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Assessment of Surface Water Contamination by Heavy Metals Due to Agricultural Practices in the Northern Part of Burkina Faso

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Authors' contributions

This work was carried out in collaboration among all authors. Author SBMY designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author ADH managed the analyses of the study. Authors SBMY, ADH and BG managed the literature searches. Author BG read and correct the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Aims: The purpose of this study was to assess the status of the heavy metals As, Cd, Pb, Mn and Zn in the surface water of the Sub-catchment Barrage of Tougou for which water comes mainly from agricultural activities.
Place and Duration of Study: A total of 73 water samples were taken at the inflow of the water body and at several points located on the water body, from August to October 2019.
Methodology: Water samples were characterized for temperature, pH, electrical conductivity (EC), sulfate (SO_4^{2-}), nitrate (NO_3^-) and phosphate (PO_4^{3-}). Heavy metals were analyzed using a microwave plasma atomic emission spectrometer (MP-AES), Agilent Model 4210.
Results: The EC range was between 27.45 and 53.90 µS/cm with an average pH of 6.4. Nitrate (NO_3^-) was the most abundant anion in the water (39.70 mg / L) and phosphates (PO_4^{3-}) were

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present in very small quantities (0.34 mg / L). The results showed very low concentrations of Pb and Cd, below 5 µg / L and below 2 µg / L, respectively. The concentrations of As, Mn and Zn in the water were 2.8 µg / L, 13.2 µg / L and 9.8 µg / L, respectively. Agricultural practices do not have a significant effect on surface waters. The concentrations of heavy metals analyzed in the water were lower than the standards established by the World Health Organization for drinking water quality.
Conclusion: This information, certainly important, does not allow us to conclude on the risk of the consumption of this water on human health. Further studies should be conducted on this water body to evaluate the potential risk for public health and to examine the concentrations of heavy metals in the sediments, because it is known that sediments have a high absorption capacity for heavy metals and are then considered the main target for water purification related to heavy metals.

Keywords: Heavy metals; surface water; pollution; fertilizers; Burkina Faso.

1. INTRODUCTION

The achievement of one of the Sustainable Development Goals (SDGs), which is to end hunger and malnutrition in all forms has led in recent years to the development of agriculture through agrochemicals and mechanization, which has caused soil and water quality degradation in many countries around the world [1,2]. Poor agricultural practices are the main contamination source of surface water and groundwater in watersheds. Indeed, irrigation practices and utilization of large quantities of chemicals such as fertilizers and pesticides are the agricultural practices applied to improve agricultural yields and fight against species harmful to plants [3,4].

In Burkina Faso, agriculture and animal husbandry play an important role in the national economy. These activities employ over 86% of the rural population and constitute the main source of food and income for the population [5]. In the current context of climate change, agriculture is faced with rainfall irregularities. To address this problem, the population has increased the amount of agricultural land around water bodies and in floodplains and has increased utilization of fertilizers and pesticides for improved agricultural yields. These practices near water bodies lead to flows of nutrients, chemicals, pesticide residues, pathogens and heavy metals into water resources and disrupt ecosystems in an adverse way [1,4,6,7]. Agricultural practices near water bodies are sometimes the source of heavy metals in surface waters. Indeed, the excessive use of agricultural fertilizers and runoff from agricultural lands are the major reasons for high levels of heavy metals in surface water [8].

Heavy metals are naturally present in soils, but their polluting effects are a consequence of human activities [8,9]. The mains sources of heavy metal contaminations are industries, domestic wastes and agrochemical products [10-12]. Heavy metals are those chemical elements that are able to accumulate in soils for long periods and then migrate into soil solutions and end up in the food chain and surface water. The heavy metals released into the environment can enter aquatic ecosystems and be integrated into particles deposits over time on the bottom material and by the phenomenon of salting out can become an endogenous source of watercourse pollution [13]. These heavy metals are non-degradable, and are present in the water as dissolved ions, suspended and colloids ions, and solids in water sediments [8,14]. Their concentrations in the environment are indicators of their pollution levels and toxic effects on human health. According to the World Health Organization (WHO), heavy metals, even at relatively low concentrations, can pose a risk to public health [15]. The main metals toxic to humans are lead (Pb), cadmium (Cd), arsenic (As), chromium (Cr) and mercury (Hg) [16]. The harmful aquatic effects of these metals include a decrease in the abundance of benthic invertebrates, an increase in mortality, lethality, behavioral changes and abnormal development in the early life stages of benthic organisms [17].

In Burkina Faso, addressing water resource problems has led the state to build water bodies to cope with the rainfall deficits that have been recorded since 1974. These water bodies serve as sources for agricultural use, livestock and fishing. Several studies have examined the hydrological performance, silting up, and sediment charge of these water bodies across the country [18-20]. However, studies on heavy metals concentrations in the nation's water are still rare. Therefore, it was necessary to conduct a study to assess the contamination levels of these waters by heavy metals.

The water body of the Sub-catchment Barrage of Tougou was designed in 1962 for the association of breeders and productions (AEP) of Sologum, Tougou and Faogodo villages. This water body contributes to agricultural production including pluvial agriculture, irrigation and market gardening. The main agricultural products are millet, maize, sorghum, beans and vegetables such as tomatoes and onions. The water body of the Sub-catchment Barrage of Tougou is also used as a source of drinking water for cattle, sheep and goats. Furthermore, these herds graze on land around the water body and drink water from other water inflow water canals of the water body of sub-catchment. Fishing is well developed in the water body and fishery products are used for domestic and commercial use in the region. During the winter period, the water body is supplied by runoff from surrounding lands [20].

The effect of agricultural practice on surface water of the Sub-catchment Barrage of Tougou was evaluated. This consists of measurements of heavy metals (e.g., As, Cd, Mn, Pb and Zn), physicochemical parameters (e.g., pH, T, electrical conductivity (EC) and major ions (e.g., SO_4^{2-}, PO_4^{3-} and NO_3^-). Furthermore, the relationships among these parameters and sampling station was established.

2. MATERIALS AND METHODS

2.1 Study Area

The study was conducted in the sub-catchment Barrage of Tougou, Lat. 13°40′43″ N; Long. 2°12′47″ W which covers an area of approximately 450 ha and is located in the village of Tougou, Department of Namissiguima in the eastern part of Yatenga Province in the northwest part of Burkina Faso (Fig. 1). The sub-catchment Barrage of Tougou is limited to the north by the Kerga sub-catchment, to the south by the Tougou sub-catchment, to the east by the Lorum sub-catchment and to the west by the Karma sub-catchment. The climate is semiarid and the dry season extends from October to May while the wet season stretches from June to September with peak rainfalls generally occurring in July / August. The mean annual precipitation is 650 mm and ranges from 300 mm to 700 mm; the temperatures range from 18 °C to 42°C. During the study period from August to October 2019, the cumulative value for rainfall amounted to 495 mm. The minimum rainfall amount was 1 mm and the maximum were 65 mm. The main soils in the region are classified as Ferric Lixisols. The hydrographic network is sparse and flows are concentrated in the talwegs and depressions. Streams and gutters guide the waters of the other sub-catchments to the sub-catchment Barrage of Tougou [20]. The sub-catchment Barrage of Tougou is the most important irrigation system and water supply in the region.

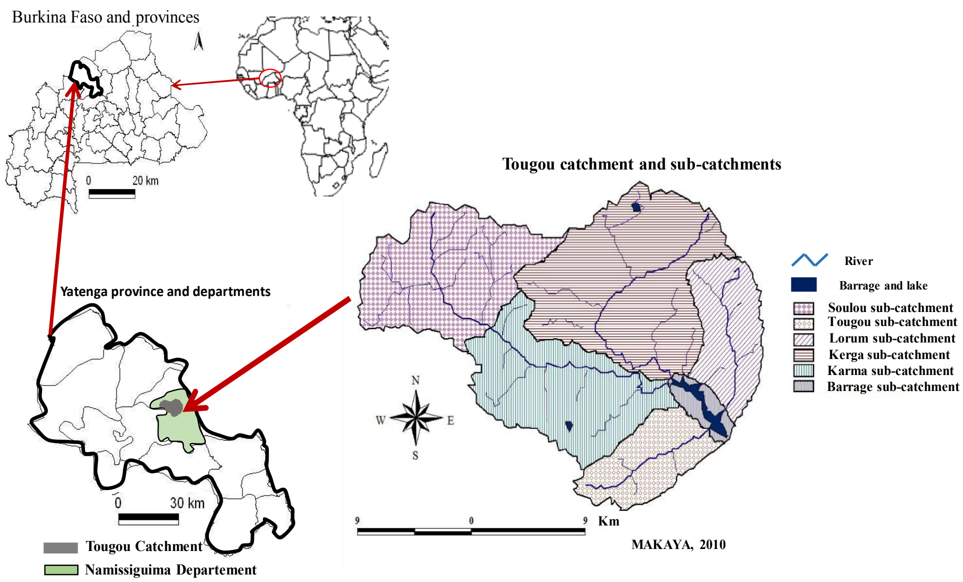

Fig. 1. Location of sub-catchment barrage of Tougou

2.2 Experimental Design and Data Collection

The sampling stations were chosen based on their accessibility and proximity to agricultural lands, which are potential source of contaminants for water flowing into the catchment water body. A total of ten (10) sampling stations were selected for this study and were distributed from upstream to downstream of the sub-catchment (Fig. 2).

The first group of stations corresponds to the sampling stations which are located at the inflows of the Sub-catchment Barrage of Tougou which collects water from other sub-catchments. Therefore, five sampling stations named Wana, Toumany, Nononga, Touroyiry and Bvo were selected (Fig. 2). Wana, located to the west of the reservoir, receives water coming from the Karma sub-basin (Laliyiri, Sougourou and Haouréma villages). Toumany and Nononga are to the north and receive water from the Kerga sub-basin (the villages of Lilbouré, Sanayiri Koumani and Siisbanko). Located to the north-east, Touroyiry receives runoff from the Lorum sub-basin (Goyiri and Pelmotanga villages). Bvo is south of the reservoir and receives runoff from the Tougou sub-basin (Faougoudou, Basnéré and Goulogou villages). The second group of stations corresponds to those located from upstream to downstream of the water body. Five sampling stations were established: Barrage, Milieu Barrage, Rive droite, Rive gauche and Deversoir (Fig. 2).

Water samples were collected during the rainy season from August to October 2019. Rainfall is irregular during this period and drought pockets can last up to 10 consecutive days. Water samples were taken at two times: one sample during the rainy period and another sample during the period without rain (during the drought pocket). In August, period with more rainy events, the samples were taken three times for each station and twice a month from September to October. Two samples were not taken from Wana and Toumany stations because of no runoff at the time of sampling. When the period of drought pockets was exceeded 15 consecutive days, one sample per station was taken for the five stations located on water body (Barrage, Milieu Barrage, Rive droite, Rive gauche and Deversoir). Samples are collected in 1 L polyethylene bottles which had previously been washed with 1-2% HCl solution, rinsed with distilled water and dried. in the field, the bottles were rinsed with distilled water before any sampling. Each sampling bottles was labeled by a date, a time and station name of collection. A total of 73 water samples were collected.

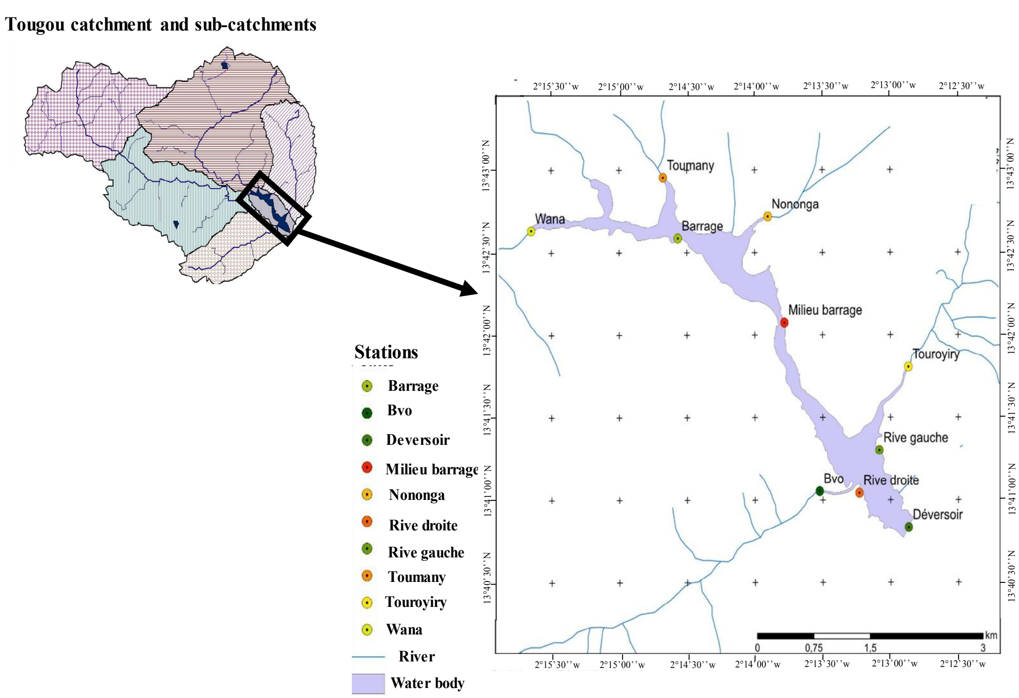

Fig. 2. Water sample collection stations

2.3 Physicochemical Analysis

Physicochemical parameters such as temperature (T), pH and electrical conductivity (EC) were measured in situ using multiparameter field kit. All analyses were carried out in the Water Hydro-Systems and Agriculture laboratory (LEHSA) of the International Institute for Water Engineering and Environment (2iE). Before analysis, water samples were filtered using a vacuum pump with a Wattman GFC 0,45 mm membrane. Sulphate (SO_4^{2-}), nitrates (NO_3^-) and phosphates (PO_4^{3-}) concentrations were determined by molecular absorption spectrometry (Direct Reading 3900). The major ions concentrations are expressed in mg / L.

2.4 Evaluations of Heavy Metals

The heavy metals, arsenic (As), cadmium (Cd), manganese (Mn), lead (Pb) and zinc (Zn) were determined following standard methods from the US EPA 2007.

The studied metals were measured with a microwave plasma atomic emission spectrometer (MP-AES), Agilent Model 4210 at a certified private laboratory, namely, the Senexel laboratory at Ouagadougou. For the analyses of Cd, Pb, Mn and Zn, 50 ml of water sample was taken and homogenized in a 50 ml centrifugal tube and was then treated with 0.5 ml of concentrated HNO_3 acid (69-70%, v/v) and 0.5 ml of concentrated HCl (36-37%, v/v). Next, the solution was filtered and the Cd, Pb, Mn and Zn concentrations were measured using MP-AES. The analytical standards were prepared in a matrix of 1% HNO_3 and 1% HCl. Arsenic (As) was measured by prereduction of arsenic with potassium iodide (KI) and then by hydride generation. For the prereduction step: 25 ml of homogenized water sample was transferred into a 50 ml tube with 5 ml of 10% HCl (v/v) and 2 ml of 25% KI (m/v) with continuous agitation. The mixture was heated in a water bath to between 50°C and 70°C for 10 min. Then, the mixture quantity was adjusted with 50 ml of deionized water after being returned to room temperature. Hydride generation was carried out with 0.6% (m/v) sodium borohydride in a solution of 0.5% (m/v) sodium hydroxide matrix. The heavy metal concentrations are expressed in µg / L.

2.5 Statistical Analysis

The data were statistically analyzed using SPSS V18.0 software. The descriptive analyses (e.g., mean, minimum, maximum and standard deviation) are represented in the form of tables and box-plot diagrams. The analysis of variance (ANOVA) was combined with the Bonferroni test to compare the means of the different categories, two by two. The differences are significant at *P* values < 0.05 or < 0.01. A correlation matrix between the physicochemical parameters, major ions and heavy metals was created using Pearson's test. A Cluster Analysis (CA) was also constructed to determine the similarity between parameters and between stations. The Ward Linkage method with squared Euclidean distance was used for the CA.

3. RESULTS AND DISCUSSION

3.1 Physicochemical Properties of Surface Water

The mean values of the physicochemical parameters, pH, Temperature (T), electrical conductivity (CE), sulfate (SO_4^{2-}), nitrate (NO_3^-) and phosphates PO_4^{3-} were measured for the surface waters in the Sub-catchment Barrage of Tougou and are presented in Table 1 and Fig. 3.

The surface water of Sub-catchment Barrage of Tougou was lightly basic. The mean pH value was 6.4 (Table 1). The mean pH was significantly higher ($P < 0.05$) during the period without rain (pH = 6.5) than during the rainy period (pH = 6.3). The average pH significantly varied ($P < 0.05$) between stations and ranged from 6.2 and 6.6 on the Nonnonga and Rive droite, respectively (Fig. 3.a). These values were in accordance with the standard levels for drinking water in the absence of distribution systems (6.5 < pH < 8.5; [21]). However, these recorded pH values were lower when comparing to other studies [22,23]. The pH value at Turnasuyu Creek, which has an alkaline character, were measured between 7.0 and 9.0 during the study [22].

The waters tended to be more acidic during the rainy period than during the period without rain (Table 1). The pH value ranged from 4.8 to 6.8 and from 6.1 to 7.0 for the rainy period and period without rain, respectively. A similar trend was reported by [24] with the lowest pH values during the wet season and the highest during the dry season. The lower pH values observed during the rainy period are attributed to runoff water from agricultural lands around the water body. Periods without rain mean that there is no runoff water from agricultural lands that can cause a significant pH drop surface waters. Indeed, adding fertilizer (generally ammonia fertilizer) leads to proton production by the nitrification process. On the other hand, as has been demonstrated by some authors, the lowest pH values in the rainy period are probably due to rainfall and leachate drainage [24–26].

The average surface water temperature was 22°C. It was lower in rainy periods than in periods without rain. This clearly reflects the decline in temperatures during wet periods compared to dry periods. This seasonal change was also observe by [27] for Pazarsuyu Stream. The differences between stations were not significant (Fig. 3.b). The highest temperature recorded was 32°C and the lowest was 14°C.

The electrical conductivity (EC) varied significantly from 40.27 µS / cm to 48.74 µS / cm in the rainy period and period without rain, respectively (Table 1). This may have resulted from decreased water volumes during periods without rain compared to the rainy period and thus impacted the concentrations of dissolved matter in the water. It is known that EC values of surface waters change according to geological structure and amount of precipitation [28]. The higher EC Values indicate the presence of higher concentration of dissolved salts in the river water and EC values are a good measure of the relative difference in water quality between different aquifers [29].The recorded values from the present study stayed much lower when comparing to the other studies. The mean conductivity (EC) values from Milet River, ranged from 124 to 520 µS / cm in March and September, respectively. This indicated that the water had different quality in different seasons as suggested by [29] for Creek water.

The EC values were significantly different between stations (Fig. 3.c). The average EC was higher for stations located on the water body (44.31 µS / cm) than for stations located at the inflow waters of the water body (38.75 µS / cm). This result suggests that the stations located at the inflow waters of the reservoir are not the only source of dissolved matter entering the water body. The EC was lower (42.01 µS / cm) than that measured in the surface waters of the Bumbu River and Kokolo Canal in the Democratic Republic of the Congo [26]. The level of EC in this study was also below the EC levels of the Pazarsuyu Stream, which one were recorded between 25.70-201 µS / cm with the average of 65.53 µS / cm [27]. In general, the waters of the sub-catchment Barrage of Tougou have low salinity. The average EC values for the surface waters in the Sub-catchment Barrage of Tougou were lower than the WHO recommended limit (200 µS / cm) [15].

The average concentrations of major ions in the surface water of the Sub-catchment Barrage of Tougou are shown in Table 1. Nitrate (NO_3^-) was the most abundant anion. Its average concentration was 39.70 mg / L, and was followed by sulfate SO_4^{2-} with an average concentration of 9.45 mg / L. Phosphate (PO_4^{3-}) was found in very small quantities in the water samples (0.34 mg / L) (Table 1). The concentration variations of SO_4^{2-} and PO_4^{3-} were not significant between stations while for NO_3^-, the concentration variations were significant between stations (Fig. 3. d, e and f). The NO_3^- concentrations ranged from 21.33 mg / L at Touroyiri to 52.89 mg / L at Deversoir. For SO_4^{2-} and PO_4^{3-} the concentrations varied between 6.67 mg / L at Touroyiri and 11.89 mg / L on Rive droite, and between 0.13 mg / L on Touroyiri and 0.70 mg / L on Milieu de barrage, respectively.

The major ion concentrations were higher in the period without rain than in the rainy period, because of the dilution effect of rainfall. The NO_3^- and PO_4^{3-} concentrations were mainly due to irrigation practices, fish farming, pastoral activities and agricultural runoff around the Sub-catchment Barrage of Tougou. Ustaoğlu et al. (2020) [30] reported that nitrogen in water is cause by agricultural activities. Indeed, during the field observations, the farmers explained that animal wastes were sometime rehung in the field. Many studies have also shown that NO_3^- and PO_4^{3-} in surface water are due to animal wastes or agricultural runoff where fertilizers are commonly used [24,31,32]. According to [33], NO_3^- and PO_4^{3-} concentrations in surface water, greater than 0.5 mg / L and 0.02 mg / L, respectively, indicate pollution levels of surface water that can cause eutrophication. The mean values of NO_3^- and PO_4^{3-} in this study were higher than the limit suggested by [33]. This indicates a risk for eutrophication in the water body of the Sub-catchment Barrage of Tougou.

Table 1. Physicochemical compositions of surface waters of the various stations during rain and without rain

	pH	T	EC	SO_4^{2-}	NO_3^-	PO_4^{3-}
		°C	µS / cm	-------------------------	mg / L	-----------------------
With Rain (*N=58*)						
Mean	6.3	21	40.27	9.12	39.38	0.34
S.E.	0.3	6	14.91	4.30	20.42	0.56
Min.	4.8	14	13.60	2.00	8.10	0.05
Max.	6.8	29	85.00	18.00	108.90	4.41
Without Rain (*N=15*)						
Mean	6.5	25	48.74	10.73	40.97	0.37
S.E.	0.3	8	9.88	6.53	19.69	0.21
Min.	6.1	14	27.30	2.00	12.50	0.05
Max.	7.0	32	60.60	28.00	82.70	0.77
Mean. (*N=73*)						
Mean	6.4	22	42.01	9.45	39.70	0.34
S.E.	0.3	7	14.38	4.84	20.15	0.51
Min.	4.8	14	13.60	2.00	8.10	0.05
Max.	7.0	32	85.00	28.00	108.90	4.41

N : Number of sample; S.E. : standard error; Min.: minimum; Max.: maximum;

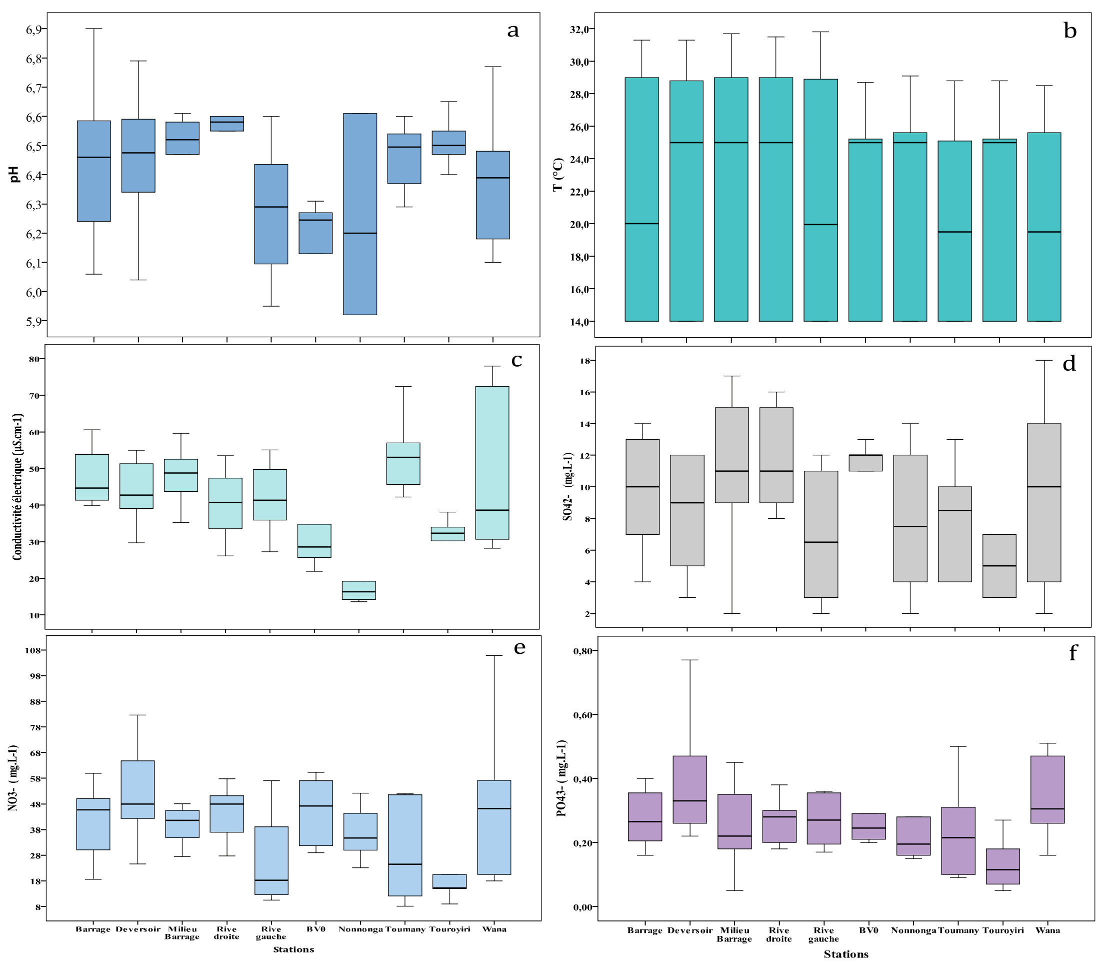

Fig. 3. Variation of (a) pH; (b) T (°C) (C) electrical conductivity (EC); (d): SO_4^{2-} (e) NO_3^-; (f) PO_4^{3-} between stations

3.2 Heavy Metal in Surface Water

The concentrations of heavy metals in the surface waters are shown in Table 2 and Fig. 4. In general, for the surface water of the Sub-catchment Barrage of Tougou, the concentrations of heavy metals such as arsenic (As), manganese (Mn) and zinc (Zn) were significantly variable ($P < 0.05$) among the stations, except for lead (Pb) and cadmium (Cd) for which the concentrations were very low. Regardless of station, the mean concentration of Pb was < 5 µg / L. Similarly, the mean concentration of Cd was < 2 µg / L except on the Rive gauche and Bvo, where the mean concentrations were 3 µg / L and 2 µg / L, respectively. The mean concentration of As was 2.8 µg / L. It varied between 1.3 µg / L on the Rive gauche and 5.2 µg / L at Bvo. Manganese was the most abundant metal in the surface water of the Sub-catchment Barrage of Tougou (Fig. 4). The mean concentration of Mn was 13.2 µg / L. The Mn concentrations ranged between 9 µg / L at Milieu Barrage and 17 µg / L on the reservoir and at Toumany. The Zn concentrations varied between 7 µg / L and 19 µg / L on Milieu barrage, Barrage and at Wana, respectively. The mean concentration was 9.8 µg / L. The mean concentrations of As, Mn and Zn were higher at those stations located on the inflow waters on the water body (e.g., Bvo, Nonnonga, Toumany, Touroyiri and Wana) than on those stations located on the water body (e.g., Barrage, Deversoir, Milieu barrage, River droite and Rive gauche). This can be explained by the anthropogenic activities upstream from the stations on the inflow waters on the water body which collected domestic waste and runoff from agricultural lands to which different fertilizers and pesticides had been applied. The mean heavy meatal concentrations were compared with the World Health Organization (WHO) standards for drinking water (Table 2). The concentrations of As, Cd, Mn and Pb in the surface waters of the Sub-catchment Barrage of Tougou were much lower than the WHO standards levels for drinking water (e.g., 10 µg / L, 3 µg / L, 400 µg / L and 10 µg / L, respectively) [15,21]. This information, certainly important, does not allow us to conclude on the risk of the consumption of this water on human health with respect to their As, Cd, Mn and Pb concentrations.

The lower lead concentration (< 5 µg / L) is probably due to its low solubility in water [34] and this presumes that it is concentrated in sediments. Many studies have shown that lead concentrations in water are lower than concentrations measured in sediments [35–37]. The low lead concentrations observed in our study may be because lead is an element which is mainly present in industrial zones and zones with high traffic density unlike the agricultural zones in our study [36,38,39].

The presence of Cd in surface waters is mainly a consequence of wastewater discharges and the use of fertilizers in agriculture [8]. The low Cd concentrations (< 2 µg / L) in the waters of this study excludes any possibility of surface water contamination by fertilizers. This is not a surprising result for wastewater because the water body of the Sub-catchment Barrage of Tougou is in rural areas. However, the fact that Cd concentrations are lower in water, despite the use of fertilizer by farmers, may be because the fertilizers used do not contain Cd.

Table 2. Concentrations of heavy metal (µg / L) in surface water of sub-catchment barrage of Tougou and maximum permitted concentration in drinking water by WHO

	As	Cd	Mn	Pb	Zn
	µg / L				
Barrage	2	< 2	17	< 5	7
Deversoir	2.3	< 2	12	< 5	8
Milieu barrage	3.4	< 2	9	< 5	7
Rive droite	<1	< 2	12	< 5	10
Rive gauche	1.3	3	13	< 5	10
Bvo	5.2	2	11	< 5	10
Nonnonga	2.2	< 2	11	< 5	9
Toumany	3.9	< 2	17	< 5	10
Touroyiri	3.3	< 2	16	< 5	8
Wana	1.6	< 2	14	< 5	19
Mean	2.8	< 2	13.2	< 5	9.8
WHO	10[1]	3[1]	400[2]	10[1]	NA

WHO : World Health Organization, As : arsenic, Cd : cadmium, Mn : Manganese, Pb : lead, Zn : zinc. NA: not available
[1]WHO, drinking water, 2017 [2]WHO, drinking water, 2008

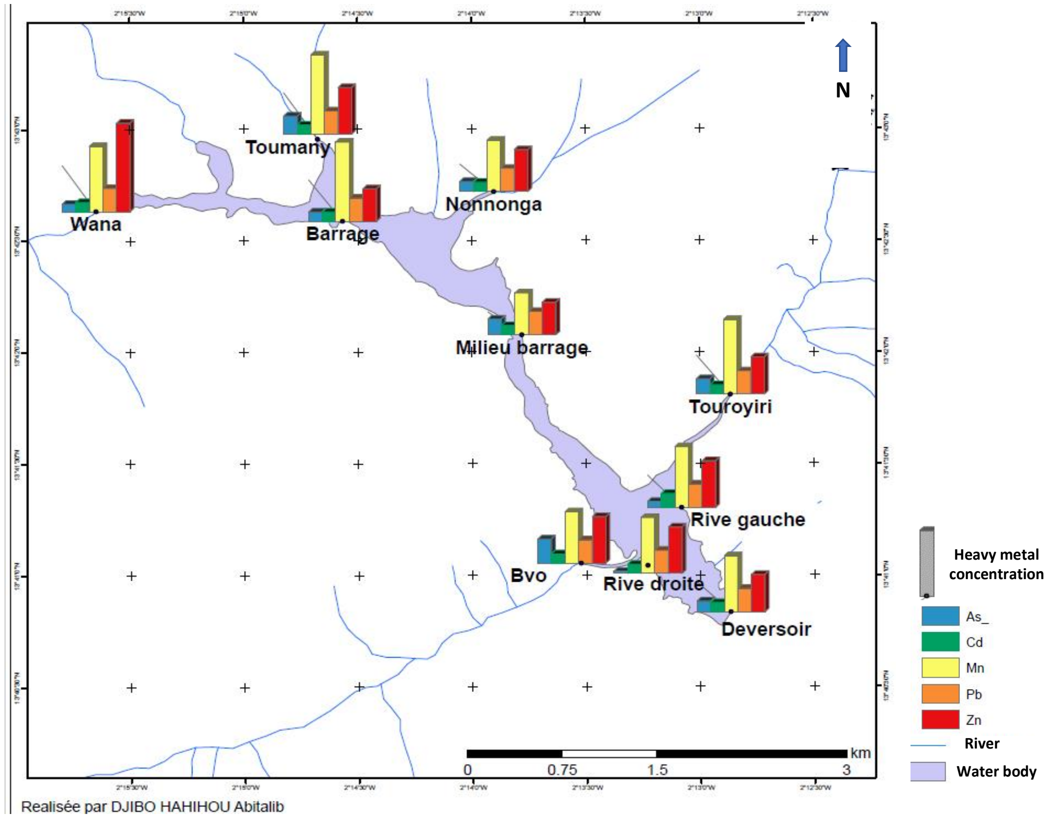

Fig. 4. Thematic map for heavy metal concentration for each station

The mean Zn concentration was higher at the stations of the inflow waters on the water body than at stations located on the water body (Fig. 4). The presence of Zn in surface waters could be the result of agricultural activities in the Sub-catchment Barrage of Tougou and the surrounding sub-catchment. Indeed, fertilizers are widely used in these plantations and could therefore enrich the waters in Zn by runoff phenomena [40]. Molina et al. [41] showed that most fertilizers which are used to mainly improve yields have high Zn concentrations. During the field observations, farmers explained that fertilizers were mostly used to increase yields and are applied before the rains.

Among all elements studied, Mn was the most abundant and this can be explained by the fact that Mn is naturally present in surface water in suspended form and at low pH values and the soluble form is persistent [42,43]. Indeed, acidic pH values in the water bodies and especially in the rainy season facilitates Mn release from sediment, hence the high contents of Mn.

A Pearson correlation matrix between the physicochemical parameters and heavy metals was carried out for the surface waters of the Sub-catchment of Tougou. The results presented in Table 3 shows that there is no correlation between pH, T, EC and SO_4^{2-}, NO_3^-, PO_4^{3-}, As, Mn, and Zn. Likewise, among the heavy metals, there is no correlation except for Zn which exhibits a significant negative correlation with As (P < 0.05) and a significant positive correlation with Mn (P < 0.01). Zn also shows a significant negative correlation with NO_3^- (P < 0.05). This correlation with NO_3^- confirms that fertilizers are the main source of Zn in water. On the other hand, the low Zn concentrations associated with high NO_3^- concentrations indicate other sources of NO_3^- originating from animal waste. The high positive correlation between Zn and Mn indicates that Zn is the metal with the second highest concentration after Mn which is naturally present in water. SO_4^{2-} shows a significant positive correlation with As and NO_3^- (P < 0.05) which indicates the anthropogenic sources of these elements, such as fertilizers, and animals waste. This is in accordance with the fact that the use of sulfate fertilizers in agricultural activities is the main raison of the presence of sulfate in surface water [27].

Table 3. Pearson correlation matrix between physicochemical parameters and heavy metal in surface water of Sub-catchment Barrage of Tougou

	pH	T	EC	SO_4^{2-}	NO_3^-	PO_4^{3-}	As	Mn	Zn
pH	1								
T	-0.189	1							
EC	-0.259	0.122	1						
SO_4^{2-}	-0.051	-0.073	0.095	1					
NO_3^-	0.087	-0.246	0.069	0.298*	1				
PO_4^{3-}	0.116	0.057	-0.002	0.104	0.113	1			
As	-0.209	0.017	-0.013	0.286*	0.268	0.158	1		
Mn	0.006	-0.014	-0.243	-0.117	-0.064	-0.120	-0.150	1	
Zn	0.176	0.069	-0.192	-0.184	-0.298*	-0.122	-0.279*	0.447**	1

**. Correlation is significant at the 0.05 level. **. Correlation is significant at the 0.01 level.*
T: temperature; EC: electrical conductivity; As: arsenic; Cd: cadmium; Mn: Manganese; Pb: Lead; Zn: Zinc

In general, the lower levels of heavy metals in the surface waters of the Sub-catchment Barrage of Tougou might be due to the dilution effect of water [44]. Heavy metal in water also originate from the geochemical structure of basin [39]. Further studies should be conducted in this water body to examine the heavy metals concentrations in the sediments because it is known that sediments have a high absorption capacity for heavy metals and are then considered as the main target for water purification related to heavy metals [8,45,46]. Furthermore, it is necessary to continue investigations to analyze the heavy metals content of fertilizers used.

Three main cluster were identified within the cluster analysis on the station basis. The selected stations located at the inflow waters of the water body and the stations located on the water body were in the same cluster. Deversoir, Nonnonga, Rive droite, Rive gauche, milieu barrage and Bvo were in the same cluster. Barrage, Touroyiri and Toumany were together and different to Wana (Fig. 5). The similarity between inflow water stations and the stations located on the water body, show that the selected stations located at the inflow waters of water body are not the only source of heavy metal entering the water body. EC and NO_3^- in the same cluster show a similarity action according to station that differ to the other parameter in the water (Fig. 5).

3.3 Heavy Metals in the Surface Water of the Sub-catchment Barrage of Tougou Compared to Surface Waters of Some Sub-Saharan Africa Countries

The heavy metal concentrations of the Sub-catchment Barrage of Tougou were compared with other results obtained from surface waters of some sub-Saharan Africa countries (Table 4).

The As concentrations in the surface water of the Sub-catchment Barrage of Tougou were higher when compared to those of natural water (1-2 µg / L, [15]). Likewise, the mean As concentration in this study was lower than those of the Lukemi and Luini River in Democratic Republic of the Congo [24]. However, the Zn concentrations had values similar to those reported for natural waters ((10-50 µg / L, [15]). The average Zn concentration in surface water was far lower than the value recorded in the Konkouré River (Guinea), Odo-Iyaalaro River (Nigeria) and Luini River (Democratic Republic of the Congo) [24, 47,48] but was higher than the results from the Bini and Dang (Republic of Cameroon) and Thohoyandou Rivers (South Africa), Lome's Lagoon (Togo) and the Lukemi River (Democratic Republic of the Congo) [24,49–51].

The Cd and Pb concentrations observed in this study were lower than those reported in some surface waters in Africa (Table 4). [49] demonstrated that the concentrations of Cd and Pb were 0.25 µg / L and 0.42 µg / L for the Bini River and 2.09 and 2.40 µg / L for the Dang river in the Republic of Cameroon, respectively. The mean concentrations of Cd and Pb ranged, respectively, from 0.1 µg / L to 10 µg / L and 1-630 µg / L, which were measured from upstream and downstream in the Konkouré surface water in Guinea [48]. Another study on the Thohoyandou River in South Africa also showed higher concentrations of Cd and Pb compared to those reported in this study [51]. As in this study, Cd concentrations in Lomé Lagoon were very low [50]. The Mn concentrations measured in the surface waters of the Sub-catchment Barrage of Tougou were lower than those measured in the surface waters of the Lukemi and Luini Rivers in the Democratic Republic of the Congo [24].

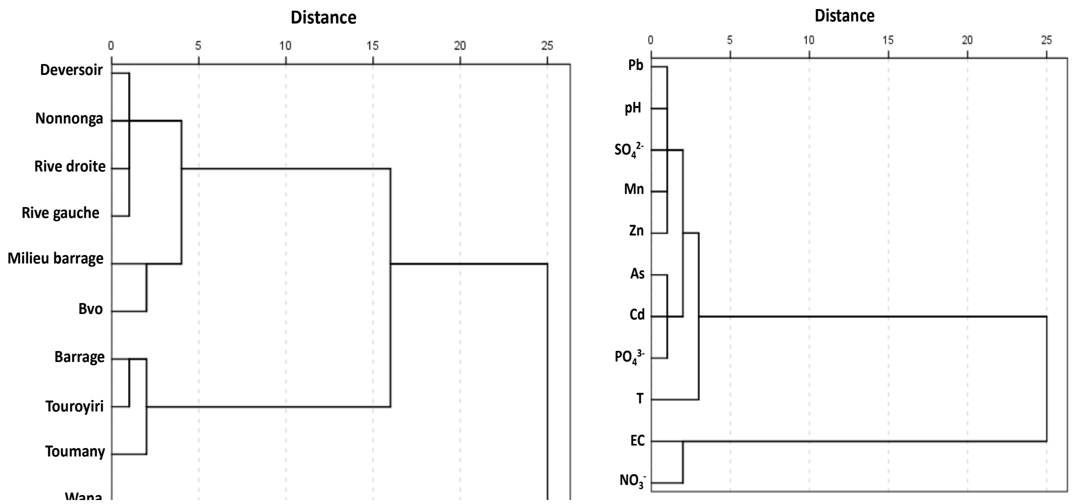

Fig. 5. Cluster of stations and parameters using Ward Linkage Method

Table 4. Comparison of concentrations (µg / L) of heavy metal in surface water with different other studies in Africa

Authors	Rivers, locations	As	Cd	Mn	Pb	Zn
		----------------µg / L --------------				
Our study		2.8	< 2	13.2	< 5	9.8
[49]	Bini, cameroon	NA	0.25	NA	2.09	0.19
	Dang, cameroon	NA	0.42	NA	2.40	0.35
[48]	Konkouré, Guinea	NA	0.1-10	NA	1-630	102
[51]	Rivière de Thohoyandou (South Africa)	NA	1.6-9.3	NA	10.5-20.1	2.1-2.5
[50]	Lomé's lagoon, Togo	NA	< 0.5	NA	8	7
[47]	Odo-Iyaalaro rivers, Nigeria	NA	1.9	NA	25	64.5
[44]	Korotoa, Bangladesh	37	8	NA	27	NA
[24]	Lukemi river, Democratic Republic of the Congo	0.11	0.03	689	0.14	8.63
	Luini river, Democratic Republic of the Congo	0.11	0.06	775	0.13	17.41

NA, not available

4. CONCLUSION

Because of insufficient and irregular water supplies throughout the region due to climate change, the surface area of cultivable land has increased considerably and fertilizers and pesticides are used in increasing quantities to increase agricultural yields. In our study, the physicochemical parameters and heavy metals in the surface waters were analyzed. The results demonstrated that the surface waters were slightly acidic with very low electrical conductivity values. Nitrates (NO_3^-) were the most abundant anion in water while phosphates (PO_4^{3-}) were present in very small quantities. The heavy metals As, Cd, Mn, Pb and Zn were present in the surface waters of the Sub-catchment Barrage of Tougou at low concentrations compared to those measured in some surface waters of Africa. The concentrations of heavy metals analyzed in the water were lower than the standards established by the World Health Organization for drinking water quality. This information does not allow us to conclude on the risk of the consumption of this water on human health. Likewise, it cannot be concluded that the amount of heavy metal in these waters will not increase with the time. The investigations should be continued on this water body to evaluate the potential risk for public health. Although, the lower levels of heavy metals in the surface waters might be due to the dilution effect of water, further studies should be carried out in this reservoir to examine heavy metals concentrations in the sediments, because it is known that sediments have a high absorption capacity for heavy metals and then are considered as a main target for water purification from heavy metal pollution. Several studies have examined the hydrological performance, silting up, and sediment charge of the water bodies across the country. This work is important because it provide the useful chemical information on surface water and lay out the groundwork for understanding the presence of heavy metals in water.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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