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Adequacy of Water Use Resources for Drinking and Irrigation, Study Case of Sarh City, Capital of Moyen-Chari Province, CHAD

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Abstract

Our objective is to evaluate adequacy of water for consumption and irrigation. We collected nineteen water samples from 21 to 26, May 2017. Twenty-two physico-chemical and bacteriological parameters were taken into account, electrical conductivity, pH, total hardness, bicarbonate, nitrates, sulfates, chlorides, calcium, sodium, magnesium, potassium, dissolved oxygen and biochemical oxygen demand, chemical oxygen demand, total coliforms, *Escherichia Coli*, and fecal coliforms. To evaluate water intended for consumption, average values measured parameters were compared to [1] for quality water drinking and we evaluated overall quality of water by means of simplified SEQ-Water grid. Concerning irrigation water, evaluation is based on interpretation of quality parameters of irrigation water that we have calculated; among these parameters we can mention the percentage of sodium, rate of sodium absorption, ratio of magnesium adsorption, residual sodium carbonate. Kelly ratio, Corrosivity ratio and Permeability Index. Results show that surface water is weakly mineralized compared to groundwater and presents a good chemical quality; however, it is slightly altered by presence of organic pollutants. The overall assessment of groundwater quality shows that about 47% of water sampled varies between average quality and very poor quality for consumption. This poor quality is mainly due to presence of nitrates in water, whose content sometimes exceeds the limit authorized by [1]. From a bacteriological point of view, germs of faecal origin such as Total Coliforms, *Escherichia Coli* and Faecal Coliforms contaminate all groundwater points sampled. They are of poor quality and unfit for human consumption without prior treatment. We also evaluated the quality of water used for irrigation using 6 parameters. The results show that all of our water points are suitable for irrigation, according to the values of CSR and Kelly ratio. The same is true for the permeability index, which shows that all samples fall into class I and II type to indicate their suitability for irrigation purposes. According to [2] all waters are excellent quality for agriculture; and for Richard diagram, 89.5% of waters are generally suitable for irrigation and 10% are generally not suitable for irrigation without prior dilution with low salinity water.

Keywords

SEQ-Eau, Water Quality, Consumption, Irrigation, Physico-Chemical and Bacteriological Parameters

1. Introduction

Our planet is composed of 70% water, but almost all of it is salty, leaving only a very small percentage (1% to 2%) made up of fresh water to meet various needs of man. This so-called fresh water, unlike salt water that makes up oceans and seas, contains only minimal amounts of dissolved salts and can be obtained from sources such as groundwater, rivers, lakes, soil profile, atmosphere and biological system. For a long time, groundwater has been considered best protected resource from pollution compared to surface water [3], as the latter is a good receptacle for pollutants and wastewater. Thus, groundwater is the main source of drinking water when it is present in a region. However, nowadays, it is clear that no resource is safe from pollution. Indeed, in recent decades, a generalized deterioration of water quality in continental aquatic systems has been reported due to rapid development of industries, agriculture, inadequate sanitation, population growth, urbanization and increasing anthropogenic activities [4]. All this has led to the decline in resource availability both in terms of quality and quantity. Water chemistry is very dynamic, and is generally influenced by natural and anthropogenic processes. Natural water may contain different types of impurities that it acquires through various processes such as rock weathering, soil leaching, dissolution of aerosol particles from the atmosphere, as well as various human activities. Aware of the influence of surface and groundwater quality on environment, economy and health, several researches on assessment of groundwater suitability for domestic and agricultural purposes have been conducted in sub-Saharan Africa [5]-[10]. Suitability of water for various uses depends on the type and concentration of minerals dissolved in water. When different chemical and physical constituents are present in water beyond their permissible limits, it becomes unsuitable for various uses can create health hazards and environmental problems [11]. In daily life, drinking water should be free of all undesirable substances and/or germs. Because drinking contaminated water poses serious risks to human health due to presence of undesirable substances [12] [13] [14]. Indeed, [15] reports that more than three million people die each year worldwide from water-related diseases and that about 80% of illness and death in developing countries are associated with water pollution.

In agriculture, too, a number of precautions must be taken. The use of poor quality water for irrigation can result in reduced plant growth and crop yields and can affect crop productivity and soil physical condition [16] [17]. Therefore, water quality testing is essential to ensure that water consumed by population meets required quality standards [18], in order to avoid any health risks. In addition, it is also essential to identify and address irrigation water quality issues in order to promote socio-economic growth in the region. In Sarh town, as in other towns in Chad, Chadian Water Company (STE), main water distribution company, has limited capacity to supply water due to rapid and anarchic growth of towns. To overcome this problem, population uses traditional wells or human-powered pumps to collect water from groundwater table, which they combine with surface water (river) to meet their various needs. Access to sanitation services is non-existent, latrines are dug close to water table, household waste is scattered throughout city, domestic wastewater is discharged indiscriminately, and wastewater from industries lined up along Chari River is discharged into river without prior treatment, chemical fertilizers and herbicides are used along river for market gardening. All of this constitutes a risk of degradation of water of Sarh city, which can make it unfit for various uses. The objective of this study is therefore to verify adequacy of Sarh city water for consumption and irrigation. The results of this study will help decision-makers to develop management and protection plans for city's water resources.

2. Material and Methods

2.1. Presentation of the Study Area

The Sarh town, formerly known as Fort-Archambault, is located in southeastern Chad (**Figure 1**) not far from Central African Republic border. It is capital of Moyen Chari province and Bahr Koh department. It is located in southern part of Lake Chad basin, specifically in Chari sub-basin. It has an area of about 37 km^2 and extends between latitudes 9˚10' and 9˚18' North and longitudes 18˚36' and 18˚42' East. The altitude is between 361 m and 389 m with a slope that varies from 0.7% to 3.1%. The city is subject to a Sudano-Guinean type of climate, the average annual rainfall calculated from rainfall data collected from 1965 to 2016 at Sarh station is 974 mm and temperatures average 28˚C. Beneath Sarh city is a sedimentary series that ranges from Cretaceous to Quaternary, all of which rest on crystalline basement. The Tertiary and Quaternary formations outcrop and harbor main groundwater tables. According to [19], the Continental Terminal formations are composed of ferruginous sandstones, variegated sandstones, mollassic sandstones, argillites, sands, lateritic armouries while those of Quaternary contain recent fluvial alluvium. The hydrographic network is represented by two permanent rivers (**Figure 1**): Chari and Bahr Koh. Chari River originates in Central African Republic and borders city along its northeast side; the surface area of watershed drained by Chari River in Sarh is estimated at 193,000 km^2;

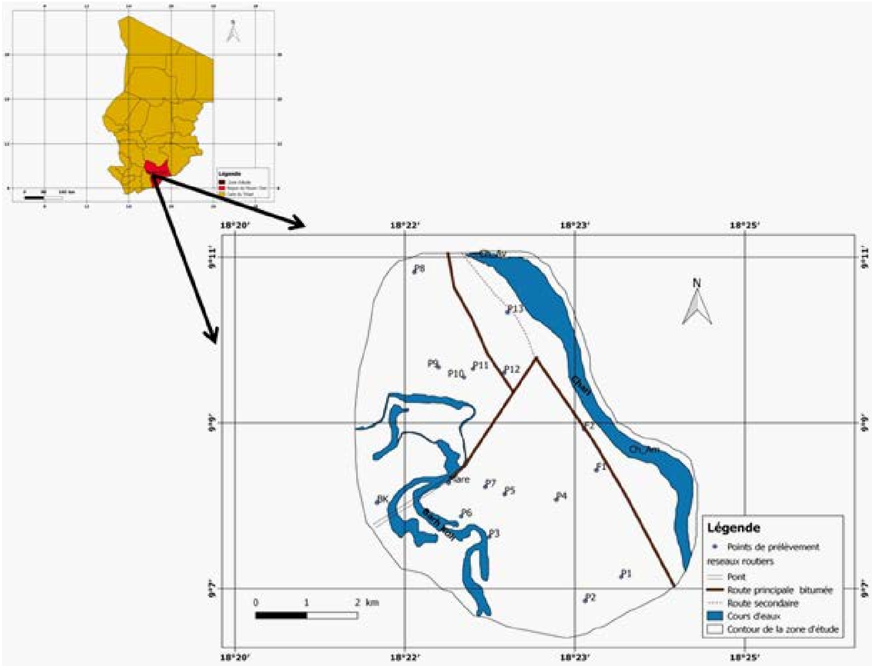

Figure 1. Location of study area and sampled points.

Bahr Koh, one of Chari's tributaries, borders southwestern part of city; the hydrological characteristics of this watercourse are not known. The water from river is used for domestic purposes, irrigation (especially for market gardening) and other activities such as swimming and animal feeding. The town is part of an agro-pastoral area where agriculture and livestock farming play an important role in the region's economy.

Water is an essential resource for life and health. Its microbiological and chemical quality is a permanent and major public health issue when it comes to its consumption, use water for hygiene purposes, or other uses that may lead to human exposure.

A small part of population of the region has access to a public water supply. The majority of population draws water directly from its source, *i.e.* from wells, rivers, or natural rainfall reserves. This is where the exposure to the consumption of contaminated water is the most important;

2.2. Sampling and Analysis

Samples were taken from 19 water points (surface water, wells, boreholes,) between May 21 and 26, 2017 so as to have an overall picture of water (**Figure 1**); these points were located by GPS. pH and temperature were measured in situ using a device with a mixed pH 323/Set B electrode and conductivity using the Lf 318/Set electrode conductivity meter and dissolved oxygen using oximeter. The samples for chemical analysis were taken in plastic bottles, which were previously rinsed thoroughly with water to be taken. Chemical analyses were carried out at National Water Laboratory (LNE) of Ministry of Water and Sanitation. The analytical methods vary according to chemical elements and concern major and minor elements; thus HCO_3^- and Cl^- were determined by volumetric method, Na^+, K^+, Ca^{2+}, Mg^{2+}, were determined thanks to Photometer DR7100 and SO_4^{2-}, NO_3^- by spectrometry (DR890). The BOD_5 was determined by instrumental method using an oximeter, after incubation of sample for 5 days at constant temperature (20˚C), and in dark. And COD by oxidation in acid medium with potassium dichromate in presence of reactor at 150˚C.

Regarding water intended for microbiological analysis, collection of water samples was done in well sterilized polyethylene bottles to avoid any accidental contamination and analysis was carried out in a time interval not exceeding 48 hours after collection. The choice of analysis method depends on nature of sample, the sensitivity and desired precision [20]. To identify colonies of microorganisms, quantification method was adopted. After dilution and filtration phase, filter membrane was deposited in a culture medium to activate proliferation of microorganisms. After a period of incubation at a variable temperature (from 37˚C to 44˚C) according to type of element to be analyzed, it appeared colonies of bacteria with different colors. Afterwards, we counted different types of bacteria using a colony counter. The result is expressed in Colony Forming Units (CFU) per milliliter (ml) of water sample.

The results of physico-chemical and bacteriological analyses are summarized in **Table 1** below.

2.3. Methodology

To determine quality of drinking water, we compared our data to standards for drinking water quality recommended by World Health Organization [19]. On other hand, we have evaluated it through interpretation of global quality on basis of a simplified grid of water quality evaluation: SEQ-EAU ((Version 2), 2003), including three parameters indicators of physicochemical and nitrogenous pollution. These parameters are electrical conductivity, which provides information on water mineralization, and chlorides and nitrates, which are markers of urban pollution [21] [22]. In this grid, five quality classes have been defined according to values of each of parameters considered and required standards (**Table 2**):

Class I: Very good quality water, represented graphically by color blue; used without special requirements;

Class II: Good quality water represented in green; used after simple treatment;

Class III: Average quality water, represented in yellow; can only be used after a very thorough treatment;

Class IV: Poor quality water, represented in orange; polluted, can only be used after specific treatment;

Class V: Very poor quality water, shown in red; excessively polluted.

In order to evaluate suitability of groundwater for irrigation percentage of sodium (% Na), sodium absorption ratio (SAR), magnesium risk (MAR), residual sodium carbonate (RSC), Kelly ratio (KR), corrosivity ratio (CR) and permeability index (PI) were calculated using Equations (1)-(7) (**Table 3**).

Table 1. Results of chemical analyses of water surface and groundwater in Sarh city.

Parameters	Surface water					Groundwater				
	n	Min	Max	Moy	Ecart-Type	n	Min	Max	Moy	Ecart-Type
C25˚ (µs/cm)	4	60	89	76.75	13.07	15	100	1513	452.87	420.68
pH	4	6.45	7.19	6.875	0.32	15	6. 7	7.6	7.27	0.29
T (˚C)	4	28.2	29.3	28.675	0.49	15	27	31.6	28.42	1.10
HCO_3^- mg/l	4	27.92	61	48.81	14.47	15	55	298	116.53	64.05
Cl^- mg/l	4	5	6	5.375	0.48	15	6	209	55.00	61.99
NO_3^- mg/l	4	0.64	3.2	1. 365	1.23	15	1.8	212	41.67	57.65
SO_4^- mg/l	4	6	26	16	10.46	15	0	21	8.00	6.74
Ca^{2+} mg/l	4	4	16	8	5.66	15	2	100	32.87	31.94
Mg^{2+} mg/l	4	2	8	5.65	2.62	15	3	40	13.80	10.12
K^+ mg/l	4	4	5.9	4.575	0.89	15	2.2	50.3	11.17	12.53
Na^+ mg/l	4	2.2	6.5	5.075	1.96	15	8.7	103.7	23. 31	243.36
DC0 mg/l	4	11	48	31.75	15.41					
DBO_5 mg/l	4	5.2	14.8	9.315	4.20					
DO mg/l	4	4.24	8.03	6.63	1.74					
Coliformes Totaux						5		10,800	19,900	3884.97
Eshérichia Coli						5		50	3650	4916.55
Coliformes Fecaux						5		9300	12390	3805.00

Table 2. Simplified grid for the evaluation of the overall water quality.

Quality class		Chemical parameters					
		*Electrical conductivity (µS/Cm)	*Cl^- (mg/L)	* NO_3^- (mg/L)	**DO (mg/L)	**DCO (mg/L)	**DBO_5 (mg/L)
I	Excellent	<400	<200	<5	>7	<30	<3
II	Good	400 - 1300	200 - 300	5 - 25	7 - 5	30 - 35	3 - 6
III	Average	1300 - 2700	300 - 750	25 - 50	5 - 3	35 - 40	6 - 10
IV	Poor	2700 - 3000	750 - 1000	50 - 100	3 - 1	40 - 80	10 - 25
V	Poor	>3000	>1000	>1000	<1	>80	>25

Table 3. Summary of formulas used for the calculation of the parameters needed to evaluate suitability of water for irrigation.

	Formulas	
Percentage of sodium	$\%Na = Na^+ + K^+ / \left(Ca^{2+} + Mg^{2+} + Na^+ + K^+\right) * 100$	Equation (1)
Sodium absorption ratio	$SAR = Na^+ / \left[\left(Ca^{2+} + Mg^{2+}\right)/2\right]$	Equation (2)
Magnesium absorption ratio	$MAR\left(meq/l\right) = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} * 100$	Equation (3)
Residuel sodium carbonate	$RSC\left(meq/l\right) = \left(CO_3^{2+} + HCO_3^-\right) - \left(Ca^{2+} + Mg^{2+}\right)$	Equation (4)

Continued

Kelly's Ratio	$KR = \frac{Na^{+}}{Ca^{2+} + Mg^{2+}}$	Equation (5)
Corrosivity Ration	$CR(mg/L) = \frac{\frac{Cl^{-}}{35.5} + 2 * \frac{SO_4^{2-}}{96}}{2\frac{HCO_3^{-} + CO_3^{2-}}{100}}$	Equation (6)
Permeabillity index	$IP = \left[\left(Na^{+} + HCO_3^{-}\right)/\left(Ca^{2+} + Mg^{2+} + Na^{+}\right)\right]$	Equation (7)

3. Results and Discussions

3.1. Quality of Water Intended for Consumption

3.1.1. Surface Water

The results of analysis of surface water samples (Chari River, Barh Koh and pond) summarized in **Table 1**, allowed us to determine statistical distribution of variables (**Figure 2**). This shows that water surface in Sarh town is dominated by bicarbonates, which represent 48% of all ions and 64% of all anions, followed by sulphates, which represent 20% of all ions and 27% of all anions, then Cl^{-}, which represents 5% of all ions and 7% of all anions, and finally nitrates, which represent 2% of both all ions and all anions. As far as cations are concerned, waters are dominated by Ca^{2+} which also represents 10% of total ions and 39% of total cations; followed by Mg^{2+} with 5% of total ions and 21% of total cations, then K^{+} and Na^{+}, which both represent 5% of total ions and also 20% of total cations.

Conductivity and chemical pollution indicators: Chloride and nitrate.

We are interested in these 3 parameters because they allow a quick evaluation of the water quality. Conductivity represents the ability of water to conduct electric current. It depends on the content of dissolved substances, ionic charge, ionization capacity, mobility and temperature of the water [23]. Most natural waters are characterized by conductivity between 10 and 1000 µS/Cm [24]; notable changes in conductivity values can reflect large inputs of mineral salts from the reservoir or a large point input. In this study conductivity ranges from 60 to 89 µS/Cm with an average of 77 µS/Cm for surface water (**Table 1**).

In drinking water, concentration of chloride should not exceed 250 mg/L, as recommended by WHO. The high chloride content in water is often due to influence of septic tanks, municipal waste, fertilizers, animal waste, effluent rich in chloride or sewage. Chlorides do not pose a health hazard. However, when they are in excess in water, they give it a salty taste and people who are not used to high chloride levels are subject to a laxative effect [25]. In study area, chloride concentration varies from 5 (Ch_Am, BK) to 6 mg/L with an average of 5.4 mg/L (**Table 1**). The concentration of nitrates in natural waters is normally low, but it can increase if there is contamination. Nitrates can come from fertilizers, food preservatives, human waste and also from animal waste. [1] for drinking water is 50 mg/L. Excessive nitrate levels in drinking water can cause health problems such as methemoglobinemia or baby blue in children. It can also cause diseases

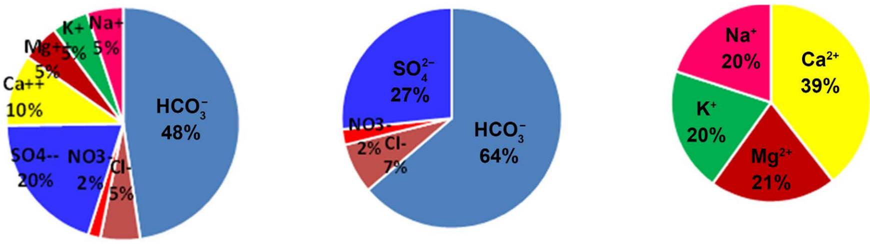

Figure 2. Statistical distribution of surface water ions in Sarh city (Chari River, Barh Koh).

such as goiter and hypertension [26]. Nitrate levels are relatively low and vary between 0.64 (Ch-av) and 3.2 mg/L (pond) for surface waters with an average of 1.4 mg/L (**Table 1**). The values obtained for different parameters measured in surface water are largely lower than standards accepted by WHO for human consumption.

The interpretation of our data in relation to simplified grid (**Table 2**), allowed us to classify surface waters of Sarh city according to values obtained. We note that all surface water points are of excellent quality with respect to three parameters indicating water degradation (**Table 4**).

Organic pollution indicators

To evaluate risk of water degradation by possible presence of organic pollutants, we were interested in three essential parameters which are dissolved oxygen (DO), biochemical oxygen demand (BOD_5) and chemical oxygen demand (COD).

Dissolved oxygen is most important gas for all aquatic organisms that have an aerobic respiration, as it is one of indispensable factors for their metabolism.

The presence of dissolved oxygen in natural waters is determined mainly by the respiration of organisms, by the photosynthetic activity of flora, by the oxidation and degradation of pollutants and finally by air-water exchange.

This parameter plays an essential role in maintenance of aquatic life and also in self-purification processes [27]. When amount of dissolved oxygen in water is very low it disturbs aquatic environment. Indeed, according to [28], when dissolved oxygen concentrations are below a certain threshold (3 ppm) it becomes stressful for most aquatic organisms and in general, fish move away from low DO areas. It has also been noted that low dissolved oxygen values promote growth of pathogens in water. Dissolved oxygen values measured in our waters ranged from 4.24 (Barh Koh) to 8.03 mg/L (Chari River) with an average of 6.63 mg/L (**Table 1**). [29] gives a classification of surface water according to its DO content. Thus, a value lower than 1 mg of O_2 per liter indicates a state close to anaerobic, a value located between 1 to 2 mg of O_2 per liter indicates a strongly polluted river. But in a reversible way, a content located between 4 to 6 mg of O_2 per liter characterizes a water of good quality and a content higher than natural content of saturation in oxygen indicate a eutrophication of medium being translated by an intense photosynthetic activity. 3 out of 4 water points, *i.e.* 75%

Table 4. Overall quality of water surface in Sarh city.

	Name of samples	c25˚C	Cl^- (mg/l)	NO_3^- (mg/l)	DO (mg/l)	DCO (mg/l)	DBO_5 (mg/l)	Overall quality
Surface water	Ch_Av	85	6	0.64	7.8	32	14.8	poor
	Ch_Am	89	5	0.76	8.03	11	5.2	good
	BK	73	5	0.86	4.24	36	7.06	average
	Mare	60	5.5	3.2	6.45	48	10.2	poor

of surface waters sampled have values higher than natural oxygen saturation level, which translates into an intense photosynthetic activity and thus a significant oxygen production by aquatic plants. On other hand, 1 out of 4 water points, or 25% of surface waters sampled have values that comply with standard set for maintenance of aquatic life, a standard that varies between 4 and 6 mg/L [30]. Biochemical oxygen demand (BOD_5), which is defined as amount of oxygen required by bacteria to stabilize decomposable organic matter under aerobic conditions, provides an indication of extent of organic matter contamination in water. According to WHO drinking water standard, concentration of BOD_5 should not exceed 6 mg/L [30].

When surface waters contain BOD values in range of 10 mg/L, they are considered moderately polluted and for values of more than 20 mg/L, they are considered highly polluted waters [31]. In our case, BOD_5 values vary from 5.2 (upstream Chari) to 14.8 mg/L (downstream Chari) with an average of 9.31 mg/L, as shown in **Table 1**. We also note that 3 out of 4 water points, or 75% of surface water points analyzed, have BOD_5 values above maximum acceptable limit defined by WHO. These waters all have values between 10 and 20 mg/L, therefore they are moderately moderate. Chemical oxygen demand is amount of oxygen required to oxidize organic matter and oxidizable inorganic substances using a strong chemical oxidant. In conjunction with BOD_5, the COD test is useful for indicating toxic conditions and the presence of biologically resistant organics [32]. The maximum allowable COD value is 10 mg/L for drinking water [33].

The chemical oxygen demand obtained in water points sampled varies from 11 to 48 mg/L (pond) with an average of 31.75 mg/L. All of waters analyzed have values above standard defined by the WHO. These high values suggest that surface waters are rich in dissolved organic compounds or oxidizable inorganic substances. This can be explained by direct discharge of effluents into river without prior wastewater treatment. With respect to our three parameters, indicators of organic pollution, **Table 4**, shows that 50% of our surface waters are of poor quality, mainly due to poor quality of BOD_5; 25% of these waters are good quality and 25% of average quality. This is due respectively to good quality of BOD_5 and the average quality of BOD_5 and DO.

3.1.2. Groundwater

The results of analyses are summarized in **Table 1** and have made it possible to determine statistical distribution of variables (**Figure 3**). The groundwater of

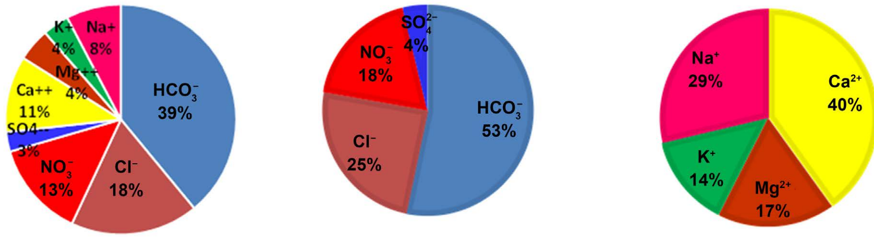

Figure 3. Statistical distribution of groundwater ions in Sarh city.

Sarh city, like surface water, is dominated by bicarbonates, which represent 39% of all ions and 53% of all anions; followed by Cl^- which represents 18% of all ions and 25% of all anions. Then nitrates, which represent 13% of all ions and 18% of all anions, and finally sulfates, which represent 3% of all ions and 4% of all anions. Regarding cations, waters are dominated by Ca^{2+} which also represents 11% of total ions and 40% of total cations; followed by Na^+, which also represents 8% of total ions and 29% of total cations. Mg^{2+} and K^+ both represent 4% of total ions and 17% and 14% of total cations, respectively.

- **Conductivity and chemical pollution indicators: Chloride and nitrate**

In groundwater, Electrical Conductivities vary between 100 (F1) and 1513 µS/Cm (P4) with an average of 452.9 µS/Cm. The chloride contents vary from 6 mg/L (P2) to 209 mg/L (P4) with an average of 55 mg/L without exceeding WHO norms of 250 mg/L. These chloride values can be considered normal; however, in context of fresh water, presence of high chloride content can be justified by influence of anthropic activities combined with temperature. Nitrate levels vary between 1.8 (P3) mg/L and 212 mg/L (P4) with an average of 41.7 mg/L. We note that 5 points or about 33% of the groundwater points have levels above WHO drinking water guideline value of 50 mg/L. The presence of nitrate in high quantities in water is probably due to use of synthetic fertilizers and manures associated with crops, intensive livestock farming and the decomposition of organic matter [34] [35]. They can also come from organic waste from latrines, poorly constructed septic tanks, and uncontrolled garbage dumping [36] [37]. The overall quality of groundwater with respect to our three parameters (**Table 5**) shows that 7 points (P1, P2, P3, P6, P8, P9, F2) or 47% of water is of excellent quality; 1 water point (F1), *i.e.* about 7% of waters are of good quality; 2 water points (P10, P12), *i.e.* 13% of waters are of average quality; and 4 water points (P5, P7, P11 and P13), *i.e.* about 27% of the waters are of poor quality and 1 water point (P4). The quality of water is very poor at 1 point (P4), *i.e.* about 7%.

- **Bacteriological parameters**

To assess bacteriological quality of groundwater, we were mainly interested in the presence of pollution indicator organisms, namely bacteria of coliform group, which normally live in intestines. The presence of these bacteria in water demonstrates that water has been polluted by human or animal waste. In **Table 1**, we have reported concentrations of microbial germs. These germs are present in the totality of sampled waters and in variable concentration (**Figure 4**). Thus

Table 5. Overall quality of groundwater in Sarh city.

Samples Name	c25˚C	Cl^- (mg/l)	NO_3^- (mg/l)	Overall quality
P1	210	13	3	Excellent
P2	160	6	3.2	Excellent
P3	282	34	1.8	Excellent
P4	1513	209	212	Very poor
P5	1082	154	79	Poor
P6	103	15	3.5	Excellent
P7	857	134	73	Poor
P8	136	8	1.9	Excellent
P9	109	22	4.5	Excellent
P10	616	64	31	Average
P11	458	52	72	Poor
P12	345	34	36	Average,
P13	649	59	92	Poor
F1	100	14	9.1	Good
F2	173	7	3	Excellent

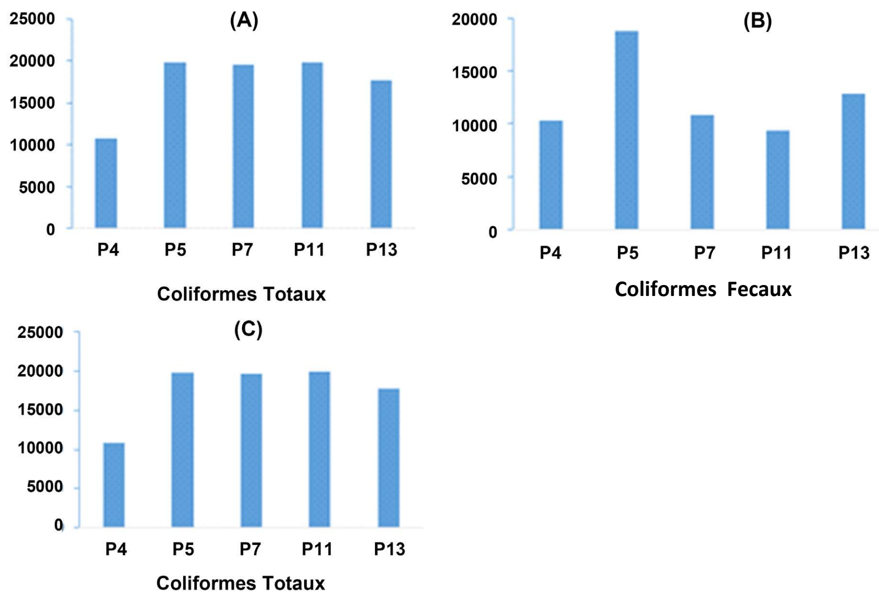

Figure 4. Distribution of germs in the groundwater of Sarh city.

we have concentrations of Total Coliforms which vary between 10,800 CFU/ml (P4) and 19,900 CFU/ml (P11) with an average of 17,560 CFU/ml. Those of Faecal Coliforms vary between 9300 CFU/ml (P11) and 18,800 CFU/ml (P5) with an average of 12,390 CFU/ml and finally concentrations of *Escherichia Coli* (*E. Coli*), vary between 50 CFU/ml (P13) and 11,500 CFU/ml (P4) with an average 3650 CFU/ml. Total coliforms are a much broader group of coliform bacteria that are present in human and animal feces. However, not all total coliforms have a fecal origin and many are present in most untreated sources in tropical regions, especially in waters enriched with organic matter [38].

As a result, risk level of fecal coliforms is very high in these waters.

E. colis is a member of fecal coliform group. This species is present in animal feces, including humans, and belongs to normal intestinal flora of healthy individuals. It is abundant in human feces and sufficiently resistant to be detected. According to [1], presence of *E. coli* constitutes undeniable proof of recent fecal pollution, whereas this microorganism should be totally absent from drinking water. WHO bacteriological standard for human consumption water for total coliforms is 10 colonies/100ml and for *E. coli* and fecal coliforms is 0 colony/100ml. However, results show presence of germs in all sampled wells. These waters are contaminated by Total Coliforms (TC), *Escherichia Coli*, Fecal Coliforms in groundwater (**Table 1** and **Figures 4(A)-(C)**). We note that values of total coliforms (TC), *Escherichia Coli*, fecal coliforms that we obtained in waters are higher than standards defined by WHO for drinking water. The presence of these bacteria in water indicates presence of a degradation of water by waste of human or animal origin. This pollution would be due to use of poorly designed and poorly used latrines, lack of protective perimeter around wells, a short distance between well and latrine, household waste deposited in bulk.

3.2. Water Quality for Irrigation

Assessing quality of irrigation water means studying effects of mineral constituents in water on plants and soil. Indeed, excess of dissolved elements in irrigation water can lead to physical and chemical changes in plants and soils, resulting in reduced productivity. There are several quality control criteria for water intended for agricultural activity. In case of our study, we used 8 quality parameters of which electrical conductivity (EC), percentage of sodium (% Na), rate of absorption of sodium (SAR), ratio of adsorption of magnesium (MAR), residual sodium carbonate (RSC), ratio of Kelly (KR), ratio of corrosivity (CR) and index of permeability (IP).

Electrical conductivity (EC) is an essential parameter that allows us to assess suitability of waters for consumption as we have seen previously and also its suitability for irrigation practices, as it determines the presence of salt in water [16] [39].

When EC value is high and combined with equally excessive Na^+ levels in agricultural waters, it negatively affects crop yields simply because it leads to a decrease in plant osmotic activity, which interferes with plant uptake of nutrients and soil water [40]. By plotting our points on [2], which relates the % Na to Electrical Conductivity (**Figure 5**), we see that all water samples (100%) are in class of excellent to good quality water for irrigation.

Sodium in irrigation water is generally expressed as percent sodium and is calculated using formula defined by [41] (**Table 3**). It is recommended that percentage of sodium (% Na) be kept below 60% in irrigation water to avoid sodium

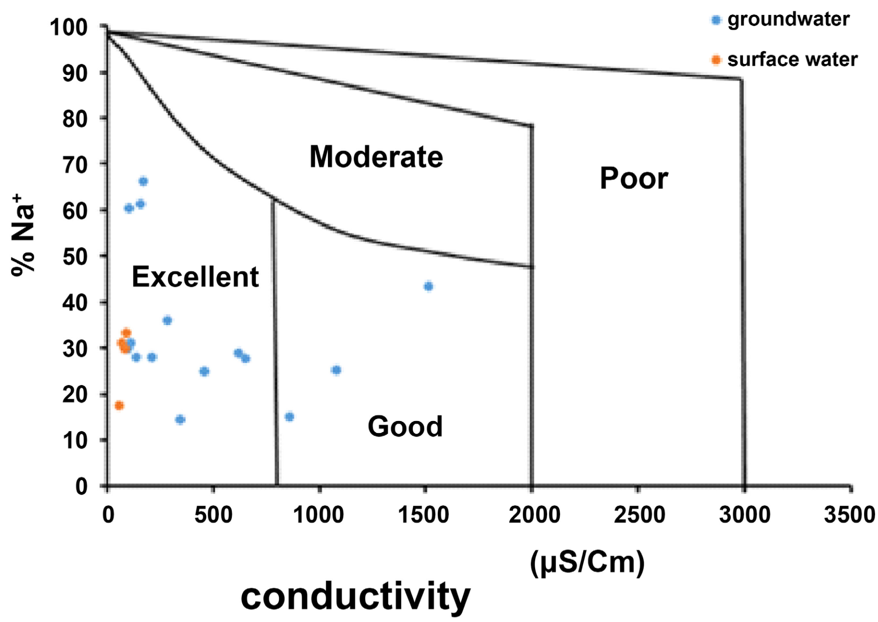

Figure 5. Wilcox diagram (1955).

buildup that can lead to degradation of soil physical properties. Indeed, high concentrations of sodium in groundwater induce adverse effects on soil, as sodium reacts with soil and decreases its permeability [42]. This has a negative influence on plant growth [43]. Based on % Na, five classes of water have been differentiated [44]: for values of % Na < 20% one has excellent water quality for irrigation. When these values vary between 20% - 40% it is of good quality, for values that vary from 40% - 60% it is admissible, for values that vary from 60 to 80% is doubtful, and for values of % Na > 80% water is considered unsuitable for irrigation. The % Na we obtained here varies from 14% to 66%, with an average of 35% for groundwater and from 18% to 33%, with an average of 28% for surface water (**Table 6**). Thus overall, we have 9 groundwater points (or about 73% of analyzed water) and 4 surface water points (100% of analyzed water). Which can be classified as excellent to good for irrigation, 2 groundwater points (or 33% of samples) of groundwater are eligible, and another 2 groundwater points (about 33% of samples) are classified as doubtful for irrigation (**Table 6**). Sodium absorption ratio (SAR) is also a parameter that is used to assess suitability of water for irrigation; it is estimated by formula of [45]. SAR allows the estimation of degree of sodium adsorption by soil. In water, Na^{+} replaces exchangeable ions Ca^{2+} and Mg^{2+} and when it is in very high quantities, excess sodium in water is absorbed onto soil particles. This produces undesirable effects by altering properties of soil and reducing its permeability [46] and as a result directly affects crop yields [47].

In order to evaluate the possible risk that irrigation water may generate, American salinity laboratory [48]. Proposed to plot SAR (sodium risk) against EC (salinity risk), which allows to differentiate different classes of water that indicate to what extent water may affect soil in terms of salinity risk. **Figure 6** shows

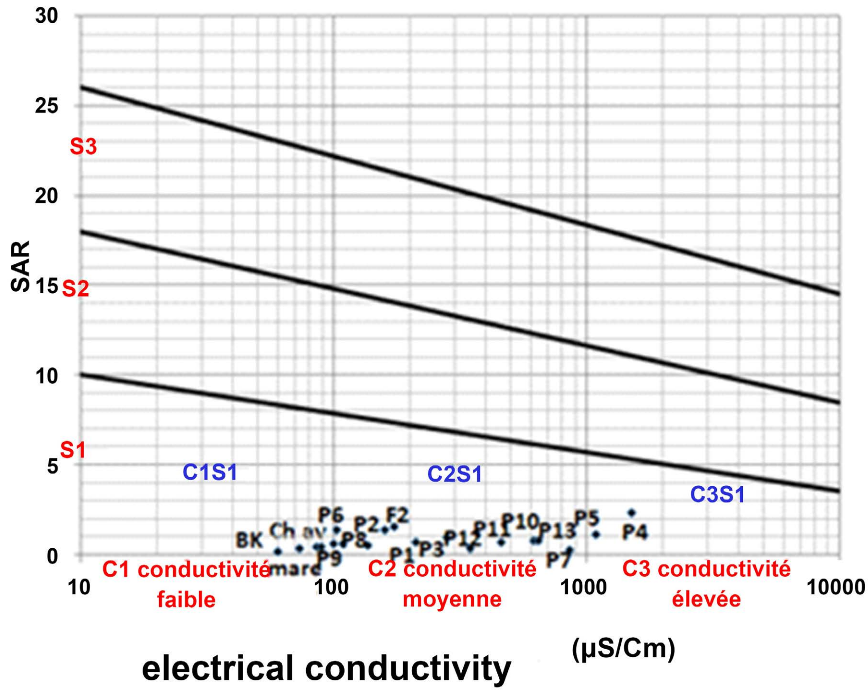

Figure 6. Sodium adsorption ratio—electrical conductivity relationship (Richards, 1954).

Table 6. Classification of water for irrigation

Parameter	Unité	Rang	Référence	Water class	N° of sample		% of sample	
					groundwater	Surface water	groundwater	Surface water
Electrical conductivity	µs/cm	<250	Raghunath, 1987	Excellent	7	4	47%	100%
		250 - 750		good	5		33%	
		750 - 2000		permissible	3		20%	
		2000 - 3000		doubtful				
		<3000		unsuitable				
Sodium adsorption ratio (SAR)	meq/L	0 - 10	Todd, 1980	Excellent	15	4	100%	100%
		10 - 18		good				
		18 - 26		doubtful				
		>26		unsuitable				
Residuel sodium carbonate (RSC)	meq/L	<1.25	Lloyd et Heathcote, 1985	good	15	4	100%	100%
		1.25 - 2.5		doubtful				
		>2.5		unfit				
Percentage of sodium	meq/L	<20	Kawo et Karuppannan, 2018	Excellent	2	1	33%	25%
		20 - 40		good	9	3	60%	75%
		40 - 60		permissible	2		33%	
		60 - 80		doubtful	2		33%	
		>80		unfit	0			

Continued

Kelly Ratio	meq/L	<1	Kelly, 1963	suitable	12	4	80%	100%
		>1		unsuitable	3	0	20%	0%
Magnesium hazard	meq/L	<50	Raghumath 1987	suitable	11	1	73%	25%
		>50		unsuitable	4	3	27%	75%
Permeability index	meq/L	>75	Oga *et al.* 2015	Class-I	8	3	53%	75%
		25 - 75		Class-II	7	1	47%	25%
		<25		Class-III	0			
Rapport de corrosité	meg/L	<1	Ryzner, 1944 Raman 1985	suitable	12	3	80%	20%
		>1		unsuitable	3	1	20%	25%

that all samples are in S1 part of the diagram, *i.e.* they all have low alkalinity (SAR) and in areas of low (C1) medium conductivity (C2) and high conductivity (C3). From above we can differentiate three classes of water:

- Class C1S1: water with low conductivity and low SAR. It includes 6 samples (32%);
- Class C2S1: water with average conductivity and low SAR, it includes (58%);
- Class C3S1: water with high conductivity and low SAR is least represented with only 2 water points (10%).

Magnesium adsorption ratio (MAR) values for irrigation water are calculated using Equation (3) (**Table 3**) proposed by [49]. In general, calcium and magnesium maintain an equilibrium state in most waters. A fairly high concentration of magnesium relative to calcium in water has adverse consequences on soil quality [50] as it causes destruction of its structure, thereby leading to a decrease in crop yield [51] [52]. The MAR values vary from 26% to 83%, with an average of 46% for groundwater and from 17% to 77%, with an average of 55% for surface water. If magnesium risk exceeds 50%, then water is dangerous for agriculture and unsuitable for irrigation, but if MAR value is less than 50%, water is suitable for irrigation (**Table 6**). Based on this classification, 73% of groundwater and 25% of water surface samples are considered suitable for irrigation, while 27% of groundwater and 75% of water surface samples remaining are considered unsuitable for irrigation purposes.

Residual sodium carbonate (RSC) represents residual alkalinity and is used to assess hazardous impact of carbonate and bicarbonate on water quality for agricultural purposes [53]. A high concentration of bicarbonate increases pH value of water, resulting in dissolution of organic matter. CSR (meq/l) is calculated using Equation (4) (**Table 3**) proposed by [53]. When quantities of carbonate and bicarbonate are very high compared to those of calcium and magnesium in water, this has a direct influence on quality of water used for irrigation. Indeed, presence of high contents of HCO_3^- and CO_3^{2-} ions in water favors deposition of Ca^{2+} and Mg^{2+} ions [54], as well as production of important precipitates of $NaHCO_3$ and $CaCO_3$ which proves to be dangerous for soil structure. CSR values of calculated water samples in our study area vary between −3.75 mg/l and +0.90 mg/l with an average of −0.86 mg/L for groundwater and between −0.51 mg/l and +0.14 mg/l with an average of −0.06 mg/L for water surface.

Kelly's ratio is ratio of sodium ion to calcium and magnesium ion and is expressed using Equation (4) (**Table 3**) proposed by [55]. This ratio must be less than 1. If the value exceeds 1, groundwater is considered unsuitable for irrigation. An excess of sodium in water alters quality of this water for irrigation, for simple reason that these sodium ions are absorbed by clay particles and replace calcium and magnesium ions, which causes dispersion of clay particles, thus decreasing permeability of soil (as we have already pointed out), moreover it can eventually affect internal drainage. Kelly ratio (KR) calculated for all groundwater samples in the study area gives KR values that vary between 0.08 and 1.38 meq/L with an average of 0.52 meq/L for groundwater and between 0.10 and 0.36 meq/L with an average of 0.26 meq/L for water surface. Thus, we find that all of our water points (100%) are suitable for irrigation as the KR value is less than 2.5 meq/L (**Table 6**).

Corrosivity Ratio (CR) is calculated using Equation (6) (**Table 3**). For a CR value < 1 water is considered good and can be transported through all types of pipes, while for a CR value > 1 water indicates a corrosive nature and therefore should not be transported through metal pipes [56] [57]. CR values obtained after calculation vary between 0.10 and 1.65 mg/L with an average of 0.63 mg/L for groundwater and between 0.24 and 1.25 mg/L with an average of 0.60 mg/L for water surface. From our results, we find that 12 groundwater points (or 80%) and 3 surface water points (or 20%) are safe while 3 groundwater points (or 20%) and 1 surface water point (or 25%) are corrosive in nature and require a non-corrosive pipe for transport (**Table 6**). The Permeability Index developed by [58] is also a very important criterion for assessing the suitability of water for irrigation. It is based on the fact that long-term irrigation negatively affects soil permeability due to the precipitation of certain ions such as Na^+, Ca^{2+}, Mg^{2+} and HCO_3^- in water. It was defined by [58], according to Equation (7) (**Table 3**).

PI values we obtained after calculation vary between 30.46% and 143.87%, with an average of 80.92% for groundwater and between 72.94% and 116%, with an average of 101.82% for surface water. The degree of infiltration depends on permeability index (PI), according to which quality of irrigation water is divided into three different classes [8]: class I indicates a percolation of 75% or more and water is acceptable for irrigation, class II indicates a percolation that is between 25% - 75% and water is slightly suitable for irrigation, and finally class III indicates a percolation of less than 25% and thus water is unsuitable for irrigation (**Table 6**). Thus, in our case, we have 8 points (*i.e.* 53%) of groundwater and 3 points (*i.e.* 75%) of surface water belong to class I, while 7 points (*i.e.* 47%) of groundwater and 1 point (*i.e.* 25%) of surface water belong to class II.

4. Conclusions

The results show that values of electrical conductivity and pollution indicators (nitrate and chloride) of water's surface are low compared to WHO standards admissible for human consumption. The water is therefore of good quality with respect to these parameters and this result is confirmed in overall assessment of water quality. On other hand, with regard to organic pollution indicators, 50% of these waters are of poor quality, mainly due to poor quality of BOD_5.

By comparing values of electrical conductivity and pollution indicators (nitrate and chloride) of groundwater with WHO standards on one hand, and based on overall assessment of water quality in relation to these indicators on other hand, we can say that some groundwater points are unfit for human consumption. Indeed, overall assessment of water quality shows that about 47% of water sampled varies between average and very poor quality water for consumption. This poor quality is mainly related to presence of nitrates in water. We note that some water points have nitrate contents that largely exceed the authorized limit by WHO standard (50 mg/L) making them unfit for consumption (These are for example points P4, P5, P7, P11 and P13).

From a bacteriological point of view, all groundwater points sampled (five well water points) are contaminated by germs of fecal origin such as Total Coliforms (TC), *Escherichia Coli* and Fecal Coliforms. This bacteriological pollution constitutes a sanitary threat for the inhabitants who use water of these wells and therefore, these waters cannot be consumed without previous treatment.

The water points we sampled were also evaluated for their suitability for irrigation. The results obtained show that totalities of sampled waters are perfectly suitable for irrigation with respect to parameters such as KR and RSC. 79% totality of sampled waters can be classified as excellent to good for irrigation and remaining 21% are classified as eligible to doubtful for irrigation with respect to % Na; 63% of totalities of waters are judged suitable for irrigation, while 77% of these waters are judged unsuitable for irrigation purposes with respect to MAR. Compared to CR, 79% of total water points are non-corrosive in nature while 21% of total water points are CR corrosive in nature; the latter require a non-corrosive pipe for transport.

Moreover, the interpretation of the diagrams allowed us to make following observation, Wilcox diagram shows that all water samples (100%) are in class of excellent to good quality water for irrigation. While relationship Electrical Conductivity—SAR shows that, 89. 5% of waters are generally suitable for irrigation and 10% of waters can not generally be used for irrigation without prior dilution with water of low salinity.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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