International Journal of Research in Agriculture and Forestry
Volume 2, Issue 8, August 2015, PP 55-64
ISSN 2394-5907 (Print) & ISSN 2394-5915 (Online)

Ground Water Suitability for Irrigation in the Korama Basin, Southern Zinder, Niger

Issoufou SANDAO[1, 4], Maman Sani ABDOU BABAYE[2], Boureima OUSMANE [1], Jean Luc MICHELOT[3]

[1]*Department of Geology, Faculty of Science and Technology, Abdou Moumouni University, Niamey, Niger*
[2]*Department of Geology, Faculty of Science and Technology, Dan Dicko Dan Koulodo University, Maradi, Niger*
[3]*Laboratory of Hydrology and Isotope Geochemistry, UMR Orsay Terre CNRS, Paris-Sud University, apart. 504, 91405 Orsay, France*
[4]*Department of Water Resources, Ministry of Water Resources and Sanitation, Niamey Niger,*

ABSTRACT

In the Korama basin, groundwater is the main source of water supply for urban and rural populations and their livestock. However, following recurrent droughts over three decades having significantly reduced agricultural production, political authorities have opted for development of irrigated agriculture from groundwater, in order to fight against food insecurity. Also, it is necessary to know the suitability of water for irrigation. To this end, forty-two (42) water points were sampled to determine the physiochemical characteristics of different water tables.

The analysis and processing of these physiochemical data by methods of conductivity, salinity, Sodium Residual (SAR), and Residual Carbonates have allowed to find that water is poorly mineralized in the area, and is generally of good quality (suitable) for irrigation.

Keywords: hydrogeology, suitability, irrigation, Korama, Zinder, Niger

INTRODUCTION

In the Korama basin, groundwater is the main source for water supply of urban and rural populations and their livestock. But since the 1973-1974 great droughts, rainfall deficits that have followed each other have led to a drastic reduction in rain-fed agricultural production. Also, to meet food needs, Sahel countries including Niger have gone in for agriculture development from groundwater.

The high water potential of the Korama Basin led the population and authorities to launch several projects in the field of small-scale irrigation. This study's main objective is the characterization of physicochemical parameters and the assessment of suitability of groundwater for irrigation.

PRESENTATION OF THE STUDY AREA

Location and Climatic Context in the Area

The study area, the Korama basin, corresponds to the western end of Lake Chad basin, and straddles Niger and Nigeria border. Covering an area of about 120,000 km2, the Korama basin, lying east to west, is limited to the north and east by outcrops of the Damagaram Mounio Precambrian basement, to the west through the Iullemenden basin sedimentary formations, and to the south by the Niger-Nigeria border.

With a density of 110 inhabitants per km2, it is one of the most populated areas in Niger. The main socioeconomic activities are: agriculture, predominantly rain-fed crops (millet, sorghum, maize, beans), with nevertheless an important development of irrigated crops (market gardening, sugarcane) from groundwater, livestock, trade and handicrafts.

The climate in the area is Sahel type with a short rainy season of four months (June to September), and a long dry season of about eight months (October to May). The annual rainfall amounts increase

Address for correspondence:

sandaoissoufou@gmail.com

from north to south, with an average over the period 1930-2011, from 500 mm to the synoptic station of Zinder Airport, north of the basin, and over 600 mm in Magaria Weather station, south of the basin. However, these precipitations are characterized by a high space and time variability.

In this endorheic basin, the well-structured hydrographic network includes Korama River and its tributaries. These streams in the process of fossilization are only represented by strings of ponds in places, even in the rainy season.

Geological and Hydro-Geological Contexts of the Korama Basin

In the Korama basin, the sedimentary series topping the crystallophyllian formations of the Damagaram Mounio Precambrian basement consists [1], [2], [3] of: (i) Continental Intercalaire / Continental Hamadien ferruginous claye[y sandstones, dated from Cretaceous, in the north-western part, (ii) Tertiary Continental Terminal clays sandstones in the southwest, (iii) Early Quaternary pink sandstone clay, known as Mallawa sandstones, to the south and southeast, and finally (iv) alluvial sands, ranging from average to coarse grained, being the most recent deposits, in the center of the basin.

The main aquifers of the Korama basin [4], ***(figure 1)*** are:

- the discontinuous aquifers of the crystallophyllian basement ;
- the aquifers of the ferruginous clayey sandstones of the Continental Intercalaire / Continental Hamadien;
- the aquifers of the Continental Terminal clay and sandstones;
- the aquifer of the early Quaternary sandstone and clays or Mallawa sandstones;
- The aquifer of recent sands, the largest in extension and containing most of available water reserves in the basin.

The depths of static levels vary from 0 to 10 meters at the alluvial aquifer and recent sands, and from 15 to over 30 meters in the basement aquifers, Continental clayey sandstone and Mallawa sandstone [5].

The piezometric map (***figure 2***) shows that all aquifers have the same flow direction, which is globally directed east-west. It appears on this piezometric map, 3 domes located north-east respectively, center and south west of the Basin. These domes appear to meet the main aquifer recharge areas. Furthermore, there is a piezometric depression southeast, in Mallawa clayey sandstone which would be the outlet of groundwater in the basin.

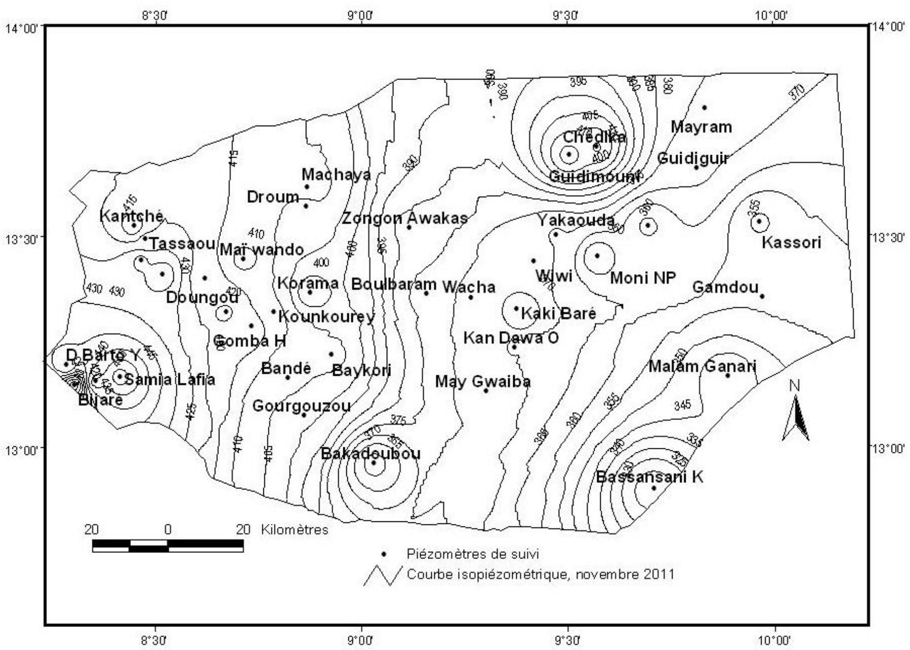

Figure2. *Korama basin piezometric map in November 2011*

The heights of seasonal fluctuations in water levels measured during the period 2009 to 2011 are very low (a few centimeters) or zero in Mallawa sandstone water tables (southeast) and Continental Hamadian sandstone (North West). On the contrary, for sandstones of the Continental Terminal aquifers and alluvial and recent sands, these fluctuations could reach one (1) meter high.

These results suggest that the direct recharge (rainwater) or indirect (transfers between water tables) for water tables of Mallawa and sandstone and Continental Hamadian sandstones Mallawa is either, low or non-existent or equivalent to samples (natural flow and various water needs). As for the alluvial aquifer and recent sands, this recharge by infiltration would be significant and much above the samples.

MATERIALS AND METHODS

Materials

Used Data

The implementation of this study required the use of the following data:

- data sheets and geological cross sections of structures established during water points achievement campaigns, which allowed to identify the lithological characteristics of aquifers;
- data from piezometric monitoring campaigns, through an optimal network of 53 piezometers, represented on the map in figure 1 [6] ;
- analytical results for chemical elements of 42 groundwater samples, collected in October 2011 in accordance with sampling and in situ measurement protocols defined in [7]. The sampled water points are shown in the map in (figure 3);
- values of water physical parameters, measured in situ during the sample collection;
- results of topographic leveling of the piezometric network, made with differential GPS, to get altitudes of monitoring and sampling items;

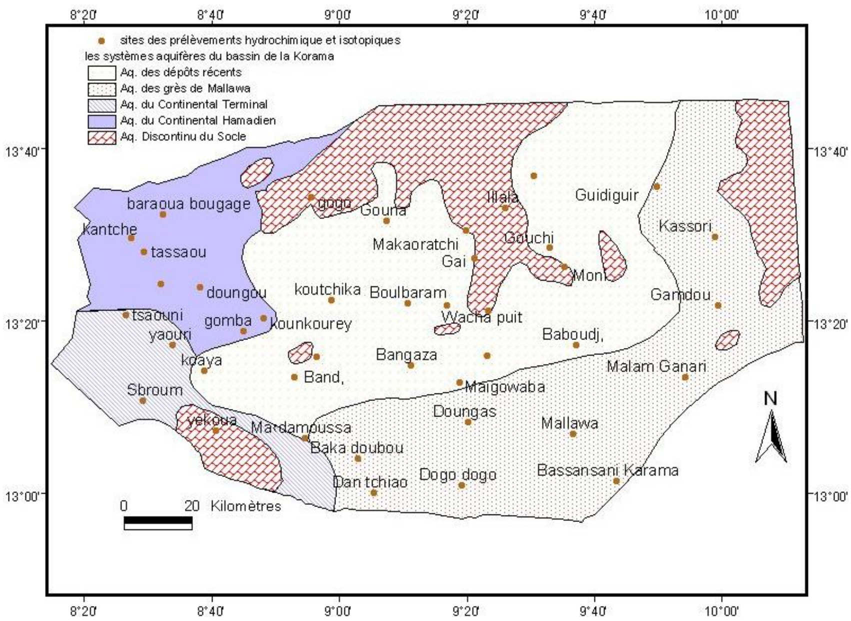

Figure3. *distribution map for the 42 chemical sampling sites, October 2011*

Tools Used

The tools used in this study are:

- The various computer software including: Excel, Word, ARCGIS; Diagram;
- The leveling equipment and GPS;
- The leveling equipment of water samples and measurements of physicochemical parameters (pH meters, conductivity meters) in situ;

- Analytical laboratories of water physicochemical parameters (Department of Geology of Abdou Moumouni University in Niamey, Regional Directorate of Hydraulics in Zinder). ***For chemical parameters, the major ions are determined;***
  - ✓ Calcium ions (Ca^{2+}) and Magnesium (Mg^{2+}), determined by titration with the corresponding specific reagents;
  - ✓ Potassium ions (K^{+}) and Sodium (Na^{+}) weighed up by flame photometry with JENWAY PFP7 spectrophotometer;
  - ✓ Total iron ions (Fe^{2+} and Fe^{3+}), nitrates (NO_3^{-}), nitrites (NO_2^{--}), fluoride (F^{-}), sulfates (SO_4^{--}) and chloride (Cl^{-}), weighed up by spectrophotometric method with the DR 2800 spectrophotometer.

The analytical results are validated by calculating the ionic balance with an error of ± 5%.

Methods

The methodological approach is as follows:

Calculating the Sodium Absorption Ratio, SAR, [8].

It is given by the following relationship:

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

Na, Ca and Mg concentrat ions are expressed in meq/l

SAR indices written in Richard Wilcox chart, allow to distribute water in four (4) classes according to their suitability for irrigation (***table 1***). This classification is completed by the total water salinity (electric conductivity, C)

Table1. *Classification of water for irrigation, according to the SAR values and conductivity*

Class	SAR Value	Suitability of water for irrigation
S1	From 0 to 10	Water with low salinity risk, and suitable for all soils
S2	10 to 18	Water with average salinity risk, can only be used for salinity-tolerant plants and for aerated and permeable soils
S3	18 to 26	Water with high alkalizing risk, can only be used for very tolerant plants and well-drained soils and with the addition of organic matter
S4	Above 18	Water with a very high alkalizing risk, unusable for irrigation
Class	**Conductivity value**	**Suitability of water for irrigation**
C1	Below 250 Sµ /cm	Low conductivity, water without salinity risk
C2	From 250 to 750 Sµ /cm	Average conductivity, water usable for tolerant plants
C3	From 750 to 2250 µS/cm	High conductivity, high salinization risk may only be used for very tolerant and well-drained soil plants
C4	Above 2250 Sµ/cm	Very high conductivity, water not suitable for irrigation

(Richards L. A. 1954)

Calculating Sodium Ratio

This calculation, performed according to the Wilcox L.V. 1948 method [9], is based on the following expression:

$$Na.(\%) = \frac{Na}{Ca + Mg + Na + K}.100 \quad (2)$$

The Wilcox diagram (total mineralization or TDS in mg/l on x-axis and the sodium ratio on y-axis), allows to distribute water into five (5) classes (excellent-good, good-possible, possible-doubtful, doubtful-unsuitable (poor), and improper or bad) depending on their suitability for irrigation (***table 1***)

Method of Residual Sodium Carbonate (RSC)

RSC indices are determined by the relation:

$$RSC = (CO_3 + HCO_3) - (Ca + Mg) \quad (3)$$

This RSC method allows to identify the three (3) following water classes:

- RSC below or equal to 1.25: good quality water for irrigation;
- RSC between 1.25 and 2.5: average quality water for irrigation;
- RSC above or equal to 2.5: salty water unsuitable for irrigation.

RESULTS AND DISCUSSION

Physical Parameters of Groundwater in the Area

The values of groundwater physical parameters, measured in situ (conductivity, pH, and temperature), (**table 2**) show that:

- The values of groundwater conductivity in the Korama basin vary from 51 to 825 µs/cm, with an average of 221 µs/cm. These values show that more than 95% of water have conductivity below or equal to 750 µs/cm. This is water which is within good and excellent classes for irrigation;
- Groundwater in the area is generally acidic or rarely neutral (pH below or equal to 7 pH units). This parameter has not been specifically studied by the use of such water for irrigation;
- The values of groundwater temperature, between 20 and 27 °C, are close to annual average values of the atmospheric temperature in the area. These temperatures do not seem to have side effects on suitability of water for irrigation.

Groundwater Chemical Parameters

The values of the total mineralization of the 41 water points vary from 25.5 to 508.2 mg /l, with an average of 142.5 mg /l (table 2).

Thus, for 32 out of the 42 samples analyzed, that is 76%, the total amount of dissolved salts remains less than or equal to 200 mg/l. This result confirms the low groundwater mineralization in the Korama basin, already illustrated by conductivity measurements [3].

The chemical water profile according to the Piper diagram (figure 4) [10], is mainly calcium bicarbonate type.

Table2. *Results of chemical analyzes of groundwater samples, collected during the sampling campaign in October 2011*

						Physical parameters measured in situ			Chemical parameters in mg/l, October 2011 samples										
N°	**Locality**	**PEM**	**Latitude**	**Longitude**	**NS**	**T (°C)**	**pH**	**C (µs/cm)**	**Ca**	**Mg**	**Na**	**K**	**Fe**	**Cl**	**SO4**	**HCO3**	**NO3**	**NO2**	**F**
1	Baraoua bougagé	Well	13,59876	8,54004	38,24	21	6,60	347,00	16,8	7,28	4,13	11,75	0,53	1,1	6	99,43	8,36	0,009	0,13
2	Kanthé pc	Well	13,53917	8,45889	14,22	27	6,80	265,00	24	2,88	9	10,2	0,07	5	0	112	5,28	0,006	0,37
3	Kantché boring	boring	13,56000	8,47000	16,00	27	7,02	457,00	33,6	12,4	18	18,75	0,03	3,4	14	207,4	6,16	0,01	0,67
4	tassaou	boring	13,50417	8,49194	5,07	27	6,90	227,00	20,8	1,92	6	2	0,03	9,5	0	67	10,1	0,003	0,24
5	Tsaouni	boring	13,33972	8,44528	30,10	21	5,70	51,00	3,2	0,96	2	0,5	0,06	3	0	12,2	4	0,006	0,29
6	Godo haoussa f	boring	13,42028	8,53417	21,00	26	5,60	158,00	8,8	2,88	5	1,5	0,05	7,5	0	22,5	12	0,02	0,28
7	Godo haoussa pc	Well	13,42028	8,53517	21,15	20	6,00	192,00	12,8	2,88	7	3	0,04	7	0	36,6	14	0,35	1,3
8	Kounkourey	Well	13,33222	8,80500	2,85	20	7,30	2 190,00	184	37,44	165	134	0,06	170	260	500,2	12	0,27	0,88
9	Gomba	Well	13,29861	8,75000	5,36	27	6,90	825,00	30,4	15,06	70	45	0,04	76	48	109,8	113,5	0,01	0,38
10	yaouri	boring	13,26111	8,56722	14,00	27	6,10	52,00	1,2	0,96	3,6	1,7	0,05	3	0	7,93	7	0,01	0,22
11	Koaya	Well	13,19556	8,64889	14,84	27	5,40	91,00	6,2	1	4	2,5	0,19	6,5	4	24,4	0,44	0,015	0,04
1	Sbroum	Wel	13,11	8,4883	23,	27	5,29	54,00	2,4	1,2	2,5	1	0,	2	0	15,8	0,4	0,0	0,

2		l	833	3	65								08			6	4	18	03
13	Yékoua	boring	13,04028	8,67861	17,97	27	5,42	85,00	4	2,88	2,5	2	0,06	2	0	26,84	4,4	0,015	0
14	Dan Tchiaou	boring	12,88028	9,09278	21,45	27	5,72	54,00	3,2	2,88	2	1,5	0,04	2	0	24,4	2,64	0,09	0,03
15	Baka doubou	boring	12,96972	9,04944	20,78	27	5,80	151,50	9,6	6,2	4	2,5	0,06	9	18	36,6	1	0,012	0
16	Maidamoussa	boring	13,02222	8,91083	15,00	27	5,52	62,00	4	2	3,6	2	0,05	2	0	12,2	21	0,012	0
17	Bandé	Well	13,17944	8,88417	13,54	27	6,23	147,00	14,4	5,2	2,5	1	0,09	2	0	73,2	2,2	0,012	0
18	Beykori	Well	13,23056	8,94111	7,04	27	6,21	231,00	3,2	10,69	9	15,85	0,06	10,9	10	37	29,48	0	0,08
19	Bangaza	boring	13,21000	9,18778	6,00	27	6,20	58,50	4,8	2	2,5	1	0,07	2	0	31,72	0,44	0,015	0
20	Dirani	boring	13,27300	9,40000	5,00	27	6,12	195,00	14,4	6,7	6	6	0,04	8	0	26,62	60	0,015	0
21	Kakibaré	boring	13,35056	9,39000	2,00	27	5,20	157,80	4	1,4	21	1,5	0,05	12	2	18,3	31	0,02	0,21
22	Baboujé	boring	13,26111	9,61944	13,00	27	6,50	192,80	14,4	2,4	25	3	0,38	3	6	97,6	9	0,02	0,32
23	Moni	boring	13,46306	9,58944	6,10	27	6,40	103,00	0,8	5,82	6,76	3,5	0,2	0,8	0	35,4	16,72	0	0,1
24	Gouchi	boring	13,51472	9,54972	15,00	27	6,50	191,00	17,6	7,6	5	4	0,03	4	0	85,4	14	0,2	0,33
25	Guidimouni	boring	13,69994	9,50944	22,00	27	6,40	86,00	5,6	2,4	4	4	0,05	3	3	18,3	18	0,01	0,29
26	Illala Abdou	boring	13,61639	9,43556	16,30	27	6,90	590,00	48	17	30	8	0,08	14	29	250,1	18,5	0,01	0,71
27	Maigouaba	boring	13,16667	9,31556	3,34	27	6,80	74,00	4	2	4	2	0,09	2	0	24,4	9	0,02	0,22
28	Doungas	boring	13,06278	9,33778	23,00	27	6,60	85,00	8	2,4	3	1,5	0,03	2	7	29,2	6	0,01	0,33
29	Dogo Dogo	boring	12,90083	9,32222	35,00	27	6,50	102,00	0	9,72	5	2,5	0,07	2,2	0	46	11	0,007	0,24
30	Fagan Kaoua	boring	12,94500	9,66600	38,15	27	6,50	385,00	29	6,7	18	4	0,08	20	17	109,8	28	0,01	0,56
31	Mallawa	boring	13,03361	9,61139	23,00	27	6,50	282,00	21	4,3	25	3,5	0,03	9	34	97,6	5	0,009	0,8
32	Malam Ganari	boring	13,17917	9,90528	17,60	27	6,60	496,00	43,2	8	50	4	0,04	5	79	183	4,4	0,006	0,64
33	Gamdou	boring	13,36472	9,99028	7,3	27	6,70	240,00	17,6	8,2	9	3	0,13	5	6	85,4	12	0,01	0,39
34	Kousseirie	boring	13,54306	9,98306	25	27	6,50	108,00	7,2	2,4	4	2	0,03	3	0	27,4	11,4	0,06	0,32
35	Guidiguir	boring	13,67139	9,83056	9,1	27	6,70	135,00	2,4	9,24	6,76	4,25	0,01	0,6	8	61	5,72	0	0,1
36	Makaouratchi	boring	13,55833	9,33167	36	27	6,00	235,00	13,6	6,2	10	8	0,02	12	0	15,2	68	0,01	0
37	Gaï	boring	13,48556	9,35556	9,80	27	6,50	357,00	30,4	6,7	8	17	0,01	10	6	109,8	28,6	0,02	0,52
38	Wacha	Well	13,36583	9,28256	6,11	27	6,70	317,00	13	3,3	25	3,5	0,16	21	16	61	19	0,1	0,42
39	Boulbaram	boring	13,37000	9,18000	5,50	27	6,50	397,00	37,6	8,6	27	6	0,15	23	51	73,2	46	0,06	0,51
40	Koutchika	Well	13,37778	8,98167	1,91	27	6,80	385,00	26,4	7,2	50	10	0,16	8	19	201,3	2,64	0,88	0,76
41	Gouna	boring	13,58450	9,12425	5,60	26	6,14	180,00	12	3,3	12	2,5	0	3	5	36,6	35	0,01	0,55
42	Gogo	Well	13,64306	8,92833	3,00	26	6,50	217,00	24,8	4	20	5	0,56	6	9	85,4	38	0,01	0,62

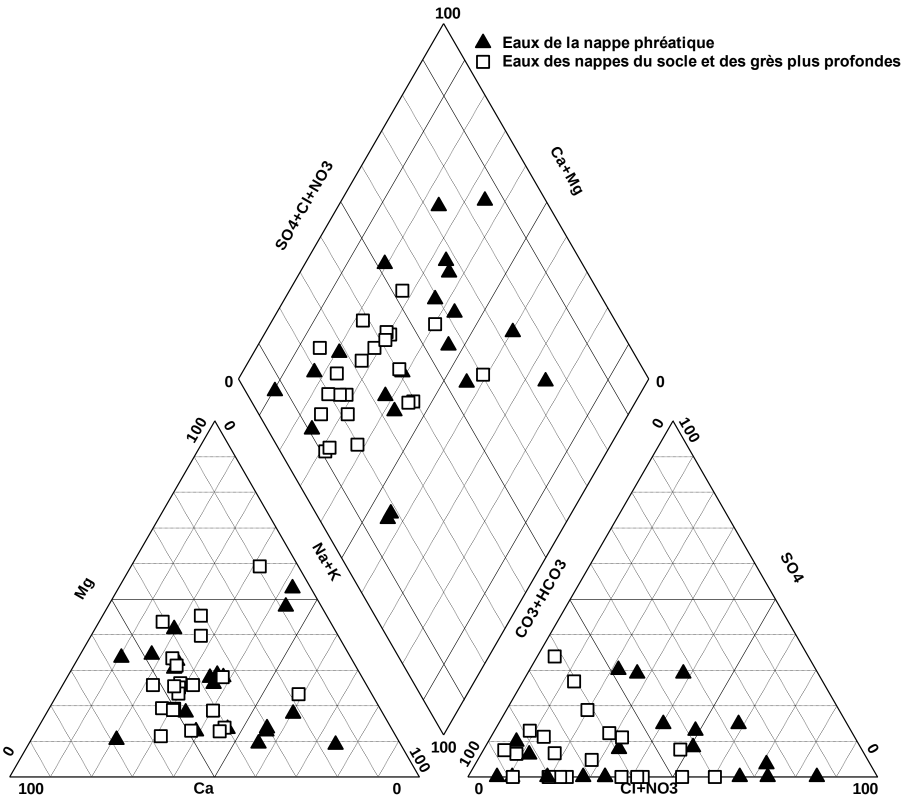

Figure4. *Piper diagram of groundwater in the area, in October 2011*

Suitability of Groundwater for Irrigation in the Korama Basin

SAR

SAR values vary from 0.1 to 2.05 (Table 3). Their representation on Richard Wilcox diagram (figure 5) shows that water is divided into S1C1 and S1C2 classes, corresponding to the following types:

- water with low sodium risk and of low Salinity, resulting in excellent quality water for irrigation;
- water with low sodium risk and of average salinity, resulting in water used for irrigation of salt-tolerant plants.

Table3. *Characteristic parameters of irrigation water (SAR, %Na and RSC)*

				Chemical parameters in meq/l					Water parameters for irrigation			
N°	Locality	Well type	Cond µs/cm	Ca	Mg	Na	K	HCO3	TDS mg/l	SAR	% Na	RSC
1	Baboujé	boring	193	0.72	0.20	1.09	0.01	1.60	161.12	1.14	54%	0.68
2	Baka doubou	boring	152	0.48	0.51	0.17	0.01	0.60	86.97	0.17	15%	-0.39
3	Bandé	well	147	0.72	0.43	0.11	0.00	1.20	100.60	0.10	9%	0.05
4	Bangaza	boring	59	0.24	0.16	0.11	0.00	0.52	44.55	0.17	21%	0.12
5	baraoua B	well	347	0.84	0.60	0.18	0.03	1.63	155.52	0.15	11%	0.19
6	Beykori	well	231	0.16	0.88	0.39	0.04	0.61	126.26	0.38	27%	-0.43
7	Boulbaram	boring	397,00	1.88	0.71	1.17	0.02	1.20	273.07	0.73	31%	-1.38
8	Dan Tchiaou	boring	54	0.16	0.24	0.09	0.00	0.40	38.78	0.14	18%	0.00
9	Dirani	boring	195	0.72	0.55	0.26	0.02	0.44	127.78	0.23	17%	-0.83
10	Dogo Dogo	boring	102	0.00	0.80	0.22	0.01	0.75	76.74	0.24	21%	-0.05
11	Doungas	boring	85	0.40	0.20	0.13	0.00	0.48	59.47	0.17	18%	-0.12
12	Fagan Kaoua	boring	385	1.45	0.55	0.78	0.01	1.80	233.15	0.55	28%	-0.20
13	Gaï	boring	357	1.52	0.55	0.35	0.04	1.80	217.05	0.24	14%	-0.27
14	Gamdou	boring	240	0.88	0.67	0.39	0.01	1.40	146.73	0.31	20%	-0.15
15	Godo H	boring	158	0.44	0.24	0.22	0.00	0.37	60.53	0.26	24%	-0.31
16	Godo H pc	well	192	0.64	0.24	0.30	0.01	0.60	84.97	0.33	26%	-0.28
17	Gogo	well	217,00	1.24	0.33	0.87	0.01	1.40	193.39	0.69	36%	-0.17
18	Gomba	well	825	1.52	1.24	3.04	0.12	1.80	508.19	1.83	51%	-0.96

19	Gouchi	boring	191	0.88	0.63	0.22	0.01	1.40	138.16	0.18	13%	-0.10
20	Gouna	boring	180,00	0.60	0.27	0.52	0.01	0.60	109.96	0.56	37%	-0.27
21	Guidiguir	boring	135	0.12	0.76	0.29	0.01	1.00	98.08	0.31	25%	0.12
22	Guidimouni	boring	86	0.28	0.20	0.17	0.01	0.30	58.65	0.25	26%	-0.18
23	Illala Abdou	boring	590	2.40	1.40	1.30	0.02	4.10	415.40	0.67	25%	0.31
24	Kakibaré	boring	158	0.20	0.12	0.91	0.00	0.30	91.48	1.63	74%	-0.01
25	Kantché	boring	457	1.68	1.02	0.78	0.05	3.40	314.42	0.48	22%	0.70
26	kanthé pc	well	265	1.20	0.24	0.39	0.03	1.84	168.81	0.33	21%	0.40
27	Koaya	well	91	0.31	0.08	0.17	0.01	0.40	49.29	0.28	30%	0.01
28	Kounkourey	well	2190	9.18	3.08	7.17	0.34	8.20	1463.85	2.05	36%	-4.06
29	Kousseirie	boring	108	0.36	0.20	0.17	0.01	0.45	57.81	0.23	24%	-0.11
30	Koutchika	well	385,00	1.32	0.59	2.17	0.03	3.30	326.34	1.57	53%	1.39
31	Maidamoussa	boring	62	0.20	0.16	0.16	0.01	0.20	46.86	0.26	30%	-0.16
32	Maigouaba	boring	74	0.20	0.16	0.17	0.01	0.40	47.73	0.29	32%	0.04
33	Makaouratchi	boring	235	0.68	0.51	0.43	0.02	0.25	133.03	0.40	26%	-0.94
34	Malam Ganari	boring	496	2.16	0.66	2.17	0.01	3.00	377.29	1.30	43%	0.19
35	Mallawa	boring	282	1.05	0.35	1.09	0.01	1.60	200.24	0.92	44%	0.20
36	Moni	boring	103	0.04	0.48	0.29	0.01	0.58	70.10	0.41	36%	0.06
37	Sbroum	well	54	0.12	0.10	0.11	0.00	0.26	25.53	0.23	33%	0.04
38	tassaou	boring	227	1.04	0.16	0.26	0.01	1.10	117.59	0.24	18%	-0.10
39	Tsaouni	boring	51	0.16	0.08	0.09	0.00	0.20	26.22	0.18	27%	-0.04
40	Wacha	well	317,00	0.65	0.27	1.09	0.01	1.00	162.48	1.13	54%	0.08
41	Yaouri	boring	52	0.06	0.08	0.16	0.00	0.13	25.67	0.42	52%	-0.01
42	Yékoua	boring	85	0.20	0.24	0.11	0.01	0.44	44.70	0.16	20%	0.00

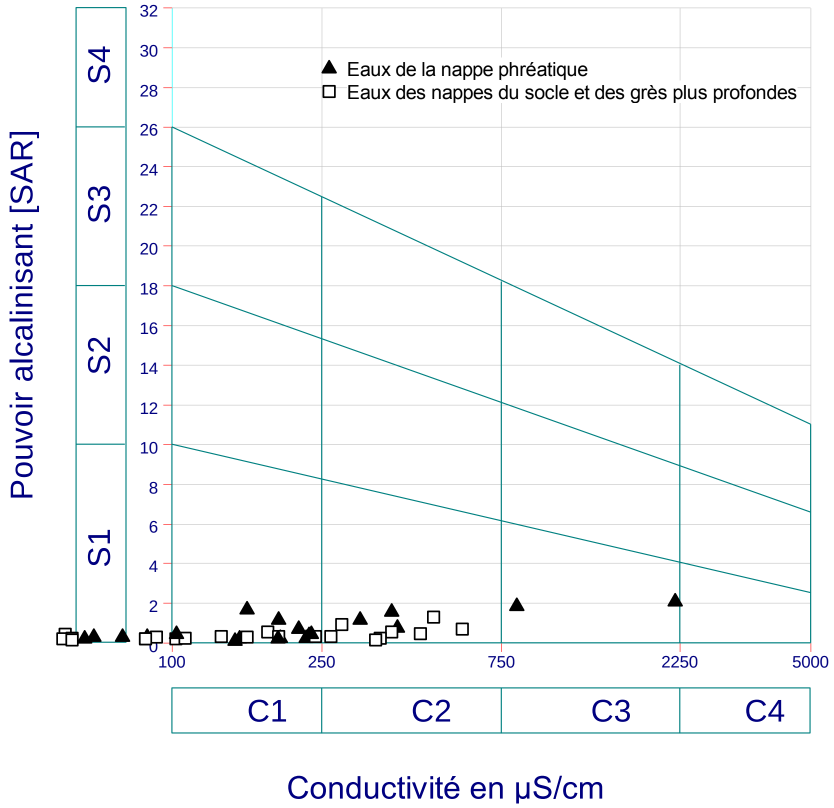

Figure5. *Richard Wilcox diagram of groundwater in the area in October 2011*

Nevertheless, water from cemented wells in Kounkourey and Gomba Hausa are placed in the S1C3 class, this is water with a high salinization risk, hence the need to control this water when it is used for irrigation.

Sodium Ratio (% Na)

The sodium ratio values (% Na) ranging from 9% to 74% (table 3) and written in Richard diagram (figure 6) show that all the water belongs to one type of irrigation water, "good to excellent", except that of Kounkourey site that is kind of "good to possible" water.

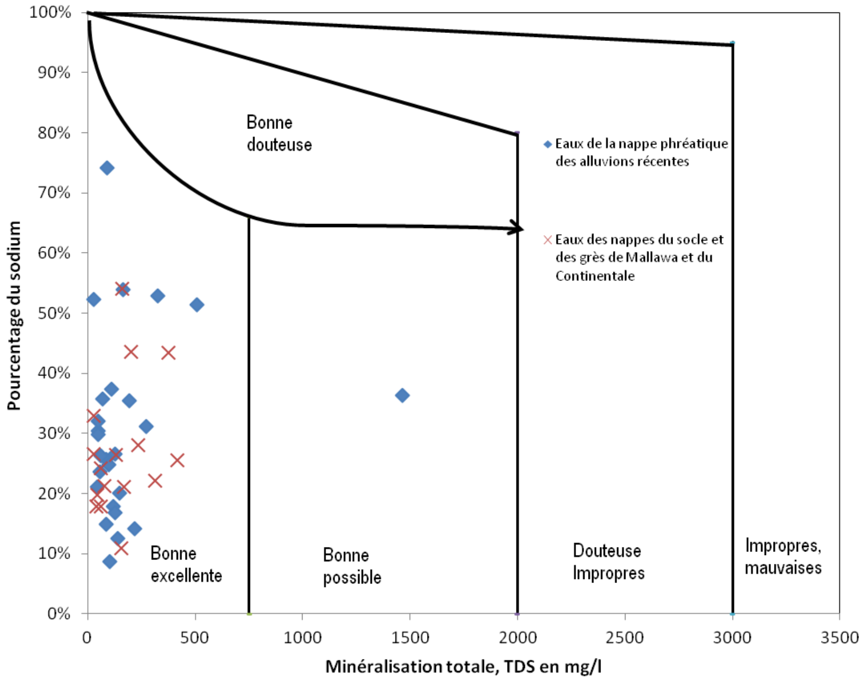

Figure6. *Richard diagram of groundwater in the Korama basin, October 2011*

Values of Residual Sodium Carbonate (RSC)

The values of Residual Sodium Carbonate (RSC) range from -4.06 to 1.39 (table 3). These results also show that over 98% of water has RSC values which are below 1.25. Therefore, this is good quality water for irrigation in its great majority. Thus, only water from Koutchika site, with an RSC value equal to 1.39, is in the class of medium quality water for irrigation.

CONCLUSION

Data from SAR calculations, Sodium ratio, total salinity and residual carbonates show that groundwater in the Korama basin do not have risks of irrigation use. Nevertheless, given the climatic conditions and the uncontrolled use of chemical fertilizers, this could result in degradation of water quality that would be likely to limit its use for certain activities including irrigation.

REFERENCES

[1] **GREIGERT J. (1972)** Atlas des eaux souterraines de la République du Niger. Etat des connaissances, BRGM report, 79 AGE001, Orléans, France

[2] **OUSMANE B. (1988)** *Etude géochimique et isotopique des aquifères du socle de la bande sahélienne du Niger (Liptako, Sud Maradi et Zinder Est),* Thèse de doctorat d’état, Université de Niamey. 175 pages ;

[3] **ZAKARA Z. (1990),** Contribution à l’étude hydrogéologique des nappes des Korama Zinder République du Niger, mémoire de diplôme de 3ème cycle du Centre d’Hydrogéologie, Université de Neuchâtel 90 pages

[4] **SOGETHA ou Société Générale des Techniques (1964**) les Koramas : reconnaissance hydrogéologique, annexes, figures et cartes, Ministère de l’Economie Rurale du Niger, 50 pages ;

[5] **SANDAO I. (2013***)* *Etude hydrodynamique, Hydrochimique et isotopique des eaux souterraines du bassin de la Korama : Sud Zinder, Niger : Impact de la variabilité climatique et des activités anthropiques*. Thèse de doctorat, Université de Niamey, 240 pages.

[6] **SANDAO I. (2010)** Contribution à la connaissance de l’état actuel des ressources en eau du bassin de la Korama : Sud de la Région de Zinder, mémoire de DEA, Université de Niamey, (2010) 96 pages.

[7] **GUILLAUME F., CHRISTIAN L. (2000)** Représentativité de l’échantillonnage géochimique et hydrodynamique en nappe libre de milieu semi-aride. In Journal of hydrology, 31(4), pp 669-678

[8] **Richards L. A. (1954),** Diagnosis and improvement of saline and alkali soil. Agric handbook 60 USDA, Washington DC, p 160.

[9] **SIMLER R., 2012,** Logiciel "Diagrammes" http://www.lha.univ-avignon.fr/LHA-logiciels.htm, (consulté le 15 mai 2013)

[10] **Wilcox L.V. (1948),** the quality of water of agricultural use, US Dept Agriculture Technique. Bulletin 1962, Washington DC.

AUTHORS' BIOGRAPHY

Docteur SANDAO Issoufou, Department of Geology, Faculty of Science and Technology, Abdou Moumouni University, Niamey, Niger