

Study of physicochemical parameters and level of cadmium and lead contamination in irrigation water in market garden areas in West Burkina Faso

Issaka SENOU^{1,2*}, Mamadou NIMI³, Souleymane SANOGO⁴, Hassan B.NACRO⁵, Antoine N. SOME¹

¹Laboratoire des Systèmes Naturels, des Agrosystèmes et de l'Ingénierie de l'Environnement (Sy.N.A.I.E), Institut du Développement Rural (I.D.R), Université Nazi BONI (U.N.B) Bobo-Dioulasso, BP 1091, Bobo-Dioulasso, Burkina Faso

²Institut des Sciences de l'Environnement et du Développement Rural, Université de Dédougou (UDDG), BP : 176, Dédougou, Burkina Faso

³Laboratoire de géochimie du Bureau des Mines et de la Géologie du Burkina (BUMIGEB), Bobo Bobo-Dioulasso, Burkina Faso

⁴Laboratoire de Recherche et de Formation en Pêche en Faune (La.R.F.P.F), Institut du Développement Rural (I.D.R), Université Nazi BONI (U.N.B) Bobo-Dioulasso, BP 1091, Bobo-Dioulasso, Burkina Faso

⁵Laboratoire d'étude et de recherche sur la fertilité du sol (L.E.R.F), Institut du Développement Rural (I.D.R), Université Nazi BONI (U.N.B); BP 1091, Bobo-Dioulasso, Burkina Faso

*Corresponding author

Abstract— The market gardening areas of Kodené and Dogona are among the main market gardening sites in the city of Bobo-Dioulasso (Burkina Faso). On these vegetable perimeters, the forms of water mobilization for irrigation are essentially wells for the Kodené site and wastewater from sewers for Dogona. In order to assess the physico-chemical quality and the level of cadmium and lead contamination in these waters, samples were taken at different points on each site and outside the site. The method used is based on the sampling of water in 0.5 liter polyethylene bottles, previously rinsed twice with the sample to be taken. The first samples are used to rinse the bottles and perform physical field analyzes which are pH, electrical conductivity (CE), temperature, salinity, turbidity and total dissolved solids (TDS). Each sample was acidified with pure analytical concentrated nitric acid (HNO₃) (0.5 cm³ in 0.5 liters of water) which was used to determine the metals. Physico-chemical analyzes and the level of cadmium and lead contamination were carried out. The results of these analyzes were processed using hydrochemical techniques (Piper diagram). Principal Component Analysis (PCA) has also been used to highlight the phenomena of mineralization of water in these market gardening areas.

The results obtained show that these irrigation waters are acidic at the Kodené site (pH = 5.49) and basic for the Dogona site (pH = 7.95). They are weakly mineralized at the Kodené site with an average conductivity of 52.56 4μS / cm and strongly mineralized at the market garden area of Dogona with an average conductivity of 508.4 4μS / cm. The cadmium and lead contents are sometimes higher than those recommended by the WHO (0.01 mg / L for cadmium and 0.003 mg / L for lead). The chemical facies give sodium calcium water. The value of the sodium absorption ratio (11.85) of the water at the Dogona site and that of the pH (5.49) at the Kodené site show that the irrigation water is chemically unsuitable for agricultural use during the dry season.

Keywords— Bobo-Dioulasso, Kodené and Dogona market gardening sites, irrigation water, physicochemical quality, heavy metals, dry seasons.

I. INTRODUCTION

The last decade has seen rapid growth in the populations of cities in developing countries. This demographic

explosion associated with advanced urbanization and development subjects populations to difficulties relating to the supply of fresh food products and the availability of

exploitable land (Bremner, 2012) for agriculture. It also results in ever-increasing wastewater flows that surpass current management, treatment and handling capacities (Huibers et al., 2001). Added to this is the climatic changes observed in recent years, characterized by the increase in average temperature and the scarcity of rains, which have as a corollary the degradation of the quality and availability of water (Denicola and al., 2015). In cities in Africa and Latin America, water scarcity and the food crisis are the major causes behind the use of wastewater and groundwater for irrigation. In sub-Saharan Africa, all the countries of the Sahel strip face a relatively long dry season (Sou, 2009). During this period, the food supply of urban areas is mainly provided by urban and peri-urban agriculture (AUP). Large volumes of wastewater produced in homes, hospitals or industries are discharged into open channels without prior treatment and these waters are often perennial and accessible water resources during the dry season to allow the realization of the agricultural activity (Sou, 2009). The same is true for groundwater, which is difficult to access and most often it dries up in wells and boreholes.

The use of wastewater in urban agriculture overcomes the problem of significant water needs for agriculture, estimated at 70% of withdrawals, or even 95% in some developing countries. On the other hand, in sub-Saharan Africa, it is recognized that the potential of groundwater can further support the development of small and large-scale irrigation and thereby reduce poverty.

However, this wastewater is generally used without prior treatment or with a partial treatment thus promoting contamination of the vegetables. Wastewater contains many pollutants such as suspended solids, pathogenic microorganisms, heavy metals, pesticides, which can make this water unsuitable for irrigation (Khan et al., 2013; Gatto et al., 2015). Various substances, among which heavy metals such as cadmium (Cd), lead (Pb) see their contents increasing in soils (Braud, 2007). This study was initiated to assess the physico-chemical quality and contamination of irrigation water in market gardening areas in the West of Burkina Faso. It is based on the use of data from hydrochemical parameters and the presence of heavy metals (cadmium and lead) to characterize the level of contamination and the phenomena which are at the origin of water degradation.

II. MATERIALS AND METHOD

2.1. Study areas

The study was carried out in the west of Burkina Faso precisely in the city of Bobo-Dioulasso (04 ° 20'W, 11 ° 06'N, 405 m above sea level). The work took place on the market gardening sites of Dogona and Kodení. The perimeter of Kodení (3 ° 55'W, 12 ° 31'N, 449 m) is located at the exit of the town of Bobo-Dioulasso on the Bobo-Banfora axis. As for the Dogona site (3 ° 60'W, 12 ° 38'N, 385 m above sea level), it is located in the heart of the city of Bobo-Dioulasso. According to Fontes and Guinko (1995), Bobo-Dioulasso is located between the 900 and 1100 mm isohyets and characterized by a South Sudanese climate. Seasonally, we have a dry season from November to April and a rainy season from May to October. Average monthly minimum temperatures range from 18 ° C to 25 ° C in May. The location of the study sites is shown in Figure 1.

2.1. Sampling method

Water sampling was carried out during the dry season. It focused on well water for the Kodení site and surface water for the Dogona perimeter. At each site, we have identified five sampling points. In addition, on each perimeter, a control sample is taken from a water source located upstream. The samples were taken in polyethylene bottles of 0.5 liter capacity, previously rinsed two times, with the sample to be taken. The bottles are filled avoiding the appearance of air bubbles and hermetically closed after acidification of the sample with concentrated analytical pure nitric acid (HNO₃) (0.5 cm³ in 0.5 liters of water). Each bottle has a number on it that identifies the unique sample. All samples were kept in an icebox containing ice and transported to the laboratory the same day.

During sampling, the physical parameters of the water such as pH, electrical conductivity (CE), temperature, salinity, turbidity and total dissolved solids (TDS) were measured in situ. The equipment used in the field consists of a Star 4 pH meter for measuring pH and Eh, a Hach Sension 5 conductivity meter for measuring electrical conductivity (EC) and salinity (Sal).

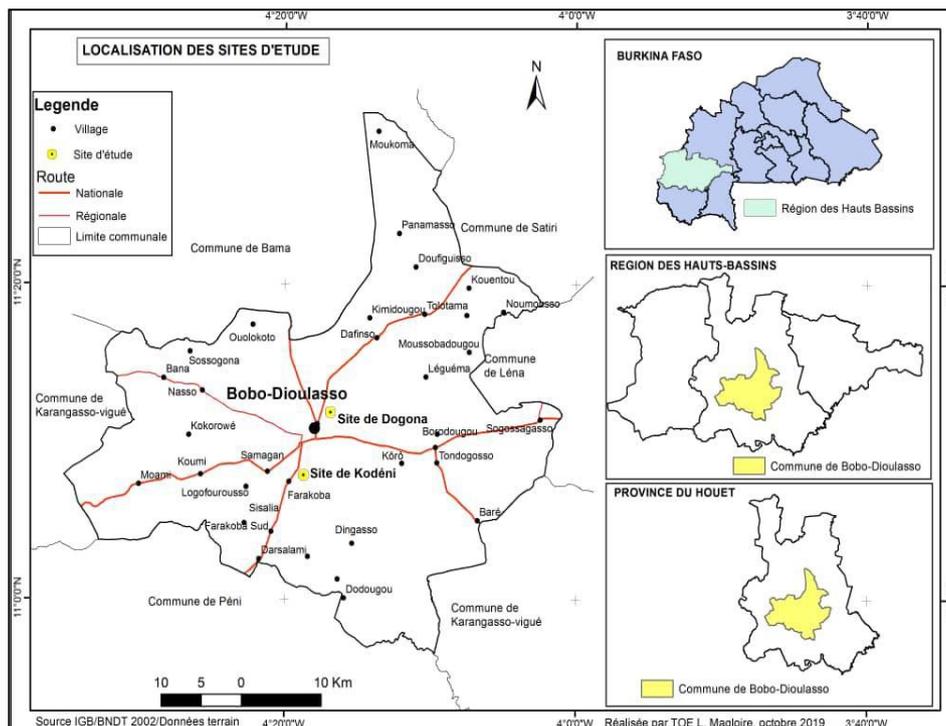


Fig.1. Location of study sites

2.3. Data analysis and processing

Once the samples were sent to the laboratory, we proceeded to determine the chemical parameters using an atomic absorption spectrometer.

The chemical parameters were measured using the Perkin Elmer model AAnalyst 100 brand atomic absorption spectrometer.

The method consists in determining the concentration of metallic elements (alkali metals, alkaline earth metals, transition metals) as well as the metalloids in a sample. These are atomized using a flame supplied with a mixture of gases (air and acetylene). This makes it possible to quantify the elements sought on the order of ppm or ppb. However, there is no specific preparation to do before the determination because the samples used are already acidified in the field.

- For the determination of the Na⁺ and K⁺ ions, 8 cm³ of the acidified sample is taken in test tubes and then added 2 cm³ of cesium chloride in order to prevent interference. The whole is homogenized with stirring with a magnetic stirrer. Standards of 10 ppm, 20 ppm and 40 ppm are prepared under the same conditions. The reading is made just after calibration.
- For the determination of Ca²⁺ and Mg²⁺ ions, 8 cm³ of the acidified sample is taken in test tubes and then added 2 cm³ of lanthanum chloride in

order to prevent interference. The whole is homogenized with stirring with a magnetic stirrer. Standards of 10 ppm, 20 ppm and 40 ppm are prepared under the same conditions. The reading is made just after calibration.

- For the determination of the other cations (Cd and Pb), there is no preparation. It is enough to calibrate the device with the establishes of the element to be determined (standard 1 ppm, 2 ppm, 5 ppm, 10 ppm and 20 ppm), serve the acidified samples in test tubes and go to the correct reading after calibration.

The spectrometer is connected to a computer, on which software is installed which allows the handling of the device. All settings are made using the software interface. Following the calibration, a linear calibration curve is obtained, the linearity coefficient of which is 0.9999. After dosing the different metals, processing and validating the results obtained using quality control. The sodium absorption ratio was calculated using the formula of Berrouch (2011).

$$S.A.R = \frac{[Na^+]}{\sqrt{([Ca^{2+}] + [Mg^{2+}])/2}}$$

The data collected in the field and in the laboratory were treated using multivariate statistical methods coupled with hydrochemical methods. The hydrochemical method required the use of the Piper diagram for the hydrochemical classification of waters.

The statistical approach is based on the use of Principal Component Analysis (PCA) for the study of the phenomena at the origin of water mineralization. The analyzes were carried out on the basis of 12 variables which are: pH, Turbidity (Turb), TDS, Salinity, CE, Na⁺, K⁺, Ca²⁺, Mg²⁺, Cd and Pb.

III. RESULTS AND DISCUSSION

3.1. Results of the physico-chemical study and heavy metal content

The physico-chemical parameters and the cadmium and lead contents of the waters are given in Table 1.

3.1.1. Results of in situ measurements

The physical parameters of the irrigation water at the Kodení market garden site are shown in Table 1. On analysis of this, it emerges that the water from the Kodení market garden area is acidic with an average of 5.49 and that of Dogona is basic with an average of 7.95. Kodení waters have an average conductivity of 52.56 µS/cm compared to 508.4 µS/cm for Dogona waters. Dogona waters have the highest conductivities; these waters are highly mineralized. Only Dogona waters have a salinity with an average of 0.32. The waters of Kodení have a turbidity which varies from 13.61 to 29.88 NTU with an average of 21.43 NTU. As for the Dogona waters, they

have a turbidity varying between 58 and 196 NTU with an average of 102.2 NTU. As for TDS, it has an average of 81.8 and 864.64 mg/L respectively for the waters of Kodení and Dogona.

3.1.2. Results of chemical parameters of water

The cations studied in the waters of the market gardening perimeters of Kodení and Dogona are made up of Na⁺, K⁺, Ca²⁺ and Mg²⁺. Among these, the most important are the Ca²⁺ ions which represent 64.86% and 53.11 respectively in the waters of Kodení and Dogona. Next come sodium Na⁺ with 26.61% and 37.78% respectively at Kodení and Dogona. In Kodení waters, Mg²⁺ represent 4.99% and K⁺ 3.37%. On the other hand, at Dogona, the Mg²⁺ ions represent 2.51% against 6.58% for the K⁺ ions. The sodium absorption ratio (SAR) is 1.97 in Kodení waters and 11.85 in Dogona waters. The hydrochemical classification of water is presented by the triangular diagram of PIPER (Figure 2). Analysis of this diagram shows that the waters of Kodení and Dogona are mainly calcium and sodium facies.

3.1.3. Heavy metal content results

In this study, cadmium and lead represent the heavy metals analyzed (Table 1). In Kodení waters, mean values of 0.02 and 0.87 mg/L are noted respectively for cadmium and lead. These contents are respectively 0.013 and 0.904 mg/L for cadmium and lead. These different contents are higher than the WHO guide value (0.003 mg/L for Cd and 0.01 mg/L for lead).

Table 1 : Physico-chemical parameters and heavy metals of the irrigation water of the market gardening sites of Kodení and Dogona

Physico-chemical parameters	Control value		Average		Minimum		Maximum	
	Kdn	Dgn	Kdn	Dgn	Kdn	Dgn	Kdn	Dgn
Physical parameters								
pH	5.5	5.57	5.49	7.95	5.07	7.58	5.96	8.39
T (°C)	31.6	31.6	30.86	36.42	29.7	33.8	31.9	38.3
Ec (µS/cm)	21.6	21.6	52.56	508.4	17.8	339	81.6	712
Sal	0	0	0	0.32	0	0.1	0	0.5
TUR (NTU)	4.6	4.6	21.43	102.2	13.61	58	29.88	196
TDS (mg/L)	22	22	81.8	864.64	19	156	245	852
Chemical parameters (mg/L)								
Ca ²⁺	7.22	7.22	12.48	145.14	10.32	47.18	14.44	220.6
Mg ²⁺	0.11	0.11	0.96	6.87	0.07	6.2	2.02	7.43
Na ⁺	1.16	1.76	5.12	103.28	2	2.87	8.31	

							29.44	
K ⁺	0.38	0.38	0.65	17.97	0.16	2.87	1	23.61
SAR			Kdn = 1.97			Dgn = 11.85		
Heavy metals (mg/L)								
Cd	0	0.126	0.02	0.013	0	0	0.08	0.041
Pb	1.26	1.26	0.87	0.904	0	0	1.57	2.09

Kdn : Kodení **Dgn** : Dogona

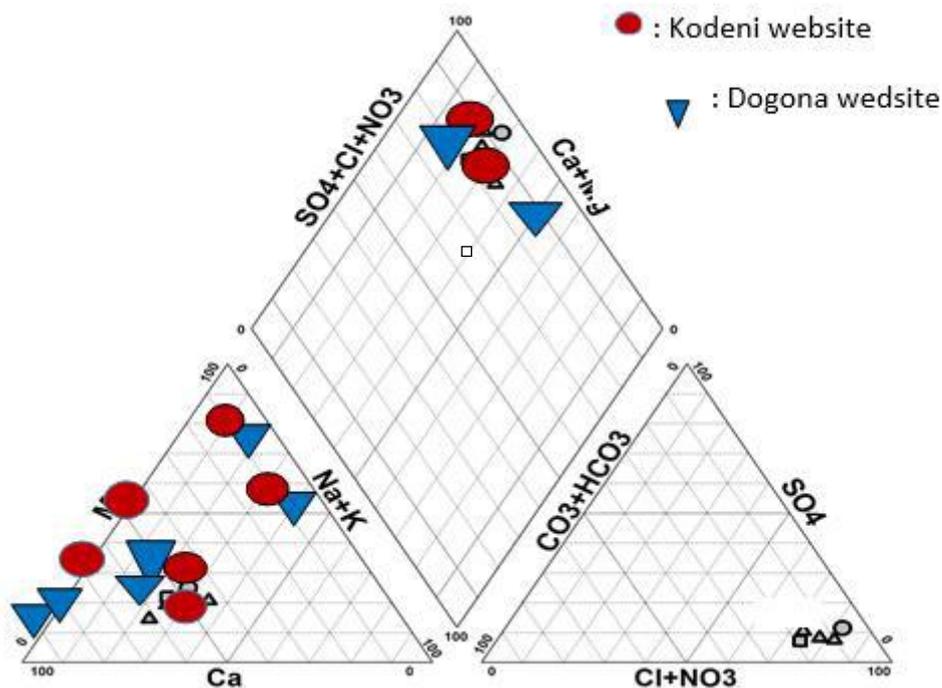


Fig.2: Hydrochemical classification of irrigation water at the Kodení and Dogona sites

3.1.3. Principal Component Analysis (PCA) for the irrigation water of study sites

➤ Kodení market garden site

The eigenvalues of the factors are presented in Table 2. The first three factors represent 92.65% of the variance expressed. These factors include the maximum of the variance expressed and are sufficient to accurately translate the information sought. The correlation matrix between the different variables is presented in Table 3. The correlation coefficient for the conductivity-sodium, conductivity-magnesium, conductivity-TDS, conductivity-salinity, salinity-magnesium, salinity-TDS, TDS-magnesium pairs, TDS-sodium, magnesium-sodium is

very strong ($r > 0.8$). Those for the pH-turbidity, pH-magnesium, temperature-calcium, salinity-sodium, potassium-sodium, potassium-cadmium couples are strong ($0.5 < r < 0.8$). The other correlation coefficients between the measured parameters are medium or low.

The analysis of PCA variables in the factorial plane F1-F2 is presented in Figure 3. This graph highlights two major groupings of the parameters studied in the water withdrawal points. The correlation formed by the axes F1 and F2 gives 71.95% of the total information. The first group which takes into account the pH, turbidity, calcium, temperature, magnesium, sodium, TDS, salinity and potassium and the second, cadmium and lead.

Table 2: Own values of the CPA

	F1	F2	F3	F4
Own values	5.558	3.076	2.485	0.881
Variability (%)	46.315	25.632	20.708	7.345
% cumulative	46.315	71.947	92.655	100.000

Table 3: Correlation matrix between variables

Variables	PH	Ec	T°C	Sal	TUR	TDS	Mg2+	Ca2+	K+	Na+	Cd	Pb
PH	1											
Ec	0,409	1										
T°C	-0,222	0,128	1									
Sal	0,229	0,979	0,159	1								
TUR	0,747	0,249	-0,470	0,073	1							
TDS	0,409	1,000	0,126	0,979	0,249	1						
Mg2+	0,529	0,944	0,307	0,878	0,359	0,944	1					
Ca2+	-0,620	0,183	0,532	0,357	-0,904	0,183	0,044	1				
K+	-0,113	0,492	-0,101	0,496	0,405	0,492	0,454	-0,140	1			
Na+	0,478	0,841	0,395	0,759	0,431	0,841	0,962	-0,064	0,552	1		
Cd	-0,663	-0,216	-0,012	-0,143	-0,019	-0,216	-0,238	-0,009	0,704	-0,060	1	
Pb	0,428	-0,434	0,021	-0,516	-0,042	-0,434	-0,315	-0,207	-0,924	-0,371	-0,765	1

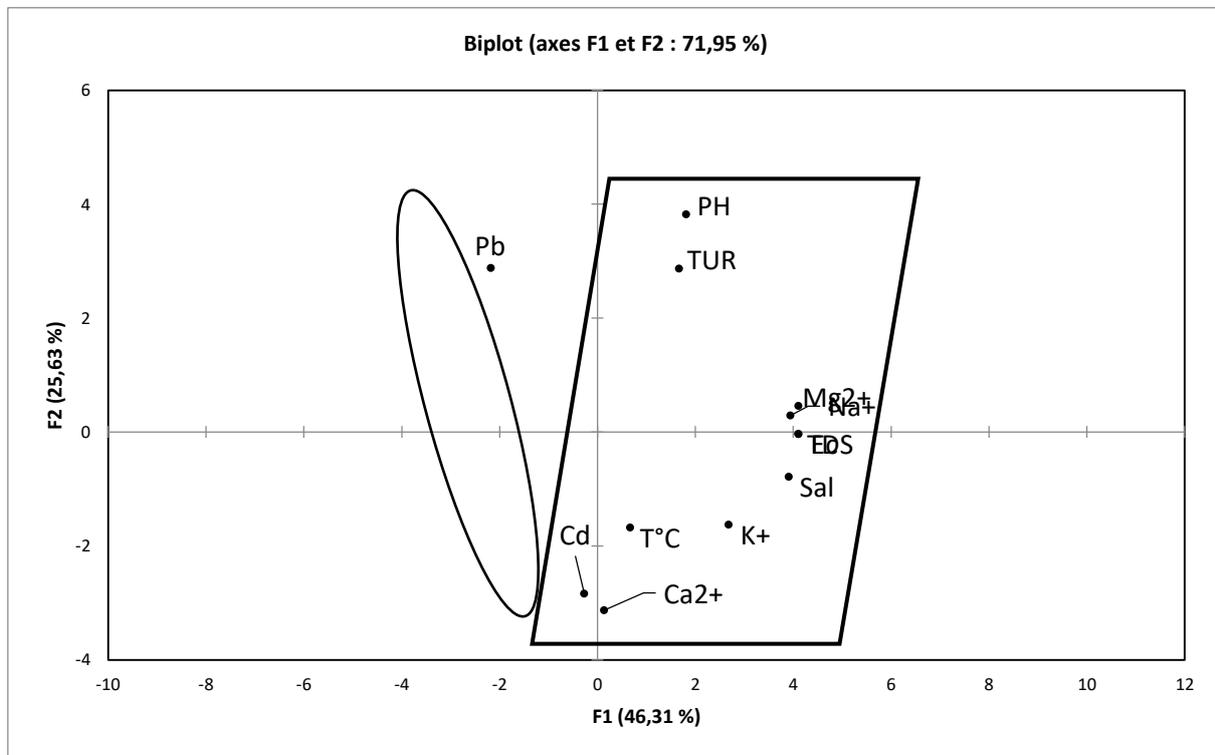


Fig.3: Analysis in the factorial plane F1-F2

➤ **Dogona market gardening site**

The eigenvalues of the factors are presented in Table 4. The first three factors represent 96.91% of the variance expressed. These factors also include the maximum of the variance expressed. Table 5 presents the correlation matrix between the different variables. The correlation coefficient for the pH-sodium, TDS-conductivity pairs is very high ($r > 0.8$). Those for the temperature-cadmium, turbidity-magnesium, magnesium-calcium, calcium-cadmium and sodium-lead couples are also strong ($0.5 < r < 0.8$). The

other correlation coefficients between the measured parameters are medium or low.

The analysis of the PCA variables in the factorial plane F1-F2 is presented in Figure 4. This graph also highlights two major groupings of the parameters studied in the water withdrawal points. The correlation formed by the axes F1 and F2 gives 77.87% of the total information. The first group takes into account turbidity, calcium, magnesium, potassium and TDS and the second group takes into account temperature, pH, sodium, lead and cadmium.

Table.4: Own values of the CPA

	F1	F2	F3	F4
Own values	4.888	3.677	2.094	0.340
Variability (%)	44.440	33.432	19.038	3.090
% cumulative	44.440	77.872	96.910	100.000

Table.5: Correlation matrix between variables

variables	Ph	Ec	T°C	Sal	TURB	TDS	mg2+	Ca2+	K+	Ca2+	Cd	Pb
pH	1											
Ec	-0,327	1										
T°C	0,794	-0,652	1									
Sal				1								
TURB	0,067	-0,71	0,135		1							
TDS	-0,334	1	-0,656		-0,71	1						
mg2+	-0,503	-0,589	-0,188		-0,589	-0,583	1					
Ca2+	-0,551	-0,359	-0,059		-0,022	-0,353	0,748	1				
K+	-0,408	0,48	-0,655		0,248	0,481	-0,122	-0,493	1			
Na+	0,813	0,272	0,452		-0,402	0,265	-0,902	-0,754	-0,143	1		
Cd	0,243	-0,758	0,631		0,115	-0,756	0,476	0,672	-0,908	-0,194	1	
Pb	0,197	0,451	0,289		-0,831	0,449	-0,733	-0,112	-0,278	0,563	-0,082	1

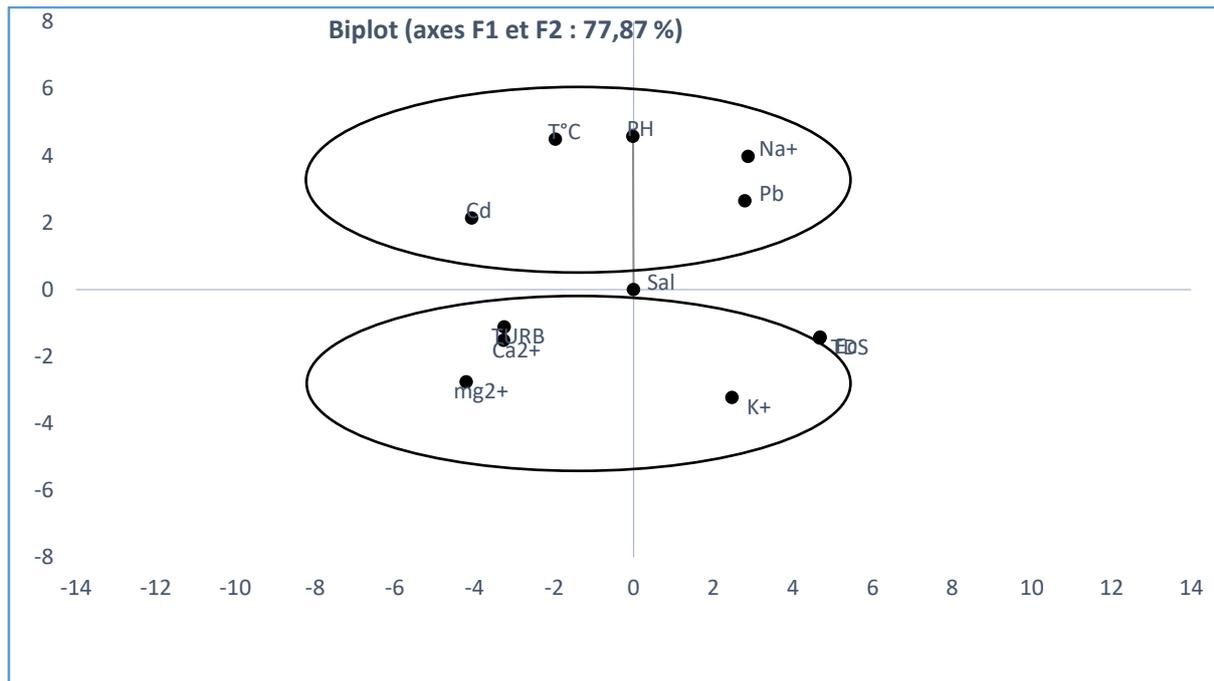


Fig.4: Analysis in the factorial plane F1-F2

3.2. Discussion

3.2.1. Physico-chemical characteristics of the irrigation water of the Kodeni and Dogona market gardening sites

The average temperature of well water (30.86 °C) is close to that of the control well (31.6 °C) and different from that of wastewater (36.42 °C). This difference in temperature of the water from the two sources is explained by the fact that the water from the wells benefits from the shade created by the shrubs present on the site while the wastewater coming from the city is exposed directly to the sun's rays. These observations are similar to those of Pazou *et al.* (2010) which stipulate that heat exchanges with the atmosphere are favored by exposure to the sun's rays. In fact, in dry periods, the ambient temperature increases due to the strong sunshine, which also affects the temperature of the irrigation water.

The pH value 7.95 at the Dogona site is higher compared to that of the waters at the Kodeni site (5.49). This difference could be explained by the effluents of water likely to increase the pH of water such as washing water, dishes, household toilets which are discharged into the gutters. This high pH of wastewater has already been reported by Gemmell and Schmidt (2010) for river water. The low pH of well water is linked to the geological nature and the chemical properties of the soil where the wells were located. Indeed, Matini *et al.* (2009) and Ahoussi *et al.* (2010) have shown that the acidity of water in the humid tropical zone is mainly linked to the decomposition

of plant organic matter, with the production of CO₂ in the first layers of the soil. Irrigating soil with such water can contribute to its acidification.

The average conductivity value is 508.4 μS/cm for wastewater and 52.56 μS/cm for well water. This difference shows a strong variation in the chemical composition of the waters between the two market gardening sites. These conductivity values indicate a strong mineralization of wastewater especially.

The waters of the Kodeni site have zero salinity; unlike the water at the Dogona site, which has a salinity of 0.32. These results corroborate those of Ahoussi *et al.* (2013) who showed zero value salinity in groundwater in the village of MangouinYrongouin (West of Côte d'Ivoire).

The value of the high turbidity in the wastewater on the market garden area of Dogona reflects the presence of particles in suspension in the water (organic debris, clays, microscopic organisms and urban waste), especially in the dry season there is diminution of the volume of water.

Their average TDS value is 81.8 mg/L for the Kodeni site and 864.64 mg/L for Dogona. The TDS values of the waters change in the same direction as the conductivity. This is explained by the waste discharged by the populations into the canal which serves as a water conduit on the perimeter of Dogona. These results are similar to the work of Senou *et al.* (2016) on the groundwater of a landfill in Bacau (Romania).

The average sodium absorption ratio (SAR) calculated at the two market gardening sites is 1.97 for the Kodeni

market garden site and 11.85 for the Dogona market site, respectively. Irrigation with water from the market gardening site of Kodené does not present enough risks because water with a SAR between 0 and 6 can generally be used on any type of soil, and this, without risk of accumulation of sodium. However, irrigation water from the Dogona site presents risks of sodium accumulation since water with a SAR of more than 9 should not be used even if the total salt content is relatively low (Benjelloun, 2013).

3.2.2. Contamination of irrigation water from market gardening sites with heavy metals

The results of the analyzes made in the waters of Kodené and Dogona gave lead concentrations respectively 0.87 mg/ L and 0.903 mg/ L. The concentration of cadmium is 0.02 mg/ L for the Kodené site and 0.013 mg/ L for Dogona. These concentrations of Cd and Pb in these irrigation waters are higher than the standards recommended by the World Health Organization (WHO) which fixes at 0.01 mg/ L and 0.003 mg/ L the admissible concentrations for the waters of irrigation. Similar results of heavy contamination of irrigation water by heavy metals have already been reported in the market garden area of Houeyiho in southern Benin (Koumolou et al., 2013).

This contamination of irrigation water at the Dogona market gardening site by heavy metals is believed to result from the dumping of household waste such as used batteries, cans, plastics, plant debris, dead animals, animal oils. Emptying into the gutters. The contamination of the water at the Kodené site could be explained by the fact that these wells are left in the open without protection. Pieces of used skips, sachets or boxes of pesticides (or even remnants of pesticides) and other garbage end up in the wells. In addition, the Kodené site is close to one of the industrial zones of the city of Bobo-Dioulasso, wells by the phenomenon of rainwater runoff can receive various types of contaminant.

IV. CONCLUSION

The data collected during our study made it possible to draw a portrait of the physico-chemical quality and the level of cadmium and lead contamination of the irrigation waters of two market gardening areas in the city of Bobo-Dioulasso (Burkina Faso). In the light of the results obtained at the level of the physico-chemical parameters measured in the waters, there is evidence of a deterioration in the quality of the waters. Indeed, the pH of the water is acceptable for the survival of living organisms, the

turbidity and the TDS, as for them remain very high in the waters of the market garden area of Dogona. These very high TDS contents made it possible to maintain the conductivity of the waters at such very high values. The average cadmium and lead contents are higher than those recommended by the WHO. With a SAR greater than 9, irrigation water at the Dogona site poses a risk of sodium accumulation and should not be used for irrigation. Positive correlations ($r > 0.8$) were also noted between the different parameters.

ACKNOWLEDGEMENT

The authors thank the Bureau of Mines and Geology of Burkina (BUMIGEB), National Geological Service for its contribution in the different stages of this work.

REFERENCES

- [1] Ahoussi K E, koffi Y B, Kouassi A M, Soro G., Biemi J. (2013). Hydrochemical and microbiological study of mountainous western spring waters of Côte d'Ivoire: Case of Village Mangouin-Yrongouin (under prefecture Biankouman). *Journal of Applied Bioscience* 63: 4703-4719.
- [2] Benjelloun E. (2013). Performance de l'irrigation localisée et son impact sur le sol dans le périmètre de N'fis. Mémoire de fin d'études. Option : Eau et Environnement. Faculté des sciences et Techniques –Marrakech. Université de Marrakech (Maroc). 57p.
- [3] Berrouch H. (2011). Etude de la qualité des eaux d'irrigation et du sol dans le périmètre de Sâada (Région de Haouz) UNIVERSITE CADI AYYAD. Mémoire de fin d'étude, 56p.
- [4] Braud A. (2007). Procédé de phytoextraction couplé à la bioaugmentation d'un sol agricole polycontaminé par du chrome, du mercure et du plomb. Thèse, Université de Haute Alsace, 254p.
- [5] Bremner J. (2012). Population et sécurité alimentaire: le défi de l'Afrique. La Population Reference Bureau: Washington, USA
- [6] Denicola E, Aburizaiza O S, Siddique A, Khwaja H, Carpenter D. (2015). Changement climatique et pénurie d'eau: le cas de l'Arabie saoudite. *Annals of Global Health*, 81 (3): <http://dx.doi.org/10.1016/j.aogh.2015.08.005>. 342–353.
- [7] Fontès J. et Guinko S. (1995). Carte de la végétation et du sol du Burkina Faso. Notice explicative. Ministère de la coopération française. Projet campus, 67p.
- [8] Gatto D M L, Salas B, Garcés V, Rodriguez A, Ma I, Vi L, Fasciolo G, Van L, Seghezzo L. (2015). Utilisation des eaux usées domestiques (traitées) pour l'irrigation: situation actuelle et les défis futurs. *Journal international du traitement de l'eau et des eaux usées*. doi: <http://dx.doi.org/10.16966/2381-5299.107>.

- [9] Gemmell M, Schmidt S. (2010). Liens potentiels entre la qualité de l'eau d'irrigation et la qualité microbiologique des aliments dans l'agriculture de subsistance au KwaZulu-Natal, en Afrique du Sud. Sujets actuels de recherche, de technologie et d'éducation en microbiologie appliquée et en biotechnologie microbienne. 92p.
- [10] Huibers F, Redwood M, Liqa R-S. (2011). Discuter les approches conventionnelles de gestion de l'utilisation des eaux usées en agriculture. L'irrigation avec es eaux usées et la santé. Evaluer et atténuer les risques dans les pays à faibles revenu. Presses de l'université du Québec IDRC/CRDI, 440 p.
- [11] Khan K, Lu Y, Khan H, Ishtiaq M, Khan S, Waqas M, Wei L, Wang T. (2013). Les métaux lourds dans les sols et les cultures agricoles et leurs risques pour la santé dans le district de Swat, dans le nord du Pakistan. *Toxicologie alimentaire et chimique*. <http://dx.doi.org/10.1016/j.fct.2013.05.014>. 449–458.
- [12] Koumolou L, Edoorha P, Montchoa S, Aklikokoub K, Lokoc F, Bokod M, Creppye E E. (2013). Health-risk market garden production linked to heavy metals in irrigation water in Benin. *Comptes Rendus Biologies*, 336(5-6): 278-283. <https://doi.org/10.1016/j.crv.2013.04.002>
- [13] Matini L, Moutou J.M., KONGO-MANTONO M.S. (2009). Evaluation hydrochimique des eaux souterraines en milieu urbain au Sud-Ouest de Brazzaville, Congo. *Afrique Science* 05(1): 82-98.
- [14] Pazou Y E A, Soton A, Azocli D, Acakpo H, Boco M, Fourn L, Houinsa D, Keke J C, Fayomi B. (2010). Contamination du sol , de l'eau et des produits maraîchers par des substances toxiques et des métaux lourds sur le site de Houéyiho (Cotonou) en République du Bénin. *Int. J. Biol. Chem. Sci.*, 4: <http://dx.doi.org/10.4314/ijbcs.v4i6.64951>. 2160–2168.
- [15] Senou I, Narcis B, Valentin N, Some N A, Nacro H B. (2016). Evaluation of the groundwater quality in a closed industrial landfill. *Journal of Engineering Studies and Research*. 22 (1): 72-80.
- [16] Sou Y M. (2009). Recyclage des eaux usées en irrigation : Potentiel fertilisant, risques sanitaires et impacts sur la qualité des sols. Thèse de doctorat: Faculté Environnement naturel, Architectural et construit, Laboratoire d'éco hydrologie Ecole Polytechnique Fédérale de Lausanne, 178 p.