Spatial and Temporal Dynamics of Chemical Parameters in Surface Waters of Bandama Catershed, Ivory Coast

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Abstract: ***The heavy pressures on Bandama watershed surface waters could expose them to pollution. This study aimed to determine spatial and seasonal variation of chemical parameters of these waters and to identify the origin of their mineralization. Thirteen (13) surface waters were collected in the northern and southern zones of Bandama watershed and analyzed for selected chemical parameters during different seasons. In-situ and laboratory analyses were carried out using standard procedures. No-parametric tests of Kruskal-Wallis and Mann-Whitney and the analysis of variance were used to compare chemical parameters values for all different sampling sites and seasons. Principal component analysis was used to identify water mineralization origin. During these seasons, water chemical quality was good according to World Health Organization (WHO)guidelines for most of the parameters. Spatial variation revealed that high loads of nitrogenous nutrients and suspended solids are recorded in the northern zone with a decrease in transparency. In contrast, the southern zone waters are more oxygenated and transparent. Results, based on temporal variation indicate that highest values of these parameters were recorded during the rainy season. Mineralization by soil leaching, anthropogenic pollution, long time of water-rock contact and acid hydrolysis of silicate minerals have been identified for Bandama surface waters.***

Keywords: Water chemical parameters, Bandama watershed, Surface water, Spatio-temporal dynamics

1. Introduction

The Bandama River, which crosses Ivory Coast from north to south, is subject to heavy pressures. In fact, nearly 184 population drinking water reservoirs have been built there [1]. Hydroelectric dams (Kossou and Taabo) [2] and hydro-agricultural dams (85% of all dams) have also been built on the middle course of the Bandama River. They are used to irrigate more than 50,000 hectares of land [3, 4, 5]. The socio-economic and food importance of Bandama river waters, has prompted numerous studies related to these waters quality and pollution degree [6]. They have revealed anthropogenic pollution of watershed surface waters in some areas [7]. Poor water quality has a direct impact on the water quantity in a number of ways: polluted water that cannot be used for drinking, bathing, industry or agriculture effectively reduces the amount of useable water within a given area. Generally, the water crisis tends to be regarded as a water quantity problem; however, water quality is documented in many countries as a major factor [8]. In recent years, the contribution of degraded water to the water crisis is also measured in loss of beneficial use: that is, water lost for beneficial human, agricultural, and ecological uses through excessive pollution by pathogens, nutrients, (semi-)metals, organic matter, salinity and other toxicwastes. Poor water quality has been mainly linked with public health concerns through transmission of water-borne diseases. This problem is well known in Africa and in manyother developing countries [8]. In the face of climate change and the threat of pollution of the waters of Bandama, on which the majority of large Ivorian cities depend for their drinking water supply, regular monitoring of the chemical quality of these waters in time and space is becoming a necessity. Monitoring is an important element in the development of strategies to gradually improve the quality of drinking water supply services [9]. The direct assessment approach is suitable for supplies serving large cities, small towns and communities and for individual household supplies.

2. Material and Methods

2.1 Study area

Bandama watershed is located between 500 000 m and 700 000 m West longitude and 300 000 m and 110 000m North latitude (Figure 1). It covers an area of 97 500 km^2 and is drained by the Bandama river [7]. The basin covers three main climatic zones: the transitional tropical climate and the mitigated transitional equatorial climate located respectively in the northern and central parts of the basin. They are characterized by one dry season (March to October) and one rainy season (November to February). The transitional equatorial climate located in the southern part of the basin is marked by four seasons including two rainy (March-July and September-October) and two dry (July-August and December-February) seasons [10]. Mean annual rainfall and temperature per year are respectively 1200 mm and 28°C. According to [11], basement crystalline rocks dominate Bandama watershed geology. The rocks types are mainly made up of clayey, silty, sandy and arenitic rocks. In this study, the watershed was divided into two zones according to seasonal variations. Thus, the northern and central part of the watershed characterized by two seasons constitutes the northern zone and the southern zone characterized by four seasons constitutes the southern part of the watershed.

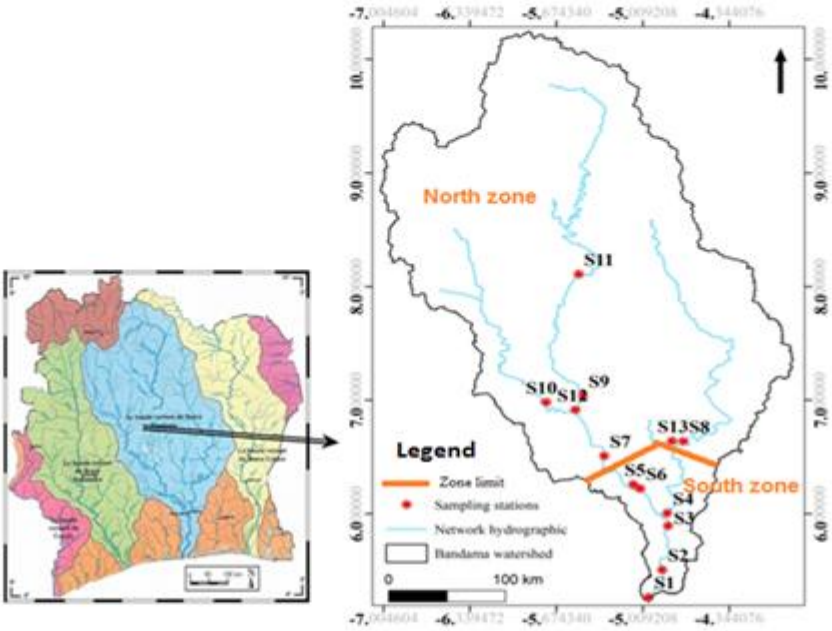

Figure 1: Location map showing the study area and sampling sites

2.2. Choice and location of sampling stations

The studies were carried out on the water body of Bandama River. Sampling points were chosen according to station accessibility during dry and rainy seasons, permanence of the watercourse, anthropogenic pressure and good spatial distribution. Based on these criteria, thirteen (13) stations were selected and they exact position were obtained by means of GPS (MLR SP 12X) (Figure 1).Main anthropogenic activities of each station are described in Table 1.

2.3 Water sampling and analysis

Fifty-two (52) surface water samples from different stations (13) were collected during four (4) sampling campaigns. Water sampling was carried out from February (dry season), July (wet season) August (mild dry) and October (mild wet) 2016. At each station, one sample was taken directly from water body and poured in a 500 mL clean polyethylene bottle. Samples were then transported to the laboratory in refrigerated conditions (6 ± 2°C) for hydrochemistry analyses according to the Rodier methods [12] described in Table 2. Electrical conductivity (EC), dissolved oxygen (O2), temperature (T) and pH were measured *in-situ* using a multipameter (YSI 6920). Transparency and turbidity were respectively measured using a Secchi disk and a turbidimeter HACH 2100 P (ISOLAB, Tunisia).

2.4 Statistical analyses

Statistical data processing no-parametric tests of Kruskal-Wallis and Mann-Whitney and the ANOVA analysis of variance were used to study the spatial and temporal variability of physicochemical parameters. These tests were used at a 95 % significance level ($p < 0.05$) and were coupled with the boxes mustaches or "boxplot" for parameter distribution. Principal Component Analysis (PCA) was applied to identify the relationships between the different parameters and determine the origin of the water mineralization. STATISTICA 7.1 software was used for the realization of those analyses.

3. Results and Discussion

3.1 Chemical characteristics of Bandama watershed surface waters

As shown in Table 3, the mean values of temperature (29.43 ± 2.34 °C), pH (29.43 ± 2.34), dissolved oxygen (3.65 ± 2.34 $mg.L^{-1}$), turbidity (38.45 ± 23.99 NTU) and conductivity (111.66 ± 33.98 $\mu S.cm^{-1}$) indicate that Bandama waters were hot, acidic, turbid and moderately oxygenated and mineralized. High turbidity and average oxygenation of surface waters were obtained respectively by [13] for water resources of the N'zi watershed and by [14] in watersof Ayamé I lake. The results for the major ions show that the mean concentrations of Ca^{2+} (9.91 ± 2.00 $mg.L^{-1}$), Mg^{2+} (6.78 ± 1.62 $mg.L^{-1}$), Na^{+} (7.21 ± 1.56 $mg.L^{-1}$), K^{+} (4.20 ± 1.70 $mg.L^{-1}$), Cl^{-} (7.78 ± 1.89 $mg.L^{-1}$), SO_4^{2-} (5.51 ± 1.34 $mg.L^{-1}$) and HCO_3^{-} (68.42 ± 21.52 $mg.L^{-1}$) were within the permissible values of WHO. Also, the nitrogen (NH_4^{+} = 0.43 ± 0.21 $mg.L^{-1}$; NO_2^{-} = 0.01 ± 0.00 $mg.L^{-1}$; NO_3^{-} = 4.22 ± 1,63 $mg.L^{-1}$; NTK =2.25 ± 1.06 $mg.L^{-1}$) and phosphorus (PO_4^{3-} = 0.39 ± 0.24 $mg.L^{-1}$; total phosphorus = 1.20 ± 0.74 $mg.L^{-1}$) nutrients values are in accordance with WHO guide values. The low mineralization of the water is illustrated by the conformity of the average values of major ions and nutrients to the WHO guide values [15]. However, the mean total nitrogen value of 3.84 $mg.L^{-1}$> 1.5 $mg.L^{-1}$ indicates a high risk of eutrophication of Bandama waters [16].

Table 1: Characteristics of sampling sites

Zone	Stations	Stations codes	North Coordinates	West Coordinates	Main anthropogenic activities of the study area
South	Gand- Lahou	S1	05°15'45.8"	04°57'58.2"	Artisanal fishing, rubber tree and oil palm plantations
	Ahouanou	S2	05°15'47.4"	04°58'03.3"	Artisanal fishing, rubber tree, oil palm, coffee and cocoa plantations
	Tiassalé	S3	05°53'32.6''	04°49'04.2''	Artisanal fishing, rubber tree, coffee and cocoa plantations
	N'zian-nouan	S4	06°00'14.3''	04°49'26.2''	Cattle breeding, artisanal fishing, rubber, oil palm, coffee and cocoa plantations
	Taabo	S5	06°14'40.7''	05°04'51.7''	Cattle breeding, artisanal fishing, coffee and cocoa plantations
	Lamto	S6	06°12'47.1"	05°01'29.0"	Gold extraction
North	Kimoukro	S7	06°30'25.7''	05°18'26.2''	Gold mining, artisanal fishing, cocoa and coffee plantations and cotton crops
	Dimbokro	S8	06°38'15.6"	04°42'24.5"	Cattle breeding, artisanal fishing, cashew nut processing company, gold extraction and cotton crops
	Kossou	S9	07°02'02.7"	05°28'22.4"	Cattle breeding, cocoa, coffee, plantain plantations and artisanal fishing
	Bouaflé	S10	06°58'47.8"	05°45'17.3"	Artisanal fishing, cocoa and coffee plantations, brasserie de Bouaflé
	Marabadiassa	S11	08°06'25.5"	05°29'49.7"	Cattle breeding, artisanal fishing, cotton crops, cashew nut plantation
	Bozi	S12	06°54'52.4"	05°31'43.6"	Cattle breeding, artisanal fishing, cocoa and coffee plantations
	Krokokro	S13	06°54'57.9"	05°32'15.7"	Cattle breeding, artisanal fishing, cotton cultivation

Table 2: Methods for chemical parameters analysis

Parameters	Methods	Laboratory
Ca^{2+} et Mg^{2+}	Titrimetric: complexometry with EDTA (NFT90-003)	National Agricultural Development Support Laboratory (LANADA)
Cl^-, HCO_3^-, NH_4^+, NO_2^-, NO_3^-, PO_4^{3-}, SO_4^{2-}	Colorimetric: spectrophotometer HACH DR 6000	Research Institute for Development (IRD)
Na^+ et K^+	Colorimetric: atomic absorption spectrophotometer with flame (NFT 90-020)	National Agricultural Development Support Laboratory (LANADA)
Total phosphorus	Method using Hach LCK 349 test cells.	Ivorian Anti-Pollution Center (CIAPOL)
Suspended Matter	Differential weighing after fiberglass filtration described by Rodier (2009)	Ivorian Anti-Pollution Center (CIAPOL)
Total Kjeldahl Nitrogen (NTK)	Kjeldahl Method (NFT 90-110)	Swiss Center for Scientific Research (SCSR)

3.2. Spatial and temporal variation of chemical parameters of Bandama watershed surface waters

According to Kruskall-Wallis test and analysis of variance (Table 3), there were statistical differences ($p < 0.05$) in dissolved oxygen, suspended matter, transparency, ammonium, nitrite and nitratefrom all water for spatial variation. For temporal variation, there were no statistical difference detected ($p > 0.05$) for turbidity, dissolved oxygen and NTK. However, a significant difference for other parameters has been revealed. The results of Mann-Whitney and Anova test combined with box plots indicate that the values of suspended matter, ammonium, nitrite and nitratein Bandama water in the northern zone were significantly higher ($p < 0.05$) than the values recorded in the southern zone. On the contrary, the waters of the southern zone are significantly ($p < 0.05$) more oxygenated and more transparent than those of the northern zone. Similar results were obtained by [17] in the waters of the Kinyankonge River in Burundi. According to [18], high levels of suspended matter, can limit light penetration into the water, decrease dissolved oxygen content and harm the development of aquatic species.

Table 3: Statistical summary of the chemical parameters of Bandama watershed surface waters

Parameter	WHO	Min	Max	Mean ± SD	Statistical test: Kruskal-Wallis/ANOVA p-value: Spatial variation	Temporal variation
PHYSICOCHEMICAL						
Temperature (°C)	25	25.80	35.70	29.43 ± 2.34	0.514	0.000*
pH	6.5-85	5.66	8.76	6.7 3 ± 0.69	0.693	0.000*
Dissolved oxygen ($mg.L^{-1}$)	5	0.70	8.65	3.65 ± 2.34	0.008*"	0.114"
Turbidity (NTU)	5	5.40	91.00	38.45 ± 23.99	0.050	0.913
Conductivity ($\mu S.cm^{-1}$)	-	60.10	199.20	111.66 ± 33.98	0.514	0.000*
Suspended Matter ($mg.L^{-1}$)	-	2.30	101.00	22.25 ± 23.97	0.009*"	0.025*"
Transparency (m)	-	0.10	1.80	0.78 ± 0.49	0.005*	0.012*
NUTRIENTS						
NH_4^+ ($mg.L^{-1}$)	1.5	0.11	0.91	0.43 ± 0.21	0.040*	0.000*
NO_2^-($mg.L^{-1}$)	3	0.00	0.02	0.01 ± 0.00	0.022*	0.000*
NO_3^- ($mg.L^{-1}$)	50	0.50	8.50	4.22 ± 1.63	0.037*	0.017*
NTK ($mg.L^{-1}$)	-	0.14	5.59	2.25 ± 1.06	0.081	0.090
Total nitrogen ($mg.L^{-1}$)	-	0.64	7.56	3.84 ± 1.59	0.186	0.004*
PO_4^{3-} ($mg.L^{-1}$)	-	0.03	0.90	0.39 ± 0.24	0.538	0.000*
Total phosphorus ($mg.L^{-1}$)	-	0.33	3.74	1.20 ± 0.74	0.225	0.000*

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MAJOR IONS						
Ca^{2+} ($mg.L^{-1}$)	150	6.10	14.92	9.91 ± 2.00	0.679	0.000*
Mg^{2+} ($mg.L^{-1}$)	50	4.10	11.02	6.78 ± 1.62	0.818	0.000*
Na^{+} ($mg.L^{-1}$)	200	3.90	11.10	7.21 ± 1.56	0.868	0.000*
K^{+} ($mg.L^{-1}$)	12	1.99	8.60	4.20 ± 1.70	0.424	0.000*
Cl^{-} ($mg.L^{-1}$)	250	3.80	11.80	7.78 ± 1.89	0.783	0.000*
SO_4^{2-} ($mg.L^{-1}$)	250	3.00	9.00	5.51 ± 1.34	0.868	0.000*
HCO_3^{-} ($mg.L^{-1}$)	-	32.80	128.00	68.42 ± 21.52	0.811	0.000*

- : not available;SD: standard deviation; *: significant difference; " : Kruskal-Wallis test

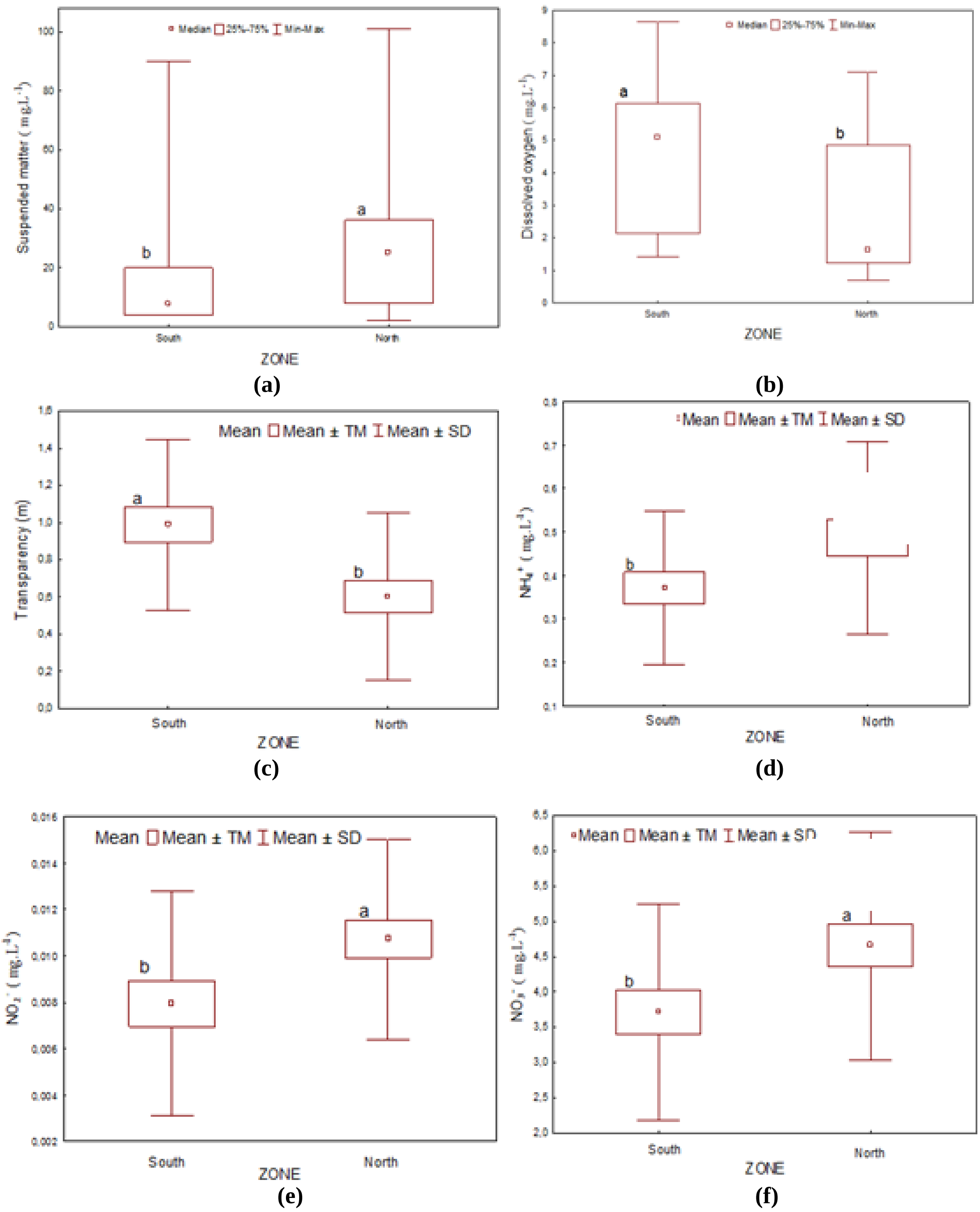


Figure 2: Box and Whisker plots of suspended matter (a), transparency (b), NO_2^- (c), dissolved oxygen (d), NH_4^+ (e), NO_3^- (f)separated by spatial discriminate analysis. Two different letters indicate a significant variability between sampling zone

Also, excess nutrients in the water could increase the production of algae and macrophytes and decrease water transparency [19, 20]. These claims are consistent with the waters of the northern zone. For temporal variation, temperature, pH, conductivity, transparency, Mg^{2+}, K^{+} and HCO_3^-values are higher during February than any other months (July, August, October). In contrast, NH_4^+, NO_2^-, NO_3^-, PO_4^{3-}, total phosphorus, Ca^{2+}, SO_4^{2-}, Cl^-, Na^+ and total nitrogen are significantly ($p < 0.05$) higher during the months of July, August, October than during February. These physicochemical parameters are thus under the rain influence. Indeed, during the wet season (July, August, October), the increase of nitrogen and phosphorus nutrients indicates that Bandama water received either directly laden runoff pollutants. Similar results were observed by [21] in Ivorian lagoon system during the rainy season. The low nutrient intake in February (dry season) can be linked to the absence of rain limiting runoff and to the proliferation of algae during this period, which are a source of nutrient salt consumption [22].

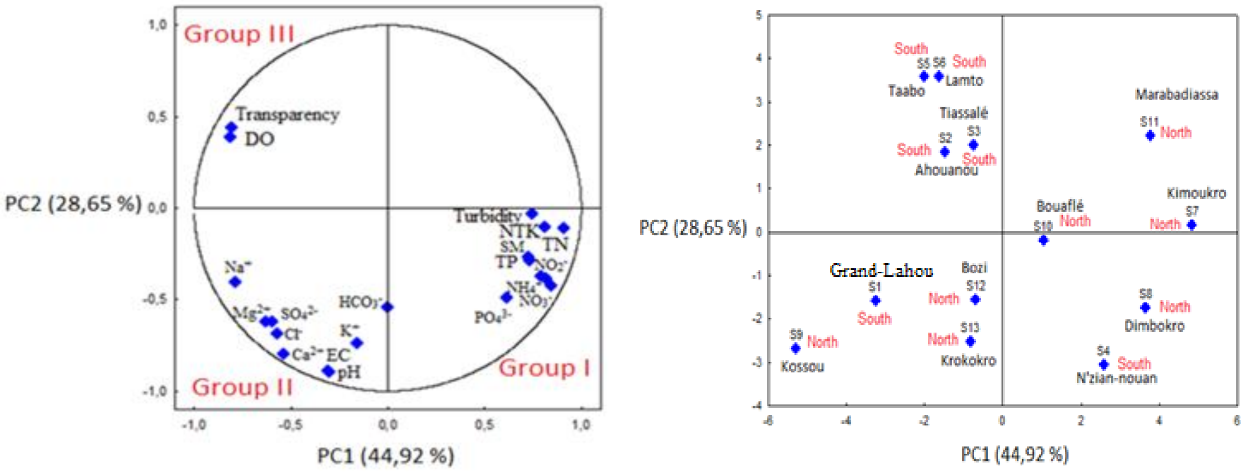
Table 4: Temporal variation of physicochemical parameters of Bandama watershed surface waters

Parameter	Month			
	February	July	August	October
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Temperature (°C)	32.22 ±2.30^{a}	29.32 ± 1.21^{b}	27.02 ± 0.89^{b}	29.16 ±1.00^{a}
pH	7.50 ± 0.70^{a}	6.20 ± 0.30^{b}	6.61 ± 0.46^{b}	6.61 ± 0.48^{b}
Conductivity (µS.cm^{-1})	153.72 ± 29.86^{a}	106.49 ±30.51^{b}	95.74 ±15.07^{b}	90.69 ±12.75^{b}
Transparency (m)	1.18 ±0.38^{a}	0.63 ±0.45^{b}	0.67± 0.54^{b}	0.65 ± 0.38^{b}
NH_4^+ (mg.L^{-1})	0.26 ±0.10^{b}	0.49 ±0.14^{a}	0.43 ± 0.26^{a}	0.54 ± 0.20^{a}
NO_2^- (mg.L^{-1})	0.00±0.00^{b}	0.01±0.00^{a}	0.01 ± 0.00^{a}	0.01 ± 0.00^{a}
NO_3^- (mg.L^{-1})	3.35 ±1.42^{b}	4.32 ±1.07^{ab}	3.80 ±1.46^{b}	5.42 ±1.85^{a}
PO_4^{3-} (mg.L^{-1})	0.10 ±0.06^{b}	0.50 ± 0.22^{a}	0.50 ± 0.22^{a}	0.46 ± 0.18^{a}
Total nitrogen (mg.L^{-1})	2.64 ±1.06^{b}	4.16 ±1.97^{ab}	4.48 ± 1.15^{b}	4.10 ± 1.47^{a}
Total phosphorus (mg.L^{-1})	0.67± 0.32^{b}	1.09 ±0.42^{b}	2.01 ± 0.77^{a}	1.03 ± 0.64^{b}
Ca^{2+} (mg.L^{-1})	8.25 ±1.24^{c}	10.32 ±1.85^{b}	11.76 ±1.80^{a}	9.30 ±1.25^{cb}
Mg^{2+} (mg.L^{-1})	8.30 ±1.48^{a}	7.18 ±1.34^{b}	4.89 ± 0.56^{c}	6.73 ± 0.54^{b}
Na^+ (mg.L^{-1})	6.16 ±1.12^{b}	7.19 ±1.55^{b}	6.91 ± 0.96^{b}	8.58 ± 1.54^{a}
K^+ (mg.L^{-1})	5.58 ±1.34^{a}	3.81 ±1.10^{b}	2.69 ± 0.73^{c}	4.74 ± 1.93^{ab}
Cl^- (mg.L^{-1})	6.24 ±1.67^{c}	7.98 ±1.68^{b}	7.50 ± 0.98^{b}	9.41 ± 1.76^{a}
SO_4^{2-} (mg.L^{-1})	4.42 ±1.12^{c}	5.68 ±1.15^{b}	6.68 ± 1.42^{a}	5.25 ± 0.39^{bc}
HCO_3^- (mg.L^{-1})	84.89 ± 25.25^{a}	74.71± 18.57^{ab}	45.94 ± 7.52^{c}	68.14 ± 6.71^{b}

Two different letters indicate a significant variability between sampling month

3.3 Origin of Bandama watershed surface waters mineralization

Mechanisms governing mineralization of the studied waters were assessed by finding interrelationships and identifying co-variations of parameters, using a Principal Component Analysis (PCA). PCA can provide a clarifying view of the parameter interrelationships. Therefore, this analysis was carried out with the complete set of the measured parameters of all samples. The firsttwo principal components (PC1 and PC2) of the PCA represent 73.57 % of the total variances in the Bandama water (Figure 3a).Interrelations between the studied parameters can provide useful information on potential contamination sources. For this purpose, correlation matrix with the different variables were obtained (Table 5). Three intercorrelatedgroups can be identified by the PCA (Figure 3a). The first one consists of turbidity, suspended matter, NTK, total nitrogen, total phosphorus, NH_4^+, NO_2^-, NO_3^-, PO_4^{3-}. Group I include Kimoukro, Dimbokro, Bouaflé and Marabadiassa stations waters which are in the northern zone (Figure 3b). The presence of NO_3^- and PO_4^{3-} in this group indicates the anthropogenic pollution [8]. Indeed, anthropogenic activities such as cattle breeding, artisanal fishing, cultivation of cashew nuts, cotton (Marabadiassa), cocoa, coffee and gold mining (Kimoukro, Bouaflé and Dimbokro) are mainly practiced in this area. These crops require extensive use of chemical fertilizers (96 % for cotton) and pesticides (90 % of the insecticide market) [24]. These substances containing nitrogen and phosphorus compounds, could reach water bodies following runoff accelerated by the savannah vegetation in this zone [25]. In addition to the nutrients contained in the runoff water, these could also come from the practices of the population in the towns and villages along the Bandama River. In fact, the people of these localities wash dishes, do their laundry, and bathe directly in the Bandama River. All products used for this purpose such as detergents are rich in phosphorus and nitrogen compounds. All pollutants are discharged directly into the plan without any prior treatment [25]. In addition to these phenomena, the fact that local populations and animals defecate directly or indirectly in the water is added to these phenomena. The stations of Kossou, Bozi and Krokokro, also located in the northern zone, are characterised by high values of conductivity, pH, HCO_3^-, Cl^-, K^+, SO_4^{2-}, Na^+ Mg^{2+} and Ca^{2+} (Figure 3a, b). They belong to group II. The positive correlation between conductivity and pH (r = 0.95), Ca^{2+} (r = 0.86), Mg^{2+} (r = 0.66), Na^+ (r = 0.63), Cl^- (r = 0.78), SO_4^{2} (r = 0.76) and the positive correlation between pH and Ca^{2+} (r = 0.88), Mg^{2+} (r = 0.82), Cl^- (r = 0.78), K^+ (r = 0.72), SO_4^{2-} (r = 0.73) are obtained (Table 5). The relationship of these major ions with conductivity and pH indicates that water mineralization can be seen by the alteration of rocks following a long time of water-rock contact and the acid hydrolysis of silicate minerals. Indeed, according to some researchers [26] - [27], water acidity in humid tropical zones could be linked to the decomposition of plant organic matter, with the production of CO_2 in the first layers of the soil. The presence of CO_2 in water facilitates the hydrolysis of silicate minerals. In contrast to the northern zone, waters of the southern zone are more oxygenated, transparent, and less loaded with nutrients. They belong to group III (Figure 3a, b). This group essentially includes the waters of the Grand-lahou, Ahouanou, Tiassalé, Taabo and Lamto stations. The low nutrient concentrations could be explained by the dilution phenomenon linked to the water input from rainfall [28].



(a) (b)

Figure 3: Principal component analysis (PC2 vs. PC1) of the studied parameters in all studied waters (a) and station and zone assemblages in two components (b)

4. Conclusion

Assessment of water quality in surface waters of the Bandama watershed shows that chemical parameters values for different areas and seasons were within WHO acceptable limits. However, high loads of nitrogenous nutrients and suspended matter are recorded in the northern zone and during the rainy season with a decrease in transparency. In contrast, the southern zone waters are more oxygenated and more transparent. Water mineralization is linked to rainfall leaching from the soil, anthropogenic pollution, alteration of rocks following a long time of water-rock contact and the acid hydrolysis of silicate mineral.

Table 5: Correlation matrix of the analyzed parameters in Bandama watershed surface waters

	T	pH	DO	Turbidity	EC	SM	Transpa-rency	NH_4^+	NO_2^-	NO_3^-	NTK	PO_4^{3-}	Total nitrogen	Total phosphorus	Ca^{2+}	Mg^{2+}	Na^+	K^+	Cl^-	SO_4^{2-}	HCO_3^-
T	1																				
pH	**0.75***	1.00																			
DO	-0.04	-0.09	1.00																		
Turbidity	-0.01	-0.09	-0.74	1.00																	
EC	**0.82***	**0.95***	-0.07	-0.05	1.00																
SM	0.13	0.07	**-0.83***	**0.80***	0.07	1.00															
Transpa-rency	-0.21	-0.19	**0.95***	**-0.78***	-0.14	**-0.89**	1.00														
NH_4^+	0.18	0.08	**-0.77***	**0.56**	0.08	0.48	**-0.73***	1.00													
NO_2^-	0.20	0.13	**-0.81***	0.66	0.09	**0.87**	**-0.87***	**0.70***	1.00												
NO_3^-	0.24	0.13	**-0.79***	0.59	0.14	**0.58**	**-0.78***	**0.98***	**0.79***	1.00											
NTK	-0.04	-0.25	-0.57	0.31	-0.26	0.40	-0.55	**0.78***	0.60	**0.78***	1.00										
PO_4^{3-}	0.39	0.24	-0.61	0.30	0.27	0.32	-0.57	**0.80***	0.51	**0.82***	0.60	1.00									
Total nitrogen	0.03	-0.22	-0.66	0.46	-0.24	0.52	-0.66	**0.84***	**0.71***	**0.86***	**0.97***	0.68	1.00								
Total phosphorus	0.36	-0.01	-0.51	0.32	0.04	0.48	-0.56	**0.70***	0.68	**0.78***	**0.81***	**0.75***	**0.87***	1.00							
Ca^{2+}	0.56	**0.88***	0.17	-0.40	**0.86***	-0.23	0.13	-0.07	-0.10	-0.05	-0.28	0.06	-0.35	-0.15	1.00						
Mg^{2+}	0.44	0.65	0.22	-0.55	0.66	-0.20	0.20	-0.34	-0.16	-0.33	-0.39	-0.16	-0.49	-0.26	**0.82***	1.00					
Na^+	0.34	0.57	0.50	-0.54	0.63	-0.49	0.48	-0.43	-0.43	-0.43	-0.63	-0.20	-0.69	-0.37	**0.79***	**0.74***	1.00				
K^+	0.53	**0.72***	-0.24	-0.12	0.66	0.14	-0.26	0.09	0.01	0.09	-0.06	0.25	-0.10	-0.06	0.57	0.54	0.19	1.00			
Cl^-	0.40	**0.78***	0.20	-0.41	**0.78***	-0.31	0.21	-0.15	-0.24	-0.13	-0.32	0.09	-0.40	-0.18	**0.93***	**0.73***	**0.84***	0.49	1.00		
SO_4^{2-}	0.59	**0.73***	0.30	-0.47	**0.76***	-0.23	0.26	-0.25	-0.19	-0.21	-0.34	-0.20	-0.40	-0.17	**0.83***	**0.77***	0.65	0.56	0.67	1.00	
HCO_3^-	0.45	0.38	-0.25	-0.11	0.34	0.05	-0.33	0.17	0.08	0.11	0.16	0.20	0.10	0.10	0.34	0.50	0.08	0.57	0.22	0.28	1.00

*Correlation is significant at the 0.05 level

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