54	41,57	0,67	-1,69	2,33	0,70
FM	285,60	0,15	0,56	22,16	0,26	-1,15	0,57	0,20
PM1	731,50	0,38	3,09	48,94	0,90	0,80	2,80	0,46
PM2	561,05	0,29	2,63	37,19	0,51	0,09	1,60	0,38
FS	215,60	0,11	0,36	48,04	0,89	0,59	1,30	0,25
PS1	856,10	0,44	3,06	43,08	0,72	1,58	2,53	0,32
PS2	375,52	0,19	2,80	56,21	1,25	-0,29	3,16	0,74
WP	596,40	0,31	2,50	63,38	1,70	1,70	3,76	0,56
FW	285,60	0,15	0,59	40,40	0,66	0,84	1,27	0,22
PW2	310,10	0,16	0,85	40,63	0,65	-0,02	1,18	0,40
PW3	445,90	0,23	0,29	51,26	0,99	2,43	2,10	0,07

The primary effect of total salinity is to reduce crop growth and production [19]. It is usually expressed by total mineralization or by electrical conductivity (EC). The latter is related to dry residual (DR) and osmotic pressure π. DR values of waters vary from 216 to 856 mg/L, with an average of 467 mg/L. As for osmotic pressure, it oscillates between 0.11 and 0.44 atm with an average of 0.24 atm **(Table 2).** According to [24] the classes selected for RS and π are the same as those for the electrical conductivity of water for agricultural use **(Table 3).**

Table 3: Agricultural water quality as a function of RS and π

Class	RS(mg /L)	π(atm)	water quality	percentage of water
C1	<175	<0,09	low salinity water	0%
C2	175-525	0,09-0,27	medium salinity water	54%
C3	525-1575	0,27-0,81	high salinity water	46%

We note that 0% of groundwater sampled is characterized by low salinity, 54% has medium salinity and 46% has high salinity. The salinity of soil is constituted by all salts of sodium chlorides and magnesium sulfates; the values of Potential Salinity (PS) of study area vary from 0.29 to 4.54 meq/L with an average of 1.94 meq/L. All groundwater PS values are less than 5 (Table 2). These waters are of good to excellent quality for agriculture. For CR values below 1, water is considered good, and when CR is higher than 1, it indicates that water is corrosive in nature and should not be transported through metal pipes [25]. In **Table 2**, corrosivity ratio (CR) values are less than 1 for all water points (100%), which indicates that groundwater can be transported through any type of pipe. Referring to [26] classification, residual sodium carbonate (RSC) values show that almost all water points are suitable for irrigation with values less than 1.25, except for two water points (PS1 and PW) which are unsuitable for irrigation because they have values between 1.25 and 2.5 (Table 2). In addition, according to [27] **(Table 2),** three water points (FD, PS2 and PW) are suitable for irrigation because they have values greater than 1; these waters represent 23% of sampled waters. The rest of water points (10 in total) are suitable for irrigation because they have values lower than 1. These waters represent 77% of sampled waters. Regarding %Na, according to classification of [28] two (02) water points (FM and PM2) have values of %Na which is between 20-40%, these are waters that are good for irrigation and they represent 23% of total water points. Ten (10) water points have values of %Na which is between 40 and 60%, these are waters that are eligible for irrigation and they represent 77% of totality of water points. And finally, one (01) water point (WP) has a value of %Na which is between 60 and 80%, this water is eligible for irrigation and represents 8% of total water points. The results of water analyses on Wilcox diagram **(Figure 3)** show that groundwater in irrigated areas ranges from excellent to good for all waters, with the exception of point WP, which is in range of water admissible for agricultural use.

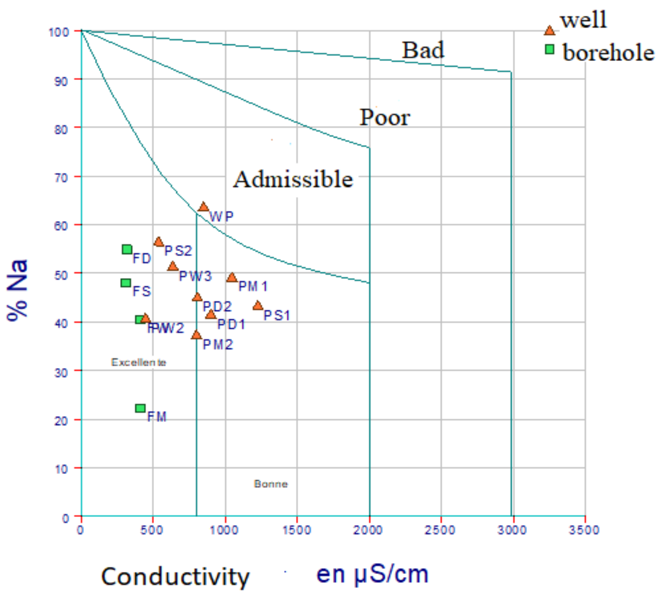


Figure 3: Representation of percentage of sodium as a function of electrical conductivity (Wilcox, 1955);

The SAR values calculated and then plotted against electrical conductivities **(Figure 4)** yielded two (02) water classes:

- Class C2S1 which includes four (04) boreholes (FD, FM, FS and FW) and three (03) wells (PW2, PW3 and PS2), this class represents 54% of the water sampled. These waters are generally suitable for irrigation of most cultivated species.

- Class C3S1, which includes six water points that come exclusively from wells (PD1, PD2, PM1, PM2, PS1 and WP). This class represents 46% of sampled water points. Generally, these waters cannot be used for irrigation without prior dilution with low salinity water.

From Doneen diagram (Figure 5), in which total concentrations of ions were plotted against the permeability index (PI), three (03) classes were differentiated. According to **[29]** in terms of permeability index, class III represents best type of water for irrigation. It includes two (02) water samples (FD and FS). Class II represents intermediate quality water and is probably used for irrigation, with some precautions. It includes four (04) water points (PW2, FW, PW3 and WP). Class I which represents water unsuitable for irrigation contains seven (07) water points (FM, PS2, PD2, PM2, PD1, PM1 and PS1). All these points are located in class C3S1 (Figure 4), thus confirming fact that these waters are quite bad for irrigation in their raw state and they are likely to have a negative influence on both soil and plant yield if certain precautions are not taken. Moreover, 54% of water samples belong to class I, 31% to class II and 15% to class III.

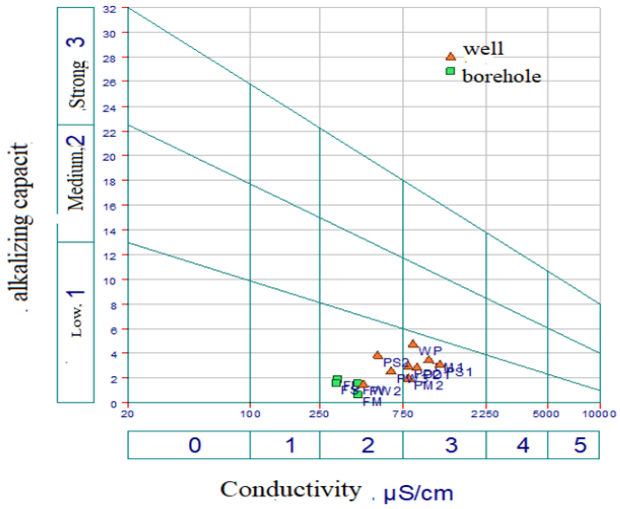
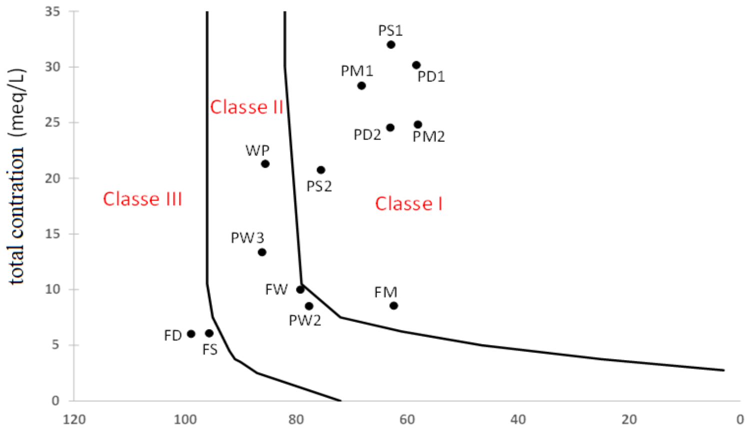


Figure 4: **Riverside diagram (Richards, 1954) of groundwater in irrigated areas**



$$P.I. = \frac{Na^{+} + \sqrt{HCO_3^{-}}}{Ca^{++} + Mg^{++} + Na^{+}} \times 100$$

Figure5: Classification of water for irrigation (Doneen, 1962).

Conclusion

Results of chemical analysis show that some parameters have levels above standard set by **([1]; [2])** Thus, for NO3-, 54% of water points have levels above 50 mg/l (WHO) and about 77% have levels above 10 mg/l (FAO). 54% of water points have NO_2^- levels above 0.1 mg/l. Approximately 23% of water points have NH_4^+ levels > 0.5 mg/l (WHO) and all water points (100%) have levels within range of standards (FAO). Concerning PO_4^{3-}, 46% of water points have levels higher than 0.50mg/l (WHO) and about 23% have levels higher than FAO standards.

The presence of pollution indicators in significant quantities in some water points show that contamination of water table in irrigated areas is undeniable. The presence of several water facies in the study area attests to presence of an interaction of several mineralization processes. According to

analysis of water quality parameters for agricultural activity, all our water points (100%) are suitable for irrigation according to values of the corrosivity ratio (CR). For Kelly ratio (KR), 23% of waters are unsuitable for irrigation while for percentage of sodium (% Na), 15% of waters are good, 77% are acceptable and 8% are unsuitable for irrigation. Wilcox plot allows us to say that groundwater is overall suitable for agriculture. The Riverside diagram identified two classes of water, namely class C2S1 corresponding to waters of medium salinity and therefore with a low risk of alkalization, it represents 54% of sampled waters and class C3S1, which represents highly mineralized waters but with a low risk of alkalization of soil. This class represents 46% of sampled waters. In Doneen diagram, 54% of water samples belong to class I, 31% to class II and 15% to class III.
At the end of this work, we recommend that government carry out regular monitoring of groundwater and control use of chemical fertilizers in irrigated areas in order to limit degradation of water table.

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