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Changes in the Physico-Chemical Properties as Pollution Indicators in the Chari River Water Samples Along the Banda Township at Sarh-Chad

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Abstract: Water as essential for life is considered everywhere as a fundamental and indispensable element of natural resources. The aim of the present study was to physico-chemically assess the properties of water from Chari river along the Banda township in the Middle-Chari region in Chad. Water samples were taken from five different sites (ChS1-ChS5) along the Chari river during the dry (February) and wet (July) seasons of 2023. The studied parameters were temperature, pH, electrical conductivity, turbidity, Total Disolved Solids, Chemical Oxygen Demand, Suspended Materials, total nitrogen, total phosphorus, Nitrate, Nitrite and Sulfate that were compared between sampling sites. *In situ* analyses revealed a significant variation in temperature between sampling sites, ranging from between 26.01-28.52°C in the dry and 29.6-33.13°C in the wet seasons. Whereas the electrical conductivity was comprised between 53.8 and 146.63 µS/cm, the Total Disolved Solids varied from between 28.87 and 73.47 mg/L. The pH values remained within the maximum limits set by Chad's National Drinking Water Standards (6.5-8.5), except for station ChS1, where a slightly acidic pH was observed. In the dry season, water quality was safe for COD, except for site ChS5, based on the SEQ-water classification. Apart from the sampling site ChS1 that was contaminated with nitrate in the wet season, water from all the other sites was not at risk for nitrate concentration. During the dry season, the concentrations in nitrite at sites ChS1, ChS3 and ChS4 were above the WHO (2002) norm, which is 0.1 $mg.L^{-1}$, thus were at risk as drinking water. The registered turbidity values were positively correlated to SM in the dry season, but were largely above the acceptable limits for drinking water which is set to 5 NTU. The physico-chemical pollution of water from Chari river was mostly originated from agricultural, industrial and urban activities. Although the risk levels quality of studied water parameters were revealed weak for some, it seems important to set up a monitoring system to reduce the water pollution attributed to the above physico-chemical properties of the Chari river.

Keywords: *water, pollution, Chari river, physico-chemical properties, Chad*

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1. Introduction

Water plays a fundamental role in many areas [1], and is considered worldwide as an indispensable element to natural resources, covering three quarters of our planet, and comprising only 0.014% freshwater [2]. The main water resources used by human are lakes, rivers, soil moisture and relatively shallow aquifers, whose management is a major challenge for many countries in the world [3]. The development of human societies and demographic pressures have caused numerous water pollutions that threaten public and environmental health. Water quality is influenced by many factors including, electrical conductivity, temperature, pH, total dissolved solids [4], and therefore, water pollution is ranked among the major ecological concerns to scientists, governmental and non-governmental bodies [5]. The geographical location of Chad implies its supply by several water sources means, supplied by a large number of water courses, which are provided for agricultural exploitations, industrial operations, homes, schools and hospitals, but also ensure the maintenance of the underground water and the sustainability of heterogeneous wildlife environments [6]. Moreover, Chad is one of the countries in the world where rivers and streams are not only subjected to climatic constraints, but is served as dumping sites of industrial wastes [7]. Studies carried out on water quality from Chari and Logone rivers have shown profound changes, due to multiplication of industrial activities that negatively affect the water quality [7,8,9]. Chari as one of the most important rivers in Central Africa, receives several urban and industrial discharges from its borders with the Central African Republic, up to Lake Chad. Along its course, the degradation of water quality is attributed to industrial and household wastes which biodegradability is only achieved under very specific conditions [7]. Moreover, the neighboring population of the Chari river through their activities exert negative effects on the aquatic ecosystems, as they are in needs for water, while producing liquid effluents polluted with pathogens or chemical substances, some of which are rarely biodegradable [10]. These pollutions from different origins have been reported to affect the quality of surface water [11]. To the best of our knowledge, no study has yet been conducted on the pollution of water flowing in the Chari river, along the Banda township within the city of Sarh. Determining the physico-chemical characteristics of this water could be a mean of assessing its pollution risks. In this research, the above parameters affecting Chari water are discussed as far as their contents are concerned, in a bit to determine their risk levels for water quality along the Banda township.

2. Material and Methods

Presentation of the study area

The study was conducted on the Chari river along the Banda township, located at Sarh sub-council in the Bahr Kôh Department of the southern Chad. It lies between 9°08 North and 18°23 East, at averagely 365 m altitude. Water samples were taken at five sites, namely ChS1, ChS2, ChS3, ChS4, ChS5 (Figure 1) from the upstream to the downstream direction for *in-situ* physico-chemical analysis at the National Water Laboratory.

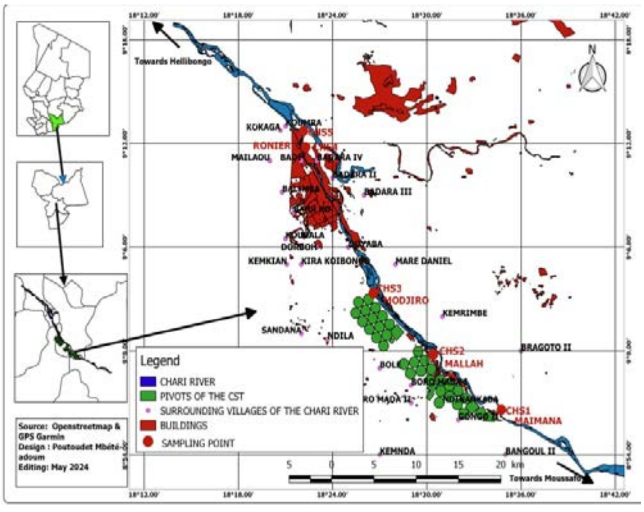

Figure 1. Location map of water sampling sites (red points) on the left bank of the Chari river

Experimental design and treatments

Along the Chari river and within the Banda township, the experiment was set up for each of the sampling periods (dry and wet seasons) in a randomized block design, the water sampling sites representing treatments, and the number of water samples (three) at each site representing the replications. There were five treatments known as Chari sampling sites from 1 to 5 (ChS1, ChS1, ChS2, ChS3, ChS4, ChS5): ChS1 was located upstream the Chari river, 5 km away of the Sugar Complex Company (CST); ChS2 was 3 km downstream ChS1, at the outlet of CST, and was receiving wastes water from CST; ChS3 and ChS2 were 5 km apart, at 3 km downstream the outlet that provides water to the sugar cane fields in the dry season; ChS4 was located 5 km away from ChS3, downstream the slaughterhouse of Sarh, and was receiving wastes water from this company; ChS5 was 1 km distant from ChS4, at 200 m downstream the city of Sarh.

In-situ physico-chemical analysis of water samples

The physico-chemical parameters of water samples such as pH, temperature, conductivity and Total Dissolved Solids (TDS) were measured directly in the field. The aim was to avoid any modification of these parameters due to possible exchanges between the samples and the outside conditions. Measurements were made as soon as water samples were collected, using a field multimeter (Palintest Waterproof 800) equipped with tools to assess conductivity, pH and TDS, with automatic temperature correction.

Physico-chemical analysis of water samples in the laboratory

Collected water samples were stored in 1.5L sterile polyethylene bottles, pre-cleaned with water to be analyzed. These water-filled bottles were carefully sealed, labeled and kept to cool in coolers containing ice packs, before transportation to the National Water Laboratory on the same day for analysis. In the laboratory, samples for physico-chemical analysis were filtered through cellulose filters (Ø ≤ 0.45 µm). The filtrates obtained were stored in 50 mL sterile bottles and kept at 4°C in the fridge. For each water sample, the turbidity, COD, SM, total nitrogen, total phosphorus, $NO3^-$, $NO2^-$, $(SO4)^{2-}$ were assessed using a DR 2400 spectrophotometer. Nitrates was measured using the sodium salicylate method, and the absorbance read through the spectrophotometer at 415 nm [12], whereas phosphorus was assessed using the ammonium molybdate colorimetric method followed by spectrophotometer reading at 440 nm against a blanc [13].

Data processes and analysis

For each parameter, data were assessed in triplicate and analyzed through ANOVA using a Statgraphic program**.** Means between treatments were separated using the Duncan Multiple range test at the indicated level of significance. Relationships between parameters of the same sampling period were assessed using the Pearson correlation.

3. Results and Discussion

Variation of water physical parameters between sampling sites and seasons

Temperature (°C): Known to be involved in almost all physical, chemical and biological reactions [14], water temperature has been reported to be an extremely useful environmental parameter used to regulate aquatic life, thus might have ecological important repercussions [15]. The physical water parameters assessed in this study varied from one sampling site to another within a season, and for a particular sampling site between seasons (dry and wet). Water temperature ranged from 26.01°C (ChS1) to 28.52°C (ChS2, ChS3) in the dry season, compared to 29.6°C (ChS1) to 33.13°C (ChS3) during the wet season (Figure 2a), indicating respectively a site difference of 2.51 and 3.53°C between sampling sites. Water temperature was significantly ($p = 0.0001$) more elevated in the wet than in the dry season for all sampling sites (Figure 2b). Water temperature is an ecological factor influencing the density, the viscosity and solubility of gases in water, the dissolution of salts, the chemical and biochemical reactions, as well as the growth and development of water organisms and microorganisms [16]. The significant thermal variation between sites could be attributed to differences in sampling periods and seasons. Variation of temperature between sites, and sampling periods have been reported for surface water of some Continental Wetlands in Mauritania [17], to follow those of the regional climate.

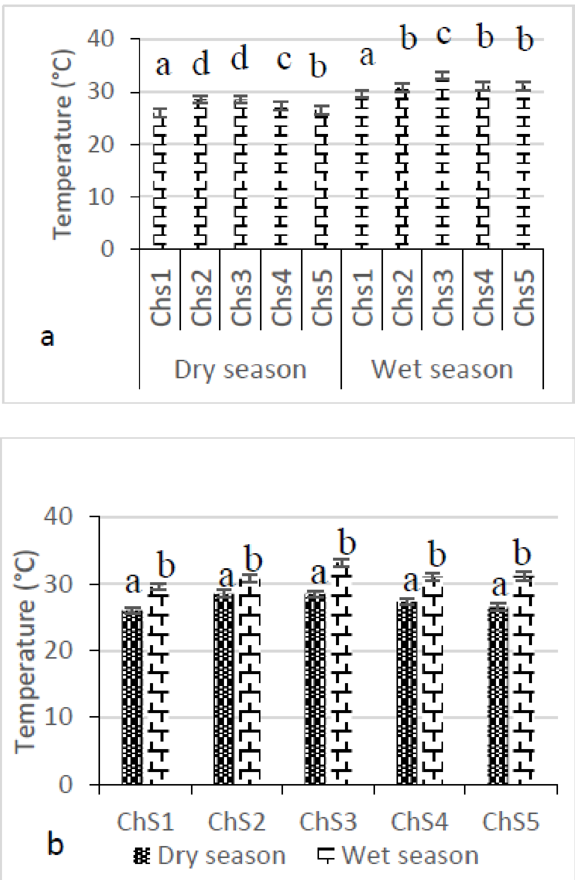

Figure 2. Variation of water temperature between sampling sites (a) and seasons (b) along the Chari river

Hydrogen Potential (pH): The water pH expresses the concentration H^+ ions contained in water [18]. Water pH was significantly ($p = 0.0001$) different between sampling sites during each of the dry and wet seasons. Water pH values were all acid, ranging from 5.72 at ChS1 to 6.6 at ChS3 and ChS5 during the dry season, compared to 6.29 (ChS1) to 6.76 (ChS4) during the wet season (Figure 3a), thus correspond to the pH of most of the underground water ($5.5 < pH < 8$). Apart from the sampling site ChS4 where water pH did not change between seasons, it was significantly ($p = 0.0001$) more elevated in the wet than the dry season for sampling sites ChS1 and 2, with the opposite happening for pH values from sampling sites ChS3 and 5 (Figure 3b). On the overall, the pH values remained within the maximum limits set by Chad's National Drinking Water Standards (6.5-8.5), except for sites ChS1, where a slightly acidic pH was measured. Opposite to your results, low pH values were revealed in the wet season for water sampled along the Comoe estuary river at Ivory Coast [19]. The reduced water acidity followed the numerical evolution of sampling sites (ChS1 to ChS5), thus from the up to the downstream in the running direction of water. The variation in water pH might be attributed to the acidity or alkalinity of soils crossed by running water.

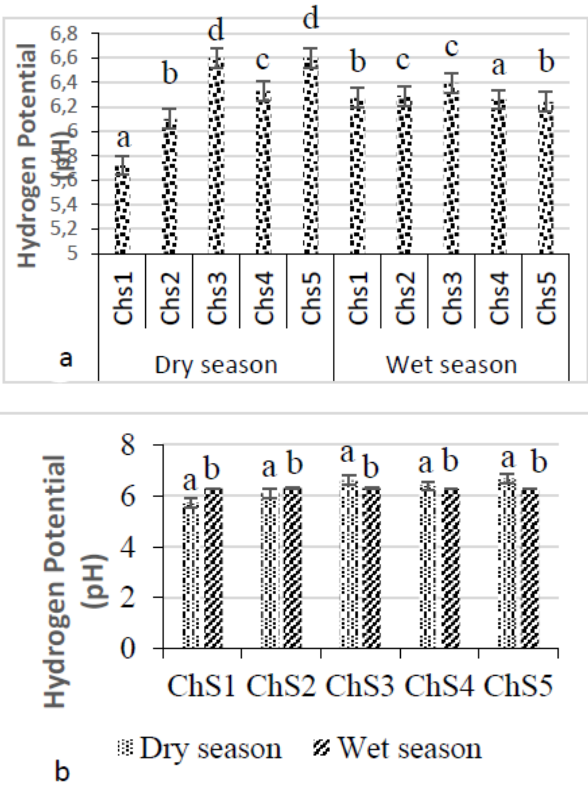

Figure 3. Changes in water pH between sampling sites (a) and seasons (b) along the Chari river

Electrical Conductivity (EC): The electrical conductivity is the numerical expression of the capacity of a solution to conduct electricity, and is used to appreciate the dissolved salts in water. It increases with temperature, and indicates the degree of mineralization of water, in which each ion acts through its concentration and its specific conductivity. In terms of temporal variation, the electrical conductivity from sampling site ChS2 (122.57 us/cm in the dry season, 146.56 us/cm in the wet season) was significantly ($p = 0.0001$) greater than those of other sampling sites (Figure 4a), the weakest values accounting for the sampling site ChS5 with 38.72 us/cm in the dry season and ChS1 with 53.8 us/cm in the wet season (Figure 4b). This could be explained by the concentration of mineral elements present in the water, showing the poor mineralization of the Chari river. These results confirm those of Ngaram [7] on the Chari river in the city of N'Djamena, which showed that water was less mineralized. Although the electrical conductivity for natural water was fixed between 50 and 1500 us/cm, fluctuations from between 219 to 3920 us/cm were reported respectively during the wet and the dry season in Morocco, indicating excessive mineralization attributed to industrial wastes [20]. On the other hand, surface water of Oued Guigouwas was revealed to be weakly mineralized with electrical conductivity values between 230-552 us/cm [21]. Results obtained from this study are below the maximum limit (50 µS/cm) set by national and the Water Quality Evaluation standards [22], indicating no rick as far as electrical water conductivity of the Chari river is concerned.

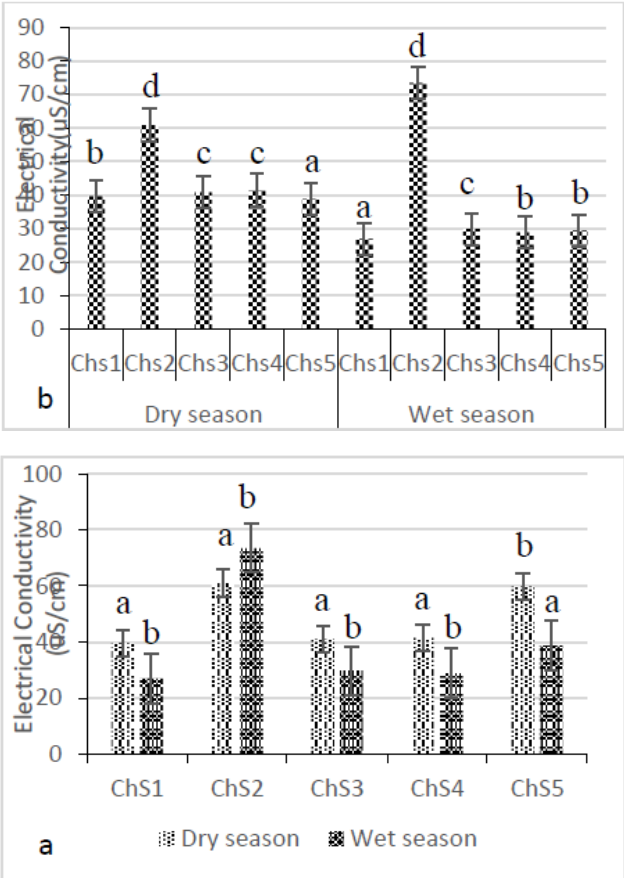

Figure 4. Influence of sampling sites (a) and seasons (b) on water electrical conductivity along the Chari river

Total Disolved Solids (TDS): The total dissolved solids comprise all mineral and organic matter, and include clay, loam, sand, plankton and other microorganisms. The TDS normally varies with seasons and water running regime. The TDS registered varied from 38.72 mg.L^{-1} (ChS5) in the dry season to 73.47 mg.L^{-1} (ChS2) in the wet season (Figure 5b), but within any of the season, the TDS significantly ($p = 0.0001$) differed from one water sampling site to another (Figure 5a). The increased TDS at sampling site ChS5 was probably attributed to liquid wastes discharges from CST factory thrown into water, in agreement with other results reported [23]. Moreover, the impact of increased water in the wet season was reflected by draining of natural organic matter from upstream (ChS1) to downstream (ChS5) sampling sites.

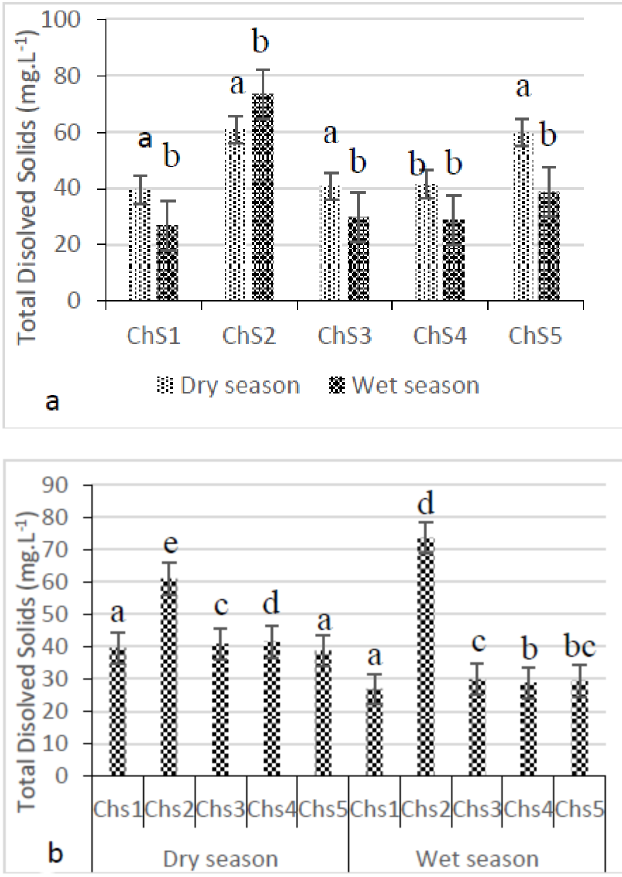

Figure 5. Influence of sampling sites (a) and seasons (b) on water total dissolved solids along the Chari river

Turbidity: Water turbidity is concerned with the presence of small size suspended matters, including clay, limon, silice, or organic matter. The appreciation of organic matter abundance expresses its degree of turbidity. The variation of turbidity during the wet season did not show an important variation (Figure 6b), whereas a significant ($p = 0.0001$) variation between sampling sites was observed during the dry season (Figure 6a) ranging between 9.39 (ChS1) to 14. 06 UNT (CHS4), although it was very low compared to the maximum content of 330 NTU reported by Tfeila *et al.* [24] on the Senegal river. The very weak variation during the wet season could be due to draining of rain water into the river. However, the registered TDS values in the dry season were largely above the acceptable limits for drinking water which is set to 5 NTU [25]. The increased turbidity has been reported to be linked to concentration of particles (organic debris, clays, microscopic organisms) in the environment due to reduced rainfall during the dry season and the development of microscopic algae [26].

Suspended Matter (SM): Suspended materials represent the entire mineral and organic particles contained in water, and is influenced by the nature of soil crossed, the seasons, the pluviometry, the nature of wastes, and the running regime of water [27]. The average mean of suspended matter was between 86.4 and 189.68 mg.L^{-1}

in the dry season, against 56.80 and 80.80 mg.L^{-1} in the wet season (Figure 7b). These values were very high compared to between 1.51 mg.L^{-1} and 23.33 mg.L^{-1} revealed by Keumean *et al*. [19] on Comoe river, but were still low when opposed to between 123-2730 mg.L^{-1} previously reported in Morocco [20]. On the overall, water was more charged in suspended materials in the dry than in the wet season, but with fluctuations varying from one water sampling site to another, and from the upstream to downstream direction (Figure 7a). These results contradict with those reported by Azzaoui [23], who instead pointed out more suspended materials in water during the wet than the dry season. These elevated SM values could be attributed to an intense erosion of watershed, that occasionally enhance the suspended materials in water, or to solid wastes deposited by neighboring inhabitants on the edges of the Chari river. Metakhoukh *et al*. [20] also showed the same trend in a study carried out in south-eastern Côte d'Ivoire. Elevated contents of suspended materials in water considered as a form of pollution, could lead to increased warming of water, that negatively affects the habitat quality of water cool organisms [28]. Water quality for SM at all water sampling sites was acceptable in the dry season, but was at risk in the wet season (SEQ-water classification).

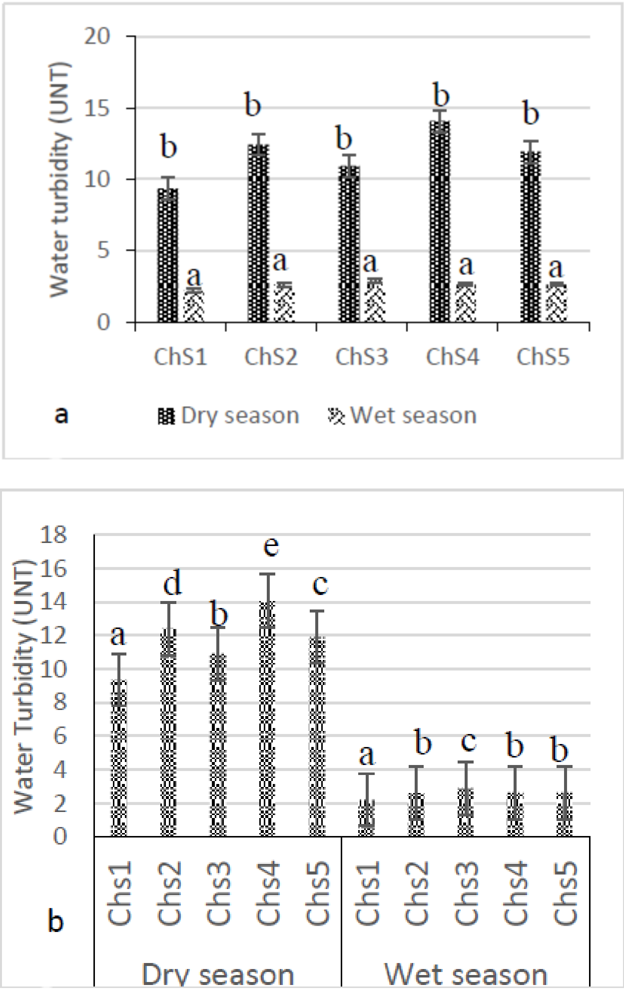

Figure 6. Variation of water turbidity between sampling sites (a) and seasons (b) along the Chari river

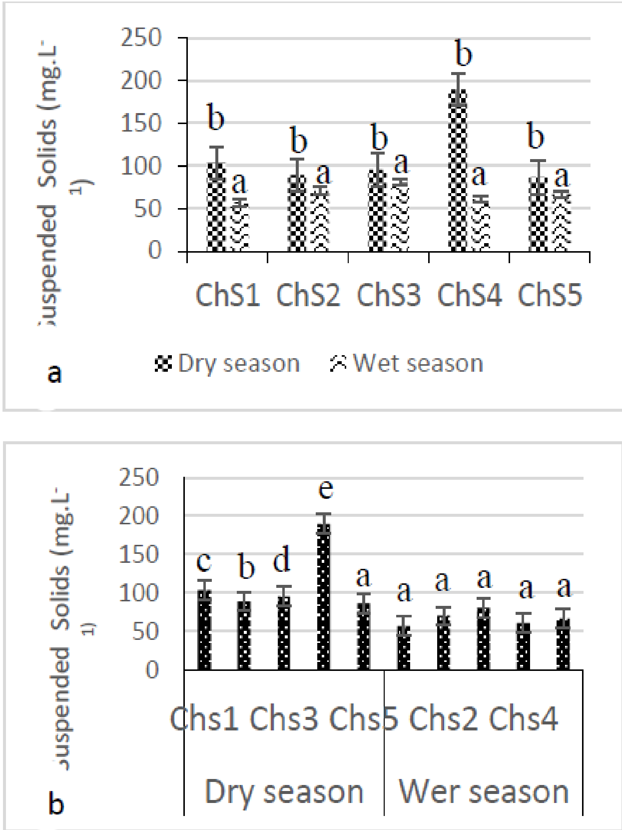

Figure 7. Influence of seasons sampling sites (a) and seasons (b) on water suspended solids along the Chari river

Variation of water chemical parameters between sampling sites and seasons

Nitrates

Nitrate constitutes the final stage of nitrogen oxidation, and represents the nitrogen form with the highest degree of oxidation present in water. Nitrate concentrations in natural water range from 1 to 10 mg.L^{-1} [20].Table 1 highlights the nitrate fluctuations between 10.49 mg.L^{-1} (ChS1) and 16.57 mg.L^{-1} (ChS5) during the dry season, against 38.11mg.L^{-1} (ChS5) and 52.01 mg.L^{-1} (ChS1) for the wet season. In other words, nitrates were concentrated downstream the Chari river in the dry season and upstream in the wet season, suggesting the dilution phenomenon. Weak nitrate contents in water in the dry than in the wet season were previously reported by Metakhoukh *et al*. [20]. Although weakly utilized by neighboring inhabitants for their agricultural activities, the elevated concentrations of nitrates in the wet compared to the dry season could be due to leaching of chemical fertilizers used for crop production, along the edges of the Chari river, as has been previously reported [14], and constitute one of the main degrading factor of water quality. Present in its natural state and soluble in the soil, nitrates penetrate in soils and ground water, then circulates into rivers. Conversely, the weak nitrates contents of the dry season could be attributed to wastes water from CST company in the Sarh township, particularly at water sampling sites close to CST factory, or to the weak oxygen content that could not oxygenate the nitrogen to its highest degree to form nitrate. However, these nitrate concentrations remained below the WHO reference value of 50 mg.L^{-1}, except for site ChS1, which recorded higher than norm values in the wet season. This increase in nitrate content is thought to be due to leaching from agricultural soils crossed by the river, as nitrogen is present in water in its nitrate form (NO_3^-). Apart from site ChS1, studied water samples were not subjected to pollution risks by nitrates, since nitrate contamination seems to be linked to ground water sources contaminated with infiltrated pollutants from agricultural activities [29]. Since nitrate content in water is influenced by climatic variations and depends on temperature and the water content, the most important nitrates flux and concentrations of nitrates generally occur during the wet season, where water is abundant to cover the plant needs [24]. Thus, draining of soils by water increase the leaching potential, thus the nitrate flux in water [30].

Table 1. Changes in water chemical parameters between sampling sites and seasons

3 **Water parameters (mg.L^{-1})**	Seasons	Water sampling points upstream to downstream the Chari river					
		ChS1	ChS2	ChS3	ChS4	ChS5	p-values
	Dry	14.707±0,03d	10.04±0.06c	8.010±0,01b	7.21±0.02a	27.30±0.01c	0.0001
COD	Wet	32,01±0,01d	27,01±0,01b	24.80±0.01a	29.49±0.01c	32.70±0.01e	0.0001
	p-values	0.0001	0.0001	0.0001	0.0001	0.0001	
	Dry	26.69±0.01d	22.39±0.02b	34.70±0.02e	18.9±0.01a	24.70±0.00c	0.0001
CO2	Wet	38.21±0.01e	24.50±0.01b	28.70±0.01c	21.40±0.02a	35.90±0.01d	0.0001
	p-values	0.0001	0.0001	0.0001	0.0001	0.0001	
	Dry	0.91±0.02a	1.59±0.01c	2.10±0.00c	2.04±0.06d	1.11±0.01b	0.0001
Total N	Wet	5.50±0.01e	3.90±0.01c	4.80±0.01d	2.50±0.01a	2.71±0.01b	0.0001
	p-values	0.0001	0.0001	0.0001	0.0001	0.0001	
	Dry	2.39±0.01e	0.59±0.01b	1.06±0.11d	0.90±0.00c	0.41±0.01a	0.0001
Total P	Wet	9.10±0.02d	7.30±0.01c	5.20±0.01b	5.21±0.01b	4.80±0.01a	0.0001
	p-values	0.0001	0.0001	0.0001	0.0001	0.0001	
	Dry	10.49±0.02a	11.60±0.01c	11.07±0.02b	12.83±0.06d	16.57±0.15c	0.0001
N03$^-$	Wet	52.01±0.01e	47.01±0.01d	39.10±0.01b	43.50±0.01c	38.11±0.01a	0.0001
	p-values	0.0001	0.0001	0.0001	0.0001	0.0001	
	Dry	5.97±0.08d	0.06±0.05a	4.01±0.01c	0.003±0.15a	3.01±0.01b	0.0001
NO2$^-$	Wet	0.21±0.00b	0.04±0.00a	0.07±0.00a	0.02±0.00a	0.09±0.11a	0.0063
	p-values	0.0001	0.0072	0.0001	0.0023	0.0001	
	Dry	/	/	1.00±0,00	/	/	/
SO4^{2-}	Wet	5.01±0.00a	2.00±0.00b	2.00±0.00b	2.001±0.02b	2.00±0.00b	0.0001
	p-values	/	/	0.0001	/		

Nitrite: Nitrites can be encountered in water, but generally at low concentrations, water containing nitrites being considered suspect [24]. Nitrite contents in water (Table 1) were significantly ($p = 0.0001$) more elevated in the sampling site (ChS1) than in others, both in the dry (5.97 mg.L^{-1}) and the wet (0.21 mg.L^{-1}) seasons, compared to between 8.75 µg.L^{-1} and 69.35 µg.L^{-1} reported by Keumean *et al*. [19] in ivory Coast. Nitrites are considered as intermediate ions between nitrates and amoniacal nitrogen, as such, is encountered in weak quantity in water. Contrary to our expectations, nitrite contents were more important in the dry than the wet season, not in agreement with observations of Akil *et al*. [21], who revealed instead more nitrites concentration in water during the wet season. During the dry season, the concentrations of nitrite at ChS1, ChS3 and ChS4, were above the [25] norm, which is 0.1 mg.L^{-1}, thus were at risk as drinking water.

Sulfates

The concentrations of surface water is generally comprised between 2.2 mg.L^{-1} and 5 mg.L^{-1} [31]. In this study, sulfate was found to be accumulated only in the water sampling site ChS3 in the dry season. Although it was quantified in all the samples during the wet season, its content was very weak, with only 2 mg.L^{-1} at ChS2, ChS3, ChS4, ChS5, and 2.5 folds concentrated at sampling site ChS1 (Table 1). This elevated sulfate content could be linked to the dissolution of sedimentary rocks and the use of chemical fertilizers in this predominantly agricultural area as pointed out by [32,33]. However, the weak sulfates contents in the studied water samples could be seen as the effect of agricultural activities practiced along the Chari river of Banda township, with no or very little use of sulfates containing fertilizers. According to Barry and Biggs [34], the anthropic origin of sulfates are the combustion of charcoal and kerosen leading to an important production of sulfures, and the use of chemical fertilizers. Similar weak values 1-1.3 mg.L^{-1} were also reported in the Senegal river [24]. Very high concentration of sulfates (14.03-237.74 mg.L^{-1}) in some water was reported to be attributed to the presence of secondary formation such as gypsium [21]. However, the studied water samples were not at risk for sulfate, as far as water quality is concerned, since its content was below the limit value set by the National Water Quality standards (250 mg.L^{-1}) according to SEQ-water.

Chemical Oxygen Demand (COD): The chemical oxygen demand (COD) represents the quantity of oxygen consumed by chemically oxidable matter contained in water, including organic compounds, but also oxidable mineral salts such as sulfures and chlorures. COD registered from the studied water samples was comprised between 7.21 mg.L^{-1} (ChS4) and 27.30 mg.L^{-1} (ChS5) in the dry season, against between 24.80 mg.L^{-1} (ChS3) and 32.70 mg.L^{-1} (ChS4) in the wet season (Table 1). COD values were very weak in the dry than the wet season, but were always more important at ChS4 sampling site both in the dry and the wet season. The increased COD values at ChS4 could be due to leaching of residual matters flowing from the upstream (ChS1) to the downstream (ChS4) direction, and containing different inorganic elements. This peak could be attributed to discharges from the Sarh slaughterhouse, agricultural waste or unidentified upstream sources of pollution. [35] also obtained a significant COD value in the waters of the Inaouene river in Morocco. In the dry season, water quality was safe from COD, except for site ChS5, and very safe in the wet season based on the SEQ-water classification.

Total nitrogen and phosphorus contents: Nitrogen is present in nature in different forms including mineral (nitrate (NO_3^-), nitrite (NO_2) and ammonium (NH_4^+), organic which is integrated in organisms (plant roots, microflora et microfauna), and soil organic matter. In this study, nitrogen content in sampled water was comprised between 0.91 and 2.10 mg.L^{-1} in the dry season, compared to 2.50 and 5.50 mg.L^{-1} in the wet season, the highest accounting for ChS1 in the wet and ChS3 in the dry season. The high total nitrogen values in the wet season could be justified by leaching of agricultural soils by rainwater into the river. Similar results were found by Houelome *et al*. [36] in Alibori river water in Benin. Although nitrogen is one of the most important elements for plant growth, it induces perturbation of aquatic ecosystems [37]. Total phosphorus comes mainly from domestic, agricultural and industrial activities [38].

Phosphorus concentration was significantly greater at ChS1 in the dry (2.39 mg.L^{-1}) and wet seasons (9.1 mg.L^{-1}). Water from ChS5 sampling site was the less concentrated in phosphorus with only 0.41 and 4.80 mg.L^{-1} during the dry and wet seasons respectively. Our values are higher than those of Keumean *et al*. [19], who presented mean phosphate values ranging from 60.43 µg.L^{-1} to 304.13 µg.L^{-1}.

Correlations between some phsico-chemical water parameters

Pearson's correlation coefficients can be used to prepare scientific measures for better management of the water. Relationships between water parameters varied between sites and seasons. During the dry season, turbidity was positively and significantly ($p = 0.009$) correlated with suspended materials ($r = 0.66$) and total Nitrogen ($r= 0.57$; $p= 0.033$). Indeed, turbidity (Tu) was been reported to be closely linked to suspended solids (SS) by the equation Tu = 13.426 + 0.04303 SM [39,40]. In contrast, negative and significant correlations were found between turbidity and CO_2 ($p = 0.008$), total phosphorus ($p = 0.003$), and nitrite ($p < 0.0001$). Elevated turbidity could thus favor the proliferation of saprophytic microorganisms that feed on these organic charges. Sulfate on its part was negatively correlated with SM ($r = -0.25$; $p = 0.038$), but was positively and significantly linked to CO_2 ($r = 0.86$; $p = 0.0001$). Whereas COD was positively linked to total N ($p = 0.021$), it was instead positively associated to nitrate ($p = 0.048$). High content of COD could indicate excessive consumption of oxygen with lethal consequences on aquatic life, leading to water eutrophization that provides Nitrate [41]. During the wet season, apart from SM which was positively and significantly correlated with the turbidity ($r = 0.28$; $p<0.0001$), sulfate ($r = -0.85$; $p = 0.0001$), nitrate ($r = -0.81$; $p = 0.0002$), Total P ($r = -0.79$; $p = 0.0004$), nitrite ($r = -0.61$; $p= 0.014$), COD ($r = -0.73$; $p = 0.0019$), CO_2 ($r = -0.51$; $p = 0.014$) were all negatively correlated with turbidity. Sulfate only negatively correlated with the SM ($r = -0.78$; $p = 0.0006$), while showing positive relationship with all the other parameters. A negative correlation was established between suspended solid and nitrite ($r = -0.58$; $p = 0.02$), nitrate ($r = -0.69$; $p = 0.005$), and $C0_2$ ($r = -0.56$; $p= 0.027$), whereas total P was positively linked to nitrite ($r = 0.62$; $p = 0.012$), and nitrate ($r = 0.62$; $p = 0.0001$). On the overall, COD shares strong negative and significant relationships with CO_2, SM, total N and P, whereas turbidity was also negatively correlated with $SO4^{-2}$, COD, CO_2, total P, nitrite and nitrate during both the dry (Table 3) and wet seasons (Table 2). On the basis of the above, it seems like COD, SM and turbidity are important water parameters, the most at risk to be considered as far as the water quality of Chari river is concerned.

Table 2. Relationships between water parameters during the wet season

	Test de Pearson	Turbidity	$SO4^{2-}$	DCO	SS	Total N	Total P
C°	r						
	p						
Turbidity	r	1					
	p						
$SO4^{2-}$	r	-0.851	1				
	p	0.0001					
DCO	r	-0.733	0.470	1			
	p	0.0019	0.076				
SS	r	0.980	-0.781	-0.848	1		
	p	<0.0001	0.0006	0.0001			
CO2	r	-0.519	0.656	-0.613	-0.566		
	p	0.0474	0.007	0.015	0.027		
Total N	r	0.292	0.696	-0.234	-0.151	1	
	p	0.290	0.003	0.401	0.591		
Total P	r	-0.795	0.846	-0.202	-0.677	0.713	1
	p	0.0004	0.0001	0.468	0.005	0.002	
NO3-	r	-0.817	0.784	0.217	-0.698	0.540	0.952

	Test de Pearson	Turbidity	$SO4^{2-}$	DCO	SS	Total N	Total P
	p	0.0002	0.0005	0.435	0.005	0.377	0.0001
NO2-	r	-0.614	0.802	0.410	-0.589	0.629	0.624
	p	0.014	0.0003	0.128	0.020	0.011	0.012

Table 3. Relationships between water parameters during the dry season

Parameters	Test de Pearson	Turbidity	$SO4^{2-}$	COD	SS	Total N	Total P
C°	r						
	p						
Turbidity	r	1					
	p						
$SO4^{2-}$	r	-0.253	1				
	p	0.382					
COD	r	-0.208	-0.391	1			
	P	0.474	0.166				
SS	r	0.668	-0.250	-0.504	1		
	p	0.009	0.038	0.066			
CO_2	r	-0.673	0.869	-0.060	-0.607		
	p	0.008	0.0001	0.836	0.021		
Total N	r	0.570	-0.583	-0.743	0.488	1	
	p	0.033	0.025	0.002	0.076		
Total P	r	-0.722	-0.030	-0.214	-0.003	-0.391	1
	p	0.003	0.918	0.467	0.991	0.166	
NO3-	r	0.423	-0.352	0.776	-0.059	-0.226	-0.692
	p	0.131	0.216	0.001	0.840	0.435	0.006
NO2-	r	-0.947	0.279	0.295	-0.535	-0.544	0.707
	p	<0.0001	0.334	0.305	0.048	0.044	0.004

4. Conclusion

The physico-chemical analysis of water from Chari river along the Banda township has revealed a high degree of spatial and seasonal variability of the assessed parameters between the water sampling sites. The pH values have remained within the maximum limits set by Chad's National Drinking Water standards (6.5-8.5) except for station ChS1, where a slightly acidic pH was observed. In the dry season, water quality was safe for COD, except for site ChS5, based on the SEQ-water classification. Apart from the sampling site ChS1 that was contaminated with nitrate in the wet season, water from all the other sampling sites were not at risk for nitrate concentration. During the dry season, the concentrations in nitrite at sites ChS1, ChS3 and ChS4, were above the OMS (2002) norm, which is 0.1 $mg.L^{-1}$, thus were at risk as drinking water. The registered TDS values in the dry season were largely above the acceptable limits for drinking water which is set to 5 NTU. Water quality for SM at all water sampling sites was acceptable in the dry season, but was at risk in the wet season (SEQ-water classification). These elevated parameter contents are suggested for some to be attributed to the leaching of agricultural input residues and organic matters drained by runoff into the Chari river, and for others to seasonal variations.

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