

Investigation of the water quality of daily used surface-sources for drinking and irrigation by the population of Segou in the center of Mali

Amadou Toure, Duan Wenbiao, Zakaria Keita and Abdramane Dembele

ABSTRACT

This study evaluates the quality and pollution status of source surface waters in Segou, Mali. The nature, sources, and extent of pollution of Comatex Stream, Cerfitex Pond, and Sonikoura River were studied for a period of twelve months (July 2016–June 2017). Analysis included 209 water samples collected from eleven different locations in the study area. Laboratory and field analysis were realized using the standard methods and concerned eleven parameters including four physicals, six chemicals and one bacteriological. Also, organoleptic parameters were observed. Most of the average values of parameters addressing the quality of water were significantly higher ($P < 0.05$) in both the stream and river compared to the pond. Fecal coliform counts (FCC) were not in significant correlation with the temperature; pH and turbidity; but had a significant and positive correlation ($P < 0.05$) with conductivity: total dissolved solids (TDS); total suspended solids (TSS); Cl^- ; PO_4P ; NO_3N and 5-day biochemical oxygen demand (BOD_5). Analysis of samples revealed a level of FCC that is above the permissible limit for both drinking water and of fresh vegetable irrigation water. In all, there is a pressing need to inform the public about the state of water bodies and the application of relevant laws regarding the proper treatment of sewage before it is discharged into surface water.

Key words | evaluation, irrigation, Mali, pollution, sewage, water sources

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INTRODUCTION

According to [Hamid *et al.* \(2007\)](#), only 0.014% of the 13,600 million km^3 of water that covers our planet constitutes fresh water which is in the form of surface water. If this quantity is sufficient to meet the future needs of humanity, alteration of water quality makes it compatible with ever smaller human uses ([Wheal 1991](#)). In fact, the quality of water is affected by an overload of organic matter, toxic substances from agricultural activities and industrial and domestic effluents being discharged into the environment.

Contamination of surface water by pathogens is a pollution problem that goes back a long way. During the nineteenth century, water-borne and food-borne diseases were responsible for widespread epidemics of dysentery,

typhoid fever, cholera, among others ([Pruss *et al.* 2002](#); [Servais & Isabelle 2002](#); [WHO 2009](#)). Nowadays, these diseases are responsible for the high morbidity and mortality rates among people in developing countries. Worldwide, about six million children die each year globally from gastroenteritis, 100 million people permanently suffer from waterborne gastroenteritis, 260 million people have schistosomiasis, 2–3 million deaths are observed each year among the 800 million malarious subjects, and 30 million onchocerciasis are counted ([Payment & Riley 2002](#)). Most of the global populations which do not have access to potable water sources fulfilling the WHO recommendations are in West and Central Africa ([WHO 2011](#)). Water sources with

poor sanitation conditions are likely to be affected by pathogenic germs (fecal pathogens) leading to public health hazards. The health issues may be due not only to the nutrient level beyond the allowable threshold but also to enteric pathogens that affect water destined for human consumption, and domestic uses as well as irrigation (Shivasharanappa *et al.* 2011). In addition to point sources (industrial effluents and sewage treatment plants), animal waste, domestic wastewater, malfunctioning septic system, and runoff flows are potential diffuse sources of contamination (Igbinoso & Okoh 2009; Odjadjare & Okoh 2010; Chigor *et al.* 2012). Moreover, high population growth, land expansion along river banks and in the watersheds, industrialization as well as climate change, impose a raised need on surface waters not only as sources of water for various purposes, but also as porters of treated and non-treated sewage (Raghuwansh & Pandey 2013; Soney *et al.* 2015). Consequently, access to clean water and proper sanitation increased needs for good health and it is also a fundamental element for the proper running order of a community (Rodier *et al.* 2009; WHO 2009). Three recent case-control studies in Mali identified the drinking of surface water as a risk factor for children's enteric infections (Bryce *et al.* 2006; Halvorson *et al.* 2011; Toure *et al.* 2018). However, in Mali, diarrheal disease accounts for about 22% of the annual deaths of children under five years of age and 90% of these deaths are directly related to contaminated water, lack of sanitation and hygiene (Bryce *et al.* 2006; CPS/MS *et al.* 2007; Halvorson *et al.* 2011).

Segou is the capital city of the fourth region situated in the center of the Republic of Mali. In Segou, surface water sources susceptible to fecal contamination constitute, in general, the main sources that are used by the population for drinking and irrigation (Byamukama *et al.* 2000; Agbogou *et al.* 2006; Karu *et al.* 2013). Using non-treated and treated effluent for the irrigation of fresh vegetables is a habit in this locality and the Nianankoro Fomba Hospital of Segou recorded a high prevalence of enteric and waterborne infections within the population (Hamidou & Sutton 2006; Diallo 2010; Seib 2011). Also, investigations showed that the sanitary condition of potable water as distributed to inhabitants in the region is dissatisfying (Seib 2011). It was thus necessary to investigate the water quality of the water sources that serve the population in this locality. Hence,

the impact of industrial wastewater and chemical pollutants on waters source (surface waters) has been reported by several works (Hamidou & Sutton 2006; Diallo 2010; Seib 2011). Unfortunately, less care has been directed to the microbiological status of surface water sources in the investigation area. In this study, we evaluated the physico-chemical, bacteriological properties and sensory of water from Comatex Stream, Cerfitex Pond and Sonikoura River situated in Segou. Also, the nature, sources, and extent of pollution of these surface waters were characterized.

MATERIALS AND METHODS

Study area and sampling sites

The study was conducted in the region of Segou, which is situated between 12°30'–15°30'N and 4°–7°W in Mali. The region of Segou covers an area of 62,504 km², representing 5% of the total land area of Mali. It has a total population estimated at 2,338,349 inhabitants according to the population and housing census of 2009 (INSTAT 2011). The region is served over 292 km by the Sonikoura and Niger River as well as one of their tributaries which is called Bani. Segou has a typical sudano-sahelian climate with a dry season (October–May) and a rainy season (June–September). The annual mean values of the temperature and rainfall are 28 °C and 200–800 mm, respectively (Sourisseau *et al.* 2016). Farming, animal husbandry, and angling are the major activities of the population in the area of Segou (OWAS 2007). Our investigations focused on three sites (Comatex Stream, Sonikoura River, Cerfitex Pond) constituting raw sources for drinking water production industries. Comatex Stream discharges into the Sonikoura River, from where the inhabitants of Alamisani and Comatex City source water for domestic uses. Cerfitex Pond discharges into Niger River. It should be noted that the Niger River is the primary raw water source for Segou waterworks. While Comatex Stream plays the role of the recreation and flock watering, Sonikoura River is mainly used for gardening.

The water samples were collected at eleven sampling points (possible contamination sites) which are presented in Figure 1. However, three sites, namely S1, S2, and S3,

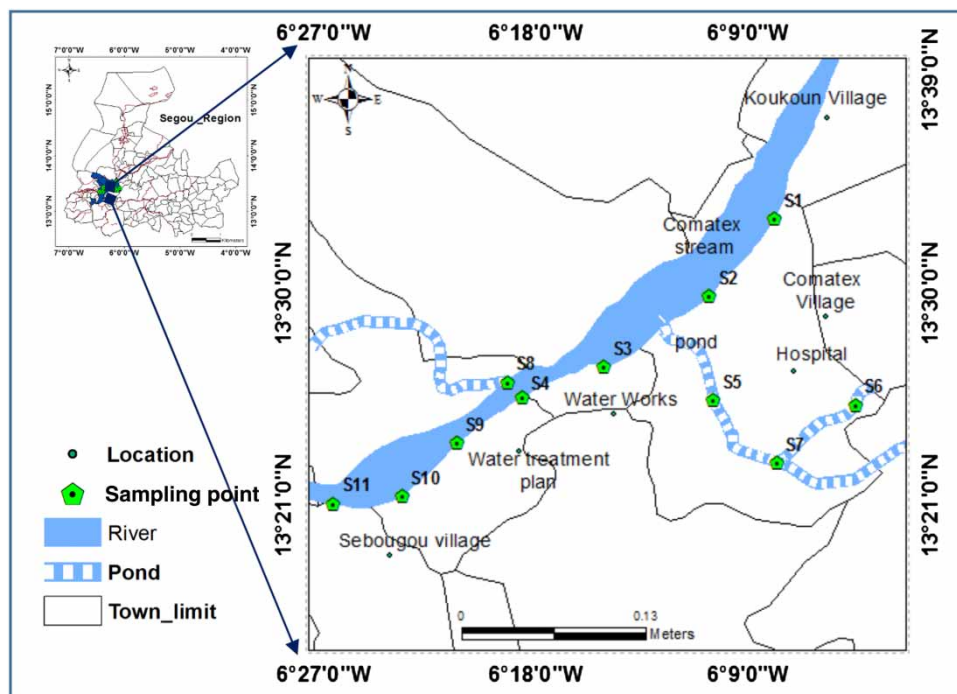


Figure 1 | Map of Segou region showing sampling sites.

were chosen along the Comatex Stream. S1 represents the source of contamination from municipal wastewater from Comatex and Koukoun village; S2 is the site close to the Comatex residence septic pits, and S3 is a point where the stream meets the Sonikoura River. Four sites were chosen along the Cerfitex Pond namely S4, S5, S6, and S7. S4 is a site where treated sewage effluent enters the Niger River; S5 is the site where anthropogenic activities are frequent; S6, where water is sourced for crop wetting and livestock needs; S7 is another point where effluent is drained into the pond. Finally, four sampling zones, namely S8, S9, S10, and S11, were adopted along the Sonikoura River. S8 is a site at a superficial area where herdsmen water their animals; S9, S10, and S11 were at 500-meters intervals downstream from S8.

Organoleptic parameters

Organoleptic parameters that may affect or cause a nuisance or undesirable environmental impact in waters used for recreation and drinking were detected using sensory methods. These include appearance, color, and odor of the water.

Water sampling

Sampling was carried out throughout 12 months during the dry and rainy seasons, from July 2016 to June 2017. A total of 209 water samples were collected from 11 different sites within the study area (as highlighted above). Sampling time was between 09:00 and 11:00 hrs, and samples were collected at a depth of about 30 cm in the wave direction. Samples were collected in polypropylene and sterile glass bottles (500 mL) for physico-chemical and bacteriological analyses, respectively. The water samples were labeled and kept between 0 and 4 °C using a cooler. The samples were transferred to the laboratory for bacteriological analysis within 6 hours of collection.

Physicochemical analyses

Temperature, pH, EC, and turbidity were measured *in situ* using a digital thermometer pH meter WTW (Wissenschaftlich-Technische Werkstätten GmbH, Germany), conductivity meter WTW, and turbidimeter, respectively. The subsequent mentioned analyses were carried following the procedures described by Rodier *et al.* (2009). Water

samples were passed through a 0.45 µm filter paper, and the permeates was analyzed for total dissolved solids (TDS), and total suspended solids (TSS). Nitrate (NO₃⁻N) concentrations were measured using the salicylate method. Chloride was measured using the Mohr's method. Phosphate (PO₄⁻P) was measured using the phosphomolybdate method. Five-day biochemical oxygen demand (BOD₅) was measured titrimetrically after incubation in BOD flasks at 20 °C in obscurity conditions.

Bacteriological analysis

The Multiple Tube Fermentation Method (APHA 1998; Stevens *et al.* 2003) was used for the bacteriological analysis of water samples comprising the most probable number (MPN) of presumptive coliforms, fecal coliforms (MPN/100 mL water). Furthermore, we relied on morphological, cultural and biochemical characteristics to detect suspected colonies of coliform groups.

Statistical analysis

The statistical analysis was carried out using SPSS software version 21.0. The average values of physicochemical parameters for the dry and the rainy seasons were compared by applying Student's t-test, and one-way analysis of variance (ANOVA) and Duncan's multiple range tests were used to establish the difference between the average values of parameters that were measured at various water bodies through the whole sampling sites. The correlation coefficient between different water quality parameters was calculated by the Pearson correlation test, using a 5% significance level ($P < 0.05$).

RESULTS

Sensory parameters

The results presented in Table 1 are organoleptic characteristics of water samples from Comatex Stream, Cerfitex Pond, and Sonikoura River obtained during the dry and the rainy seasons. In the dry season, the Comatex Stream water had water hyacinths and emitted undesirable odors. During the rainy season, trash solids were present in both the Comatex Stream and Sonikoura River. The Cerfitex pond water was clean and clear during the dry season, and in the rainy season, the water was clear despite having water hyacinths at the sampling point. Results show that almost all the waters were colorless and odorless except for Comatex Stream which had an undesirable odor in the dry season.

Water quality assessment using different water parameters

The water samples from Comatex Stream (S1, S2, S3), Cerfitex Pond (S4, S5, S6, S7) and Sonikoura River (S8, S9, S10, S11) were measured and a comparison between the average values of the different water quality parameters for each sampling sites is shown in Table 2 and Figures 2(a)–2(c). Since water from those sites is also used for domestic purposes, the results were compared with the World Health Organization (WHO 2008) and the United States Public Health (USPH 1998) Guidelines for Drinking Water. The water samples at the sampling sites had a temperature range of 18–31 °C with an average value range of 25.18–25.84°. S5 had the highest average value. pH was in the range of 5.80–7.85. In all the tested sites, S9 had the highest pH value, and S1 had the lowest values (Figure 2(a)).

Table 1 | Results of organoleptic parameters

Surface water	Appearance		Color		Odor	
	Dry season	Rainy season	Dry season	Rainy season	Dry season	Rainy season
Comatex Stream	Not clear with water hyacinth	Not clear with trash solids	Colorless	Colorless	Undesirable odor	Odorless
Cerfitex Pond	Clean and clear	Clear with water hyacinth	Colorless	Colorless	Odorless	Odorless
Sonikoura River	Clear with algae aquatic weeds	Not clear many trash solids	Colorless	Colorless	Odorless	Odorless

Table 2 | Average values of water parameters compared to all the sampling sites

Surface water	Site	T (°C)	pH	EC (µS/cm)	Turbidity (NTU)	TDS (mg/L)	TSS (mg/L)	Chloride (mg/L)	PO4 P (mg/L)	NO3 N (mg/L)	BOD5 (mg/L)	FCC (MPN/100 mL)	Variables (average ± standard deviation)		
													EC (µS/cm)	Turbidity (NTU)	TDS (mg/L)
Comatex stream	S1	25.18 ^a ± 2.58	6.30 ^a ± 0.43	647.27 ^a ± 45.48	55.66 ^{cd} ± 4.18	45.43 ^a ± 1.81	31.71 ^a ± 1.41	97.79 ^{ab} ± 4.46	0.31 ^a ± 0.04	2.47 ^a ± 0.14	7.95 ^a ± 0.20	6.7 × 10 ^{5a} ± 7.6 × 10 ⁴			
	S2	25.67 ^a ± 3.24	6.41 ^{ab} ± 0.28	515.82 ^b ± 43.38	38.50 ^{cd} ± 3.07	29.00 ^{bc} ± 1.15	31.14 ^a ± 1.80	82.39 ^a ± 2.63	0.15 ^{cd} ± 0.03	2.16 ^{ab} ± 0.04	5.75 ^b ± 0.50	1.2 × 10 ^{5b} ± 1.1 × 10 ⁴			
	S3	25.46 ^a ± 3.46	6.54 ^{ab} ± 0.22	233.92 ^{cd} ± 26.27	259.92 ^a ± 9.35	19.14 ^d ± 1.57	23.07 ^{bcd} ± 1.09	35.29 ^{bc} ± 1.92	0.24 ^{bc} ± 0.03	1.74 ^{abc} ± 0.25	1.33 ^{de} ± 0.11	25 × 10 ^{5b} ± 0.3 × 10 ⁵			
Cerfitex pond	S4	25.62 ^a ± 3.45	6.59 ^{ab} ± 0.15	251.36 ^{cd} ± 30.74	227.87 ^{ab} ± 7.48	26.86 ^{bc} ± 1.21	20.36 ^{bcd} ± 1.99	36.92 ^{bc} ± 2.28	0.17 ^{cd} ± 0.03	1.99 ^{abc} ± 0.25	1.65 ^{de} ± 0.09	6.7 × 10 ^{5b} ± 4.7 × 10 ²			
	S5	25.84 ^a ± 3.14	6.56 ^{ab} ± 0.19	192.49 ^{cd} ± 26.59	86.30 ^{cd} ± 6.02	20.00 ^{cd} ± 1.29	16.07 ^{cd} ± 1.77	21.16 ^c ± 2.41	0.08 ^d ± 0.06	1.46 ^c ± 0.09	0.63 ^c ± 0.15	0.4 × 10 ^{2c} ± 0.2 × 10 ¹			
	S6	25.38 ^a ± 3.31	6.45 ^{ab} ± 0.30	203.04 ^{cd} ± 59.87	101.69 ^{bcd} ± 4.70	19.71 ^{cd} ± 2.81	25.71 ^{ab} ± 1.04	25.10 ^{bc} ± 2.07	0.16 ^{cd} ± 0.03	1.67 ^{bc} ± 0.15	1.52 ^{de} ± 0.06	3.2 × 10 ^{5b} ± 1.6 × 10 ²			
Sonikoura river	S7	25.50 ^a ± 3.20	6.29 ^a ± 0.18	180.53 ^{cd} ± 14.64	128.79 ^{bcd} ± 4.75	22.29 ^{bcd} ± 2.43	12.14 ^d ± 1.25	30.52 ^{bc} ± 3.18	0.25 ^{ab} ± 0.03	1.74 ^{bc} ± 0.03	1.06 ^{de} ± 0.07	1.1 × 10 ^{5b} ± 1.1 × 10 ²			
	S8	25.52 ^a ± 3.57	6.37 ^{ab} ± 0.19	279.32 ^c ± 13.68	38.00 ^{cd} ± 4.29	30.00 ^{bc} ± 2.58	15.21 ^{cd} ± 0.86	29.85 ^{bc} ± 1.51	0.21 ^{abc} ± 0.23	1.95 ^{abc} ± 0.13	3.47 ^c ± 0.38	3.0 × 10 ^{4b} ± 0.8 × 10 ³			
	S9	25.54 ^a ± 3.47	6.65 ^b ± 0.25	252.42 ^c ± 5.42	80.17 ^{cd} ± 1.91	24.71 ^{bcd} ± 1.38	12.86 ^{cd} ± 0.69	27.59 ^{bc} ± 1.56	0.16 ^{cd} ± 0.03	1.67 ^{cd} ± 0.11	1.00 ^{de} ± 0.11	0.4 × 10 ^{4b} ± 0.2 × 10 ³			
Range	S10	25.56 ^a ± 3.25	6.58 ^{ab} ± 0.22	190.21 ^{cd} ± 23.65	133.13 ^{abcd} ± 5.58	22.29 ^{bcd} ± 0.95	19.29 ^{bcd} ± 1.25	22.56 ^c ± 1.99	0.15 ^{cd} ± 0.02	1.84 ^{abc} ± 0.04	1.10 ^{de} ± 0.09	0.1 × 10 ^{4b} ± 0.1 × 10 ³			
	S11	25.27 ^a ± 3.09	6.41 ^{ab} ± 0.36	190.47 ^{cd} ± 17.61	168.55 ^{abcd} ± 6.77	33.36 ^{ab} ± 1.95	25.50 ^{ab} ± 1.71	40.38 ^b ± 2.55	0.14 ^{cd} ± 0.09	2.00 ^{abc} ± 0.05	2.40 ^c ± 0.16	2.4 × 10 ^{4b} ± 5.5 × 10 ³			
WHO		18–31	5.80–7.85	71–1,012	2.3–786	12–69	11–71	9.6–175	0.02–0.37	0.50–2.95	0.12–13.1	3.95 × 10 ¹ –1.9 × 10 ⁶			
USPH			6.5–8.5		5	500		250		50		0			
			6.0–9.0		≤ 5	500		250	0.1	50		0			

For each parameter, averages with the different letters (superscripts) are significantly different ($P < 0.05$), using Duncan's multiple range tests. PO4 P phosphate-phosphorus, NO3 N nitrate-nitrogen, FCC fecal coliform counts, WHO World Health Organization, USPH United States Public Health.

The electrical conductivity of the water samples from the different waters ranged from 71 to 1,012 µS/cm. The highest concentration was obtained by the S1 sample, whereas the lower value was found in the S7 sample. The turbidity of the samples ranged from 2.3 to 786 NTU, with the highest being the S3 sample.

The TDS of the samples had a range of 12–69 mg/L with S1 having the highest concentration (Figure 2(b)). The TSS varied from 12.14 to 31.71 mg/L and the highest average value observed was presented by S1. Distinctive lower chloride (Cl⁻) concentration was noticed at Cerfitex Pond and Sonikoura River compared to that of Comatex Stream. Similarly, S1 had the highest phosphate concentration, and S5 had the lowest concentration. Overall, the concentrations of the nitrate in all the water samples were below the WHO and USPH limits (250 mg/L). The highest concentrations were observed in the Comatex Stream (Figure 2(b)). BOD₅ values for different sites ranged from 0.12 to 13.1 mg/L, the highest average value (7.95 mg/L) was observed in the Comatex Stream (S1) and the lowest (0.63 mg/L) in the Cerfitex Pond (S5). However, the significantly higher ($P < 0.05$) average BOD₅ values were noticed at S1, S2, S8, and S11.

S1 and S2 had higher FC counts, respectively, while S3 was the lowest. Also, S8 had significantly higher fecal coliform counts (FCC) values than S9, S10, and S11 (Figure 2(c)).

The correlation analysis (Table 3) indicated that temperature correlated positively with pH, turbidity, TDS, phosphate, and nitrate (0.67, 0.55, 0.19, 0.35 and 0.29, respectively). No significant correlation was observed between pH and FCC and between pH and other parameters. EC was highly significantly and positively correlated with the TDS (0.76; $P < 0.05$), TSS (0.68; $P < 0.05$), phosphate (0.50; $P < 0.05$), nitrate (0.77; $P < 0.05$) and BOD₅ (0.94; $P < 0.05$), chloride (0.95; $P < 0.05$), FCC (0.85; $P < 0.05$). Turbidity was found to be significantly and positively correlated ($P < 0.05$) with the water temperature (0.55), TSS (0.45) and phosphate (0.30). Similarly, TDS had a positive relationship with temperature (0.19), conductivity (0.76), TSS (0.54), nitrate (0.85), chloride (0.78), phosphate (0.51), BOD₅ (0.85), and FCC (0.83), but negatively correlated with turbidity (-0.34). TSS positively correlated with conductivity (0.68), BOD₅ (0.72) and FCC (0.58). Similarly, chloride (Cl⁻) indicated a significant positive correlation with EC (0.95), TDS (0.78), TSS (0.77),

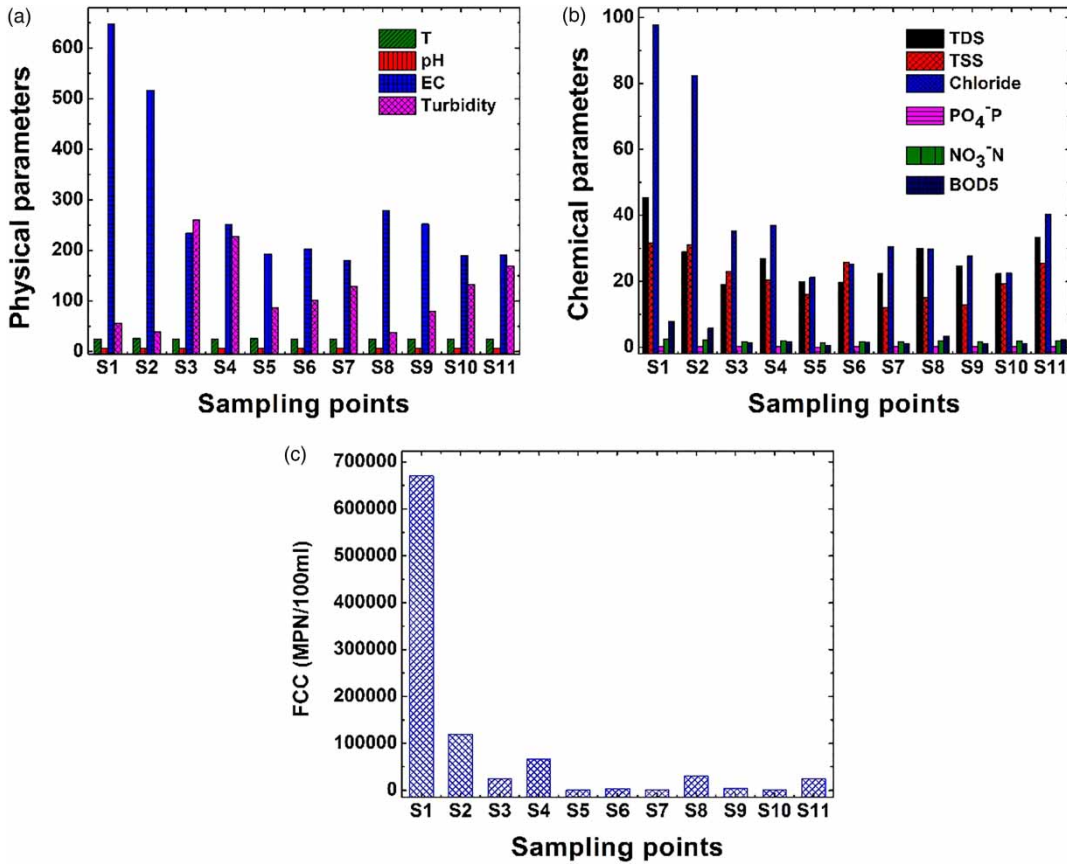


Figure 2 | (a)–(c) Physical, chemical and bacteriological parameters of the different water samples.

Table 3 | Pearson correlation between different water quality parameters of the study site

Variables	Temperature	pH	EC	Turbidity	TDS	TSS	Chloride	PO ₄ -P	NO ₃ -N	BOD ₅	FCC
T	1.00										
pH	0.67*	1.00									
EC	0.10	-0.08	1.00								
Turbidity	0.55*	0.10	-0.45	1.00							
TDS	0.19*	-0.09	0.76*	-0.34	1.00						
TSS	0.14	0.003	0.68*	0.45*	0.54*	1.00					
Chloride	0.05	-0.15	0.95*	-0.33	0.78*	0.77*	1.00				
PO ₄ -P	0.35*	0.09	0.50*	0.30*	0.51*	0.14	0.48*	1.00			
NO ₃ -N	0.29*	0.01	0.77*	-0.16	0.85*	0.68*	0.82*	0.60*	1.00		
BOD ₅	0.04	-0.11	0.94*	-0.49*	0.85*	0.72*	0.95*	0.50*	0.83*	1.00	
FCC	-0.001	-0.13	0.86*	-0.05	0.83*	0.58*	0.84*	0.60*	0.71*	0.86*	1.00

*Correlation is significant at $P < 0.05$.

nitrate (0.82), PO₄-P (0.48), BOD₅ (0.95), and FCC (0.84), but negatively correlated with turbidity (-0.33). Phosphate-phosphorus related positively with nitrate-nitrogen, BOD₅

and FCC, (0.60, 0.50 and 0.60, respectively). Finally, BOD₅ was in positive correlation with EC (0.94), TDS (0.85), TSS (0.72), chloride (0.95), phosphate (0.49), nitrate (0.83),

and FCC (0.86); and in negative correlation with turbidity (-0.49).

The samples were grouped into three groups, namely Comatex Stream (S1, S2, S3), Cerfitex Pond (S4, S5, S6, S7) and Sonikoura River (S8, S9, S10, S11), and the average values for each group with respect to the different seasons and quality parameters are presented in Table 4. The results are also graphically exemplified in Figures 3(a)–3(c). Water temperature reflected changes corresponding to the seasons, with significantly higher values ($P < 0.05$) recorded during the rainy season. The highest average value (28.20 °C) was observed in Cerfitex Pond, while the lowest was seen in Sonikoura River (21.89 °C). The average pH value varied between 6.16 and 6.26 during the dry season (i.e. significantly lower average values were observed in the dry period); and in the rainy season, the average value varied from 6.65 to 6.81. Similarly, the highest EC during the rainy season was obtained in the Comatex Stream, whereas the lowest average values were found in the dry season at the Cerfitex Pond (Figure 3(a)). Turbidity values were heightened during the rainy season.

The Comatex Stream water had the highest average TDS value ($P < 0.05$) which was in the dry season, and the Cerfitex Pond during the dry season had the lowest average TDS concentration (Figure 3(b)). In the rainy season, the highest average TSS values were recorded, whereas the lowest was obtained in the dry season in the three different water bodies. The Comatex Stream water had the highest average Cl^- value ($P < 0.05$) which was recorded in the rainy season, while the Cerfitex Pond had the lowest mean value which was observed in the dry season. The observed values for chloride in both seasons were within the permissible limit. Overall, the nitrate concentrations were higher in Comatex Stream and Sonikoura River as compared to Cerfitex Pond. However, the Comatex Stream during the rainy season had a significantly higher average value ($P < 0.05$) than the other samples. The highest BOD₅ average values were recorded by the Comatex Stream during the rainy season, while the Cerfitex Pond in the dry season had the lowest average BOD₅ value.

According to the Student's t-test, among the sample groups, Comatex Stream had a significantly greater ($P < 0.05$) FCC (MPN/100 mL) during the rainy season as compared to the dry period (Figure 3(c)).

Table 4 | Average values of water parameters compared to two seasons at the three water bodies

Parameter	Variables (average ± standard deviation)											
	Comatex Stream				Cerfitex Pond				Sonikoura River			
	Dry season	Rainy season	Dry season	Rainy season	Dry season	Rainy season	Dry season	Rainy season	Dry season	Rainy season	WHO	USPH
T (°C)	22.23 ^b ± 0.84	28.08 ^a ± 1.03	22.06 ^b ± 0.68	28.20 ^a ± 0.97	21.89 ^b ± 0.43	28.06 ^a ± 0.75	-	-	-	-	-	-
pH	6.16 ^b ± 0.28	6.69 ^a ± 0.14	6.26 ^b ± 0.25	6.65 ^a ± 0.11	6.24 ^b ± 0.13	6.81 ^a ± 0.08	6.5–8.5	6.0–9.0	-	-	-	-
EC (µS/cm)	397.04 ^b ± 171.56	445.81 ^a ± 203.77	166.47 ^b ± 41.69	219.80 ^a ± 33.02	220.21 ^a ± 58.67	230.68 ^a ± 33.20	-	-	-	-	-	-
Turbidity (NTU)	103.42 ^b ± 100.67	111.51 ^a ± 109.04	117.59 ^b ± 48.34	127.93 ^a ± 51.43	90.73 ^b ± 49.31	119.04 ^a ± 51.16	5	≤5	-	-	-	-
TDS (mg/L)	34.29 ^a ± 12.43	28.14 ^b ± 11.36	20.86 ^b ± 3.76	23.71 ^a ± 2.63	25.64 ^b ± 4.19	29.21 ^a ± 5.42	500	500	-	-	-	-
TSS (mg/L)	27.43 ^b ± 4.68	30.36 ^a ± 4.04	17.29 ^b ± 5.77	19.36 ^a ± 0.7	16.00 ^b ± 4.13	19.93 ^a ± 5.85	-	-	-	-	-	-
Chloride (mg/L)	63.64 ^b ± 28.78	78.54 ^a ± 29.14	25.38 ^b ± 6.68	30.89 ^a ± 6.67	26.38 ^b ± 5.46	31.78 ^a ± 8.10	250	250	-	-	-	-
PO4 P (mg/L)	0.19 ^b ± 0.06	0.25 ^a ± 0.08	0.11 ^b ± 0.07	0.21 ^a ± 0.05	0.16 ^b ± 0.03	0.19 ^a ± 0.03	-	-	-	-	-	-
NO3-N (mg/L)	1.91 ^b ± 0.38	2.24 ^a ± 0.28	1.60 ^b ± 0.15	1.80 ^a ± 0.22	1.73 ^b ± 0.14	1.94 ^a ± 0.13	50	50	-	-	-	-
BOD ₅ (mg/L)	4.21 ^b ± 2.97	5.37 ^a ± 2.85	1.06 ^b ± 0.48	1.41 ^a ± 0.35	1.71 ^b ± 1.09	1.72 ^a ± 0.77	-	-	-	-	-	-
FCC (MPN/100 mL)	1.96 × 10 ^{3a} ± 2.66 × 10 ³	8.99 × 10 ^{3a} ± 5.95 × 10 ³	2.79 × 10 ^{3a} ± 2.65 × 10 ³	3.40 × 10 ^{3a} ± 2.90 × 10 ³	1.33 × 10 ^{4a} ± 1.37 × 10 ⁴	1.35 × 10 ^{3b} ± 1.34 × 10 ³	0	0	-	-	-	-

For each parameter, averages with the different letters (superscripts) are significantly different ($P < 0.05$), using Student's test. PO4 P phosphate-phosphorus, NO3-N nitrate-nitrogen, FCC fecal coliform counts, WHO World Health Organization, USPH United States Public Health.

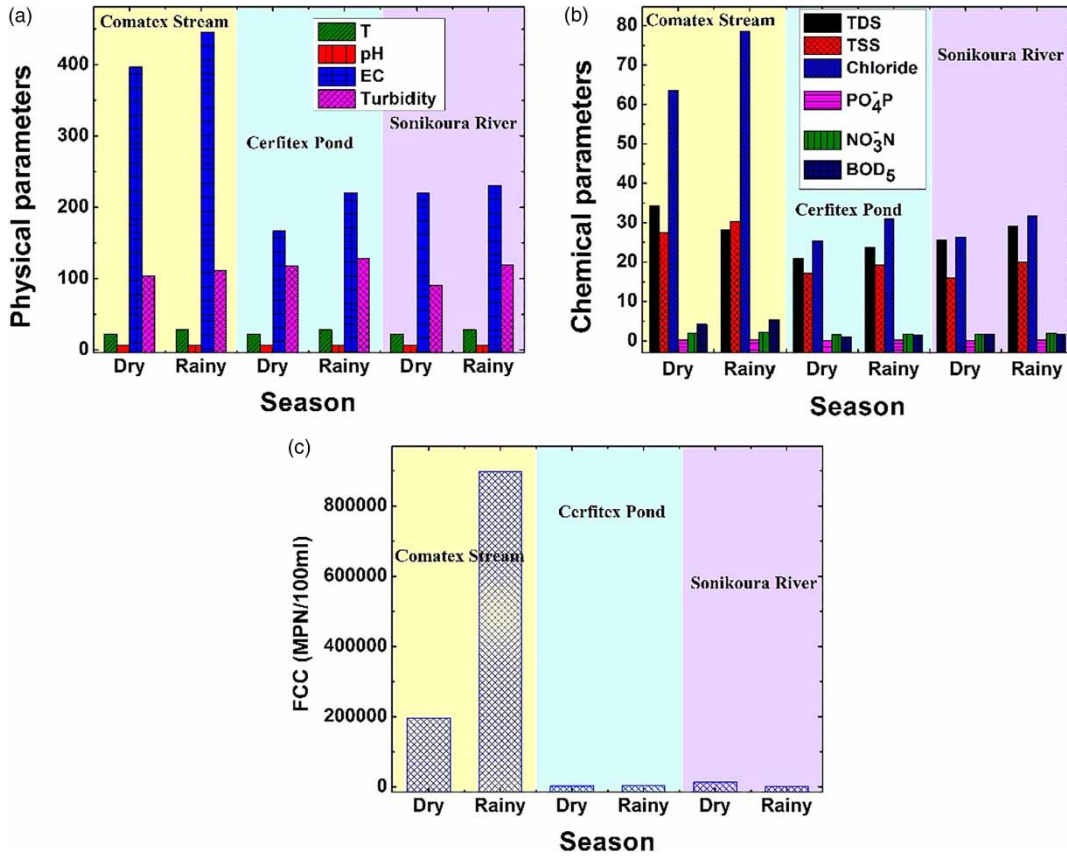


Figure 3 | Seasonal variations in some physical, chemical and bacteriological parameters in the water sample from the three water bodies.

DISCUSSION

The effect of climatic seasons on different surface waters contaminated by physical, chemical and microbial contaminants serve as the basis for this study. It is noticed that almost all the water bodies were colorless and odorless except for Comatex stream which had an undesirable odor in the dry season. Indeed, it was noted that during the dry season, the Comatex Stream had water hyacinth and emitted undesirable odors, which consequently limited their use for recreational purposes. Additionally, in the rainy season, trash solids (polythene bags and plastic bottles, cans, etc.) were found in the Comatex Stream and Sonikoura River. This indicates poor sanitary and wastes disposal practices by inhabitants around those water systems. It was observed that the Cerfitex Pond was clean (clear water) during the dry season and also clear in the rainy season, despite the presence of water hyacinths. A

large flora of water hyacinths was observed downstream where treated sewage effluent from Cerfitex enters the Niger River. Similar observations were noted by [Alhou et al. \(2009\)](#) on the Niger River and revealed that it is the visual and odorous aspects of the environment that considerably impacts on the popular conception of water quality.

Correlation of physical parameters

The temperature of the three water bodies was variable according to the sampling period (rainy or dry). The highest temperature was observed from May to October corresponding to the rainy season. Thus, water temperature was significantly higher ($P < 0.05$) in the rainy season than in the dry season. Results showed that there was a significant correlation between water temperature and pH, turbidity, TDS, and nitrate, respectively. This is due to

the fact that the temperature has an impact on physical and chemical properties of water; in particular density, viscosity, the solubility of its gases (in particular that of oxygen) and speed of chemical and biochemical reactions (HCEFLCD 2006). Although there was no significant correlation between temperature and FCC, it was noted that S5 recorded not only the highest temperatures but also the lowest number of coliforms. This could be explained by the fact that the water was retained for a considerable time in the extraction pipe.

No significant correlation was observed between pH and FCC. However, significantly lower pH value was observed at S1 during the dry season. It may be as a result of the discharge of stormwater (which was alkaline in nature) from Comatex and Koukoun village into this water source. The low pH values during the dry season may be due to rising CO₂ concentrations as a result of the reduction in water level. All the sampling locations were found to have pH within the permissible limits prescribed by USPH (1998) and WHO (2008).

EC is a numerical term which is the capacity of water to transport electric current, while ionic force as conductivity is a measure of TDS (Agbogu *et al.* 2006). The ionic force of a sample depends not only on the ionization of solutes, but also on other dissolved substances (WHO 2008). However, the significant positive correlation that has been found between EC and TDS (0.76), chloride (0.95), nitrate (0.77), respectively, is consistent with this relationship. The higher conductivity obtained at point S1, compared with other sampling locations, may be explained by the discharge of effluent from domestic sewage from Comatex village.

Interestingly, the turbidity load of the water samples did not significantly correlate with the FCC of the samples. It may be linked to the fact that turbidity typically is influenced by the presence of clay or silt particles, plankton, as well as organic and inorganic matter (WHO 2008). It was therefore not surprising that the highest turbidity value was recorded at S3 as field investigations revealed that S3 was more affected by the water from upper Sonikoura river that was more influenced by soil erosion, stormwater runoff, and eutrophication. It was observed that the turbidity values at Comatex Stream, Cerfitex Pond, and Sonikoura River were above 5.00 NTU, the allowable limit recommended by USPH (1998) and WHO (2008) for drinking water. Turbidity

was severely influenced by storms, which allowed the highest values to be recorded in a rainy season. Variations obtained during this season may be due to possible sedimentation, according to the time interval among storm event and sampling. The significantly greater turbidity values experienced in the rainy period is similar to Chigor *et al.* (2012) who stated that the turbidity was strongly affected by storm events within the rainy period in Zaria surface waters, Nigeria.

Correlation of chemical parameters

Dissolved solids were analyzed in order to ascertain the level of inorganic and organic substances contained in the water samples which were in molecular, ionized or microgranular suspended forms. A positive correlation existed between TDS and temperature, conductivity, TSS, nitrate, chloride, phosphate, BOD₅, and fecal coliform count, respectively. The most desirable limit of TDS is 500 mg/L (USPH 1998; WHO 2008). The highest TDS average value (34.29 mg/L) was obtained in the Comatex Stream during the dry season, which is below the permissible limit. However, this high level of TDS could be attributed to the low volume of water during the dry season when water flow becomes low. This observation agreed with Chigor *et al.* (2012) who reported a correlation between TDS and water flow.

The concentrations of TSS related significant positive correlation with conductivity, BOD₅, and FCC. July had the highest TSS level, whereas the lowest was obtained in April in Comatex Stream, Cerfitex Pond, and Sonikoura River. The high average value of TSS was noticed in the rainy season in Comatex Stream compared to that of Cerfitex Pond, and Sonikoura River may be attributed to effluents from industrial premises and runoff waters from Comatex and Koukoun village.

Throughout the study period, distinctly lower chloride (Cl⁻) concentration was noticed at Cerfitex Pond and Sonikoura River compared to that of Comatex Stream. The Cl⁻ contents were in the order of 9.6–175 mg/L and indicated a significant positive correlation with EC, TDS, TSS, nitrate, PO₄P, BOD₅, as well as FCC. These strong correlations (between Cl⁻ and EC, TDS) suggest, on the one hand, that Cl⁻ raises the EC of water, and on the other hand, that

Cl^- is one of the main anionic components of dissolved solids. Additionally, domestic waters and thermal waters of the Comatex Stream (rich in chlorides) could be at the origin of these fluctuations because according to WHO (2008), Cl^- levels are higher in domestic sewage than raw water. According to WHO and USPH, the maximum permissible limit for chloride in drinking water is 250 mg/L. Results showed that average values in this present study ranged from 21.16 to 97.79 mg/L, which indicates less contamination of chloride.

Phosphates come not only from domestic sewage (human urine and detergents) but also from agricultural activities via soil erosion (Nora *et al.* 2015). High concentrations of phosphates and nitrates can bring about eutrophication, which substantially increases algae content in the water body. These algae may affect the passage of light and oxygen consumption in a water body, which can be hazardous to existing wildlife in such water (Garras *et al.* 2015). The phosphate values of the water samples from the different water bodies ranged from 0.02 to 0.37 mg/L, and 10 of the 11 sites exceed the permissible limit (0.1 mg/L) of the US Public Health Standards. The highest phosphate value (0.31 mg/L) was noted during the study in April at S1, and the lowest value (0.09 mg/L) was observed in July at S5. This increase in value in April may be explained by the significant release of domestic wastewater which contained high amounts of phosphate constituents. There was a significant correlation between phosphate-phosphorus and nitrate-nitrogen, BOD_5 , and FCC, (0.60, 0.50, and 0.60, respectively). Lehtola *et al.* (1999) demonstrated that phosphorus determines the microbial growth of water. The positive correlation between phosphate and BOD_5 suggests that nutrient enrichment may cause eutrophication in aquatic systems, thus affecting the level of dissolved oxygen in the water. Additionally, the positive correlation between PO_4P and FCC suggests that phosphorus can influence the microbial growth of water (Chigor *et al.* 2012).

Currently, the most common ecological challenges with surface waters are eutrophication and the presence of excess nitrogen. However, results showed that the Comatex Stream had nitrate concentrations higher than Sonikoura River and Cerfitex Pond. It may be caused by run-off of soils containing inorganic fertilizers into the stream as a result of rainfall or

floods, as well as the discharge of organic matter from domestic wastewater into the stream by the community close to the stream. In high concentrations, nitrate may cause methemoglobinemia, also known as 'blue baby' syndrome which usually affects bottle-fed infants (Karu *et al.* 2013). Despite some sampling sites recording relatively high levels of nitrates, the mean values of all the analyzed water samples were in accordance with the WHO and USPH standards (50 mg/L). Therefore, monitoring the level of algal growth in Comatex Stream is necessary because it can present significant health risks to consumers and generate severe environmental issues.

BOD_5 is another significant element used to evaluate the water quality concerning both suspended and dissolved organic materials. However, surface water is considered to be free from pollutants when it has a $\text{BOD}_5 \leq 2$ mg/L (Hobson & Poole 1988). In all the tested sampling sites, the highest average BOD_5 value was observed in the Comatex Stream during the rainy season, and the lowest average value was the Cerfitex Pond in the dry season. The high amount of BOD observed within the rainy season may be due to the increased efficiency of surface run-off, discharge of municipal sewage from Comatex and Koukoun villages, Sebougou sewage treatment plant and industrial effluents discharge into Comatex Stream and Sonikoura River. Additionally, the low BOD_5 values (<5.00 mg/L) noticed at Cerfitex Pond suggest low organic pollution. Owing to the high volume of water, the extent of pollution may not pose a significant danger to aquatic life and people using it for domestic and irrigation purposes.

Correlation of biological parameters

Fecal coliforms are common bacteria in the digestive tract of humans and animals. It is an index of fecal contamination of water. The results in Table 2 and Figure 2(c) shows that high FC counts were recorded at S1 and S2, and S3 had the lowest count. The high coliform at S1 and S2 is an indication of poor sanitary practices of inhabitants around those sites. Moreover, the FCC at S8 was significantly higher than S9, S10, and S11. It may be due to the malfunction of the Sebougou sewage treatment plant (STP) which released raw wastewater into the river at a point upstream of S8. Notably, in January, all the water samples had low FCCs which coincided with the usual drop in population and anthropogenic activities

associated with migration of inhabitation during the Christmas and New Year holiday period. The Student's t-test revealed that Sonikoura River had significantly greater ($P < 0.05$) FCC (MPN/100 mL) during the dry season compared to the rainy period. The high presence of FCC in the dry period is a result of the combined effect of the discharge of effluent from Sebougou wastewater treatment plant as well as the low water volume during the dry season. The result of the correlation analysis between the bacteriological and physicochemical parameters concurred with the previous works reported by Katherine et al. (2015). So, the present analysis meets the requirement that consists of using the bacterial density as the fundamental measure in evaluating freshwater sources quality. The results reveal coliform bacteria in every water sample, and none of the water samples met the WHO and USPH guidelines for human consumption. The fecal coliform count should be zero (per 100 mL) of the sample in all drinking water supplies, piped or unpiped, treated or untreated, and <1,000 fecal coliforms/100 mL for unrestricted irrigation (USPH 1998; WHO 2008). Therefore, these waters are not suitable for domestic use, recreation purpose, and the irrigation of fresh vegetables without treatment.

CONCLUSIONS

This paper investigated the pollution status of Comatex Stream, Cerfitex Pond, and Sonikoura River which are polluted continuously by both point and non-point sources of feces, especially by municipal wastewater, failing septic tanks, surface run-off and an inefficient sewage treatment plant. With respect to the significant differences in BOD₅ and FCC, Comatex Stream and Cerfitex Pond were the highest and lowest polluted, respectively. This study revealed that the quality of the water exceeded the limits set for microbiological infection risks proposed in water quality guidelines, notably for domestic use, recreation purpose, as well as for irrigation of fresh vegetables. Excessive applications of chemical fertilizers and pesticides have increased the nitrate concentration in Comatex River. It is suggested that heightened attention regarding sanitary and waste disposal practices in the study area should be given in order to prevent an epidemic of waterborne diseases in that area.

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