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Assessment of the Physicochemical and Ecological Quality of Aquatic Environments in Mount Sangbé National Park (Western Côte d'Ivoire)

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Abstract— *This hydrobiological study of the Bafing River and the Sassandra River within Mont Sangbé National Park was conducted as part of Phase 8 of the park's ecological monitoring program. The study aimed to establish a baseline for water quality. Measurements of physicochemical parameters (for chemical quality) and macroinvertebrate sampling (for ecological quality) were carried out in February and July 2024 covering the dry and rainy seasons, respectively at five sampling stations designated P1 through P5. Water sampling for the analysis of heavy metals and nutrients took place in February at stations P1 and P3 on the Sassandra River and at station P4 on the Bafing River. Overall, the water quality within the park is good. However, both the Sassandra and Bafing rivers show high lead concentrations exceeding the 10 µg/L threshold. The Bafing River also exhibits phosphate concentrations above the 0.5 mg/L threshold. Furthermore, the ecological quality indicates poor water quality in the Sassandra and Bafing rivers during the rainy season.*

Keywords— *Physicochemical and ecological quality, Macroinvertebrates, Biosedimentary Index (IBS), Mont Sangbé National Park (PNMS), Ivorian Office of Parks and Reserves (OIPR), and Côte d'Ivoire.*

I. Introduction

Mont Sangbé National Park (PNMS), located in western Côte d'Ivoire, boasts an extensive river network. It is bordered to the east by the Sassandra River, to the north by the Baba River, and to the south by the Gouê and Bafing rivers (OIPR, 2019). In the past, the unstable socio-political situation that prevailed in Côte d'Ivoire between 2002 and 2011 caused administrative management difficulties for the park following the withdrawal of official authorities from the country's western region. This situation led to an increase in illegal human settlement within the park. Consequently, this natural heritage site suffered severe damage, with accelerated degradation affecting the entire park, and particularly its aquatic ecosystems. Today, the management of the PNMS by the Ivorian Office of Parks and Reserves (OIPR) has succeeded in reversing this trend. However, the park faces anthropogenic pressures specifically fishing and livestock grazing stemming from its proximity to neighboring village communities. Managing this protected area, and especially its freshwater resources, is a major challenge for the OIPR, given that the Sassandra and Bafing rivers are the park's primary perennial watercourses. Furthermore, this study is prompted by the frequent occurrence of green algae blooms (Chlorophyceae) on the Sassandra River in the Worodougou and Bafing regions, which sometimes result in fish die-offs. According to local riverside communities, this phenomenon is attributed to the discharge of limestone residues and carbon dioxide substances used for sugar purification by the African Sugar Company (SUCAF), located upstream of the park. In light of this situation, the present study conducted as part of specific ecological monitoring initiatives for the park aims to determine the physicochemical and ecological quality of the waters of the Sassandra and Bafing rivers within the PNMS during the region's two prevailing climatic seasons.

II. Geographical and Climatic Data

Mont Sangbé National Park (PNMS) is located in western Côte d'Ivoire, between 7°51' and 8°10' North latitude and 7°03' and 7°23' West longitude. This protected area covers 97,554 hectares and straddles the departments of Biankouma (spanning the Biankouma and Gbonné sub-prefectures), Touba (Foungbesso, Guintéguéla, and Touba sub-prefectures), and Séguéla (Sifié and Kamalo sub-prefectures). The PNMS lies within a transition zone between sub-equatorial and tropical climates (Béda et al., 2023). This climate features two seasons: a dry season extending from November to April and a rainy season from May to October. In the region, the average annual temperature and rainfall are 28.5°C and 116.9 millimeters, respectively.

III. Methodological Approaches

A. Sampling periods and station selection

The assessment of water quality in the Bafing River and the Sassandra River within the PNMS was conducted in 2024 across two sampling campaigns: one in February (dry season) and the other in July (rainy season). Five sampling stations, numbered P1 to P5, were established. On the Sassandra River, stations P1, P2, and P3 are located in the upstream, middle, and downstream sections, respectively. On the Bafing River, however, stations P4 and P5 are located in the downstream and middle sections, respectively (Figure 1). The geographical coordinates and upstream-downstream positions of these stations are listed in Table I.

B. Assessment of physicochemical and ecological quality

1. Assessment of physicochemical quality

At each station and during each sampling campaign, a series of three (03) basic measurements temperature, conductivity, Total Dissolved Solids (TDS), dissolved oxygen levels, and pH were taken in situ using a portable pH meter. Additionally,

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transparency and depth were measured using a Secchi disk and a graduated rod, respectively.

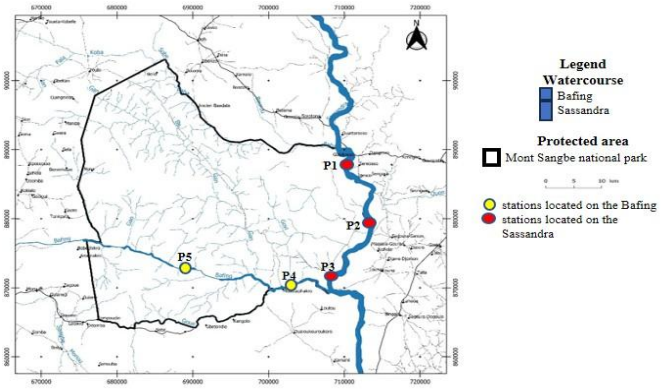

Figure 1. Location of sampling stations in the PNMS

TABLE I: Geographic coordinates and upstream-downstream positions of the stations in the PNMS

Watercourse	Stations	Gradient	Latitude	Longitude
Sassandra River	P1	Upstream	8°2'39" N	-7°6'10" W
	P2	Middle	7°56'2" N	-7°4'2" W
	P3	Downstream	7°51'45" N	-7°6'46" W
Bafing River	P4	Downstream	7°51'33" N	-7°6'50" W
	P5	Middle	7°52'24" N	-7°7'44" W

Furthermore, during the dry season, water samples were collected from the Sassandra River at stations P1 and P3 and from the Bafing River at station P4 using a Van Dorn sampler; the samples were transferred into opaque 1-liter plastic bottles and stored in a cooler at 4°C using ice packs. Nutrients (nitrates, nitrites, phosphates, and ammonium), heavy metals (cadmium, mercury, lead, cyanide, and pesticides), as well as salinity, Chemical Oxygen Demand (COD), and oils and fats, were analyzed in the water samples by the laboratory of the Ivorian Anti-Pollution Center (CIAPOL) Man regional branch following standardized protocols from the French Association for Standardization (AFNOR) and using a spectrophotometer. The assessment of the chemical water quality of the Bafing and Sassandra rivers within the PNMS involved comparing measured parameters against surface water quality standards from several sources: the 2007 version from Morocco's State Secretariat for Water and Environment (S.E.E.E.); the 2003 version of the Watercourse Quality Assessment System (SEQ-Eau); the 2006 World Health Organization (WHO) standard; the 2010 Environmental Health Information System for Water (SISE-Eaux); the March 2001 fundamental water management standard (NF EN 1717); and the 2001 reference guide on surface water quality.

2. Ecological quality assessment

At each station and during each sampling campaign, macroinvertebrates from submerged substrates were sampled over a 1 m² area using a dip net, with the contents subsequently drained on the riverbank. Regarding sediments, three samples were collected over a 0.15 m² area using a Van Veen grab sampler. Samples obtained via these methods were washed through a 1 mm mesh sieve and preserved in labeled 1-liter plastic jars containing 70% ethyl alcohol. In the laboratory, specimens were sorted under a binocular microscope at 40x magnification and identified using works by Déjoux et al. (1981), Durand and Levêque (1991), Mary (2000), De Moor et al. (2003), Barbe et al. (2003), Tachet et al. (2000, 2003, and 2006), Brown (1979 and 2005), and Forcellini et al. (2011).

The ecological quality of the waters of the Bafing River and the Sassandra River within the PNMS was assessed across both climatic seasons using the Biosedimentary Index (IBS). Adapted for chemical and organic pollution, this index assigns a sensitivity score to macroinvertebrates. The IBS for a sampling station is calculated by dividing the sum of the scores of the indicator species present by the total number of indicator species. The adjacent table shows water quality classes based on IBS values.

Index value IBS	Quality	Color
IBS > 6,50	Excellent	Blue
5,75 < IBS ≤ 6,50	Good	Orange
5,00 < IBS ≤ 5,75	So-so	Yellow
4,25 < IBS ≤ 5,00	Bad	Green
IBS ≤ 4,35	Very bad	Red

C. Data analysis

Hierarchical Cluster Analysis (HCA) was used to group sampling stations based on their physicochemical similarity (Kampa et al., 2000). Principal Component Analysis (PCA) was also performed to correlate physicochemical parameters with the sampling stations. These statistical analyses were conducted using Statistica version 7.1 software (running within Microsoft Office 2013 Excel).

IV. Results

A. Assessment of physicochemical and ecological water quality

1. Physicochemical quality assessment

The waters of the PNMS (Table II) are more mineralized during the dry season (52 ±1.2 µS/cm to 84.67 ±1.3 µS/cm) than during the rainy season (40.67 ±1.1 µS/cm to 53.33 ±1.4 µS/cm). As these conductivity values are all below 100 µS/cm, this indicates good water quality in the Sassandra and Bafing rivers for aquatic life during both climatic periods, in accordance with the 2003 SISE-Eaux surface water quality standard.

Watercourses in the PNMS exhibit higher dissolved solids levels (20.67 ±2.3 ppm to 43 ±1.3 ppm) during the dry season than during the rainy season (19.67 ±1.4 ppm to 26.33 ±1.1 ppm). Within the PNMS, the water is more alkaline during the rainy season (8.22 ±2.2 to 8.65 ±2) than during the dry season (7.93 ±2.3 to 8.38 ±2.3). The waters of the Bafing and Sassandra rivers are of good quality for aquatic life, with pH values ranging between 8 and 8.5 across both climatic seasons, in accordance with the 2006 WHO surface water quality standard.

PNMS waters also show higher oxygen levels during the rainy period (1.77 ±1.1 mg/L to 2.87 ±2.3 mg/L) than during the dry period (0.95 ±3.1 mg/L to 1.05 ±2.1 mg/L). Water temperatures are higher (31.27 ±2.1°C to 32.33 ±2.4°C) during the dry season than during the rainy season (28.63 ±3°C to 31.8 ±1.1°C). As these mean temperature values all exceed 28°C, this indicates that the waters of the Sassandra and Bafing rivers

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within the PNMS are of very poor quality in both the dry and rainy seasons.

Water in the PNMS is deeper (2.84 ±3.2 m to 6.49 ±3.1 m) and more turbid (16.67 ±2.5 cm to 66.33 ±2 cm) during the rainy season than during the dry season (1.51 ±2.1 m to 5.69 ±2.1 m and 65.9 ±3 cm to 74.57 ±2.3 cm, respectively).

TABLE II: Mean values and standard deviations for water physicochemical parameters in the PNMS

Environments	Stations	Seasons	Cond (µS/cm)	TDS (ppm)	pH	Oxy (mg/L)	Temp (°C)	Prof (m)	Trans (cm)
Sassandra River	P1	Ss	84,67 ±1,3	43 ±1,3	7,93 ±2,3	1,05 ±2,1	31,6 ±2,1	1,51 ±2,1	66,1 ±2,1
		Sp	43,33 ±1,2	20,67 ±2,3	8,34 ±2,1	2,87 ±2,3	31,8 ±1,1	2,84 ±3,2	26,33 ±2
	P2	Ss	80,67 ±2,3	39,67 ±2,3	8,17 ±2,2	0,95 ±3,1	31,6 ±3,1	3,11 ±1,1	65,9 ±3
		Sp	43,33 ±1,1	22 ±1,3	8,65 ±2	1,77 ±1,1	28,63 ±3	3,63 ±2,1	28,03 ±2,4
	P3	Ss	52 ±1,2	30,33 ±2,3	8,38 ±2,3	1,02 ±2,2	32,33 ±2,4	5,68 ±2,4	74,57 ±2,3
		Sp	40,67 ±1,4	19,67 ±1,4	8,64 ±2,1	2 ±0,1	30,47 ±1,1	6,08 ±2,5	16,67 ±2,5
Bafing River	P4	Ss	52 ±1,5	30,33 ±2,3	8,37 ±2,2	1,02 ±1,1	32 ±2,5	5,69 ±2,1	74,53 ±3,3
		Sp	53,33 ±1,4	26,33 ±1,1	8,25 ±2,3	2,01 ±2,2	30,57 ±2,3	6,49 ±3,1	62,07 ±2,4
	P5	Ss	64,3 ±1,2	20,67 ±2,3	8 ±3,1	1 ±2	31,27 ±2,1	1,78 ±2,7	68,53 ±2,1
		Sp	40,67 ±1,1	26 ±3,1	8,22 ±2,2	2,01 ±1,1	30,32 ±2,3	3,93 ±1	66,33 ±2

Cond = Conductivity, TDS = Total Dissolved Solids, pH = pH, Oxy = Dissolved oxygen, Temp = Temperature, Prof = Depth and Trans = Transparency, Ss = Dry season and Sp = Rainy season

Heavy metal concentrations (Table III) indicate that the Sassandra River and the Bafing River show the same levels of arsenic (< 6 µg/L), cyanide (< 0.020 µg/L), mercury (< 0.1 µg/L), cadmium (< 0.5 µg/L), and pesticides (< 0.01 µg/L). These values are below the threshold values of 6 µg/L for arsenic, 0.020 mg CN/L for cyanide, 0.1 µg/L for mercury, and 0.5 µg/L for cadmium and pesticides. The values for these parameters reflect the good water quality of the Sassandra and Bafing rivers according to the 2006 WHO surface water quality standards. However, the lead concentration is higher (17.5 µg/L to 132 µg/L) in the Sassandra River than in the Bafing River (13.1 µg/L). Lead concentrations exceeding the 10 µg/L limit indicate poor water quality.

Nutrient concentrations show that nitrate levels are higher (3.2 mg/L) in the Bafing River than in the Sassandra River (1.4 mg/L to 1.6 mg/L). Nitrite levels are higher (0.006 mg/L to 0.011 mg/L) in the Sassandra River than in the Bafing River (0.009 mg/L). Ammonium levels are higher (0.03 mg/L to 0.15 mg/L) in the Sassandra River than in the Bafing River (0.11 mg/L). Concentrations below the threshold values of 50 mg/L for nitrate, 0.5 mg/L for nitrite, and 0.2 mg/L for ammonium indicate that the waters of the Bafing River and the Sassandra River are of good quality.

Furthermore, phosphate levels are higher in the Bafing River (1.26 mg/L) than in the Sassandra River (0.11 mg/L to 0.34 mg/L). Phosphate concentrations below the 0.5 mg/L threshold in the Sassandra River indicate good water quality. However, in the Bafing River, they reflect poor water quality according to the fundamental water management standard (NF EN 1717) of March 2001 (NFMGE, 2001).

Chemical Oxygen Demand (COD) concentrations are higher (28 mg O2/L to 54 mg O2/L) in the Sassandra River compared to the Bafing River (41 mg O2/L). COD values ranging between 25 mg O2/L and 80 mg O2/L indicate poor water quality, according to the 2001 surface water quality framework reference guide (GRCQES, 2001).

TABLE III: Nutrient and heavy metal values for the stations in the PNMS

		Sassandra River		Bafing River
Nutrients and heavy metals	Symbols	P1	P3	P4
Filthiness (%)		0,05	0,04	0,05
Nitrates (mg/L)	NO_3^-	1,4	1,6	3,2
Nitrites (mg/L)	NO_2^-	0,011	0,006	0,009
Phosphates (mg/L)	PO_4^{3-}	0,11	0,34	1,26
Ammonium (mg/L)	$NH4^+$	0,03	0,15	0,11
Chemical demand for oxygen CDO (mg O_2/L)		28	54	41
Arsenic (µg/L)	As	< 6	< 6	< 6
Cadmium (µg/L)	cd	< 0,5	< 0,5	< 0,5
Mercury (µg/L)	Hg	< 0,1	< 0,1	< 0,1
Lead (µg/L)	Pb	132	17,5	13,1
Cyanide (mgCN/L)	CN^-	< 0,020	< 0,020	< 0,020
Oils and fats (mg/L)		< 0,5	< 0,5	< 0,5
Pesticides (µg/L)		< 0,01	< 0,01	< 0,01

The correlation between sampling stations and physicochemical characteristics, as revealed by Hierarchical Cluster Analysis (HCA) (Figure 1), identifies three groups of sampling stations based on their physicochemical similarity: Group I comprises stations P1 and P2, Group II includes stations P3 and P4, and Group III consists of station P5.

Principal Component Analysis (PCA) based on the physicochemical similarity of the sampling stations reveals that axes F1 and F2 account for 76.89% and 22.92% or 99.81% of the information contained in the data matrix, respectively (Figure 2). The classification of stations projected onto the factorial axes indicates that, along axis 1, stations P1 and P2 (Group 1) have water that is low in mineralization, low in dissolved solids, low in transparency, and relatively cool. Along this same axis, station P5 (Group 3) has water that is more

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alkaline and more oxygenated. On axis F2, stations P3 and P4 (Group 2) have deeper water.

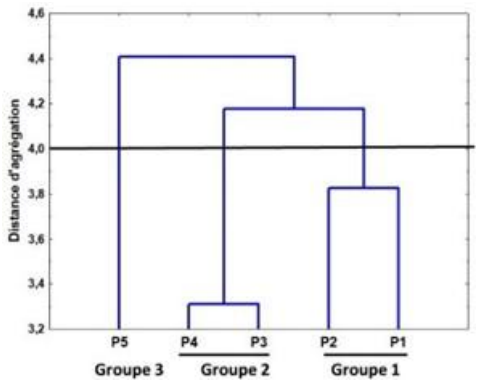

Figure 1. Agglomerative Hierarchical Clustering (AHC) of sampling stations P1, P2, P3, P4, and P5 = Sampling stations; P1, P2, and P3 = Stations located on the Sassandra River; P4 and P5 = Stations located on the Bafing River.

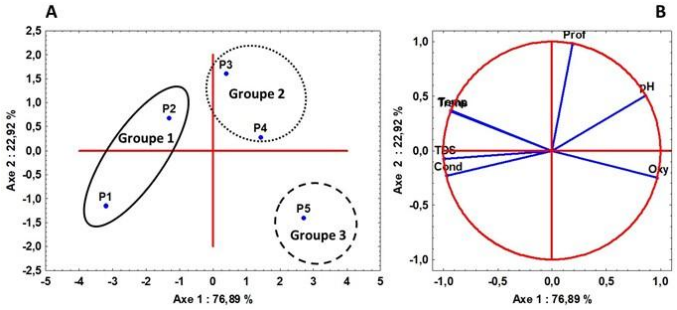

Figure 2. Principal Component Analysis (PCA)

A = Correlation circle of abiotic parameters on the factorial axes; B = Factorial map showing the distribution of the five sampling stations based on their physicochemical characteristics; Cond = Conductivity, TDS = Total Dissolved Solids, pH = pH, Oxy = Dissolved oxygen, Temp = Temperature, Prof = Depth, and Trans = Transparency; P1, P2, P3, P4, and P5 = Sampling stations; P1, P2, and P3 = Stations located on the Sassandra River; P4 and P5 = Stations located on the Bafing River.

TABLE IV: Ecological quality of aquatic environments in the PNMS

Environments	Stations	Index Value IBS	Qualitys	Colors
Dry season				
Sassandra	P1	5,5	So-so	
	P2	6,5	Good	
	P3	7,33	Excellent	
Bafing	P4	6,5	Good	
	P5	9,5	Excellent	
Rainy season				
Sassandra	P1	4	Very bad	
	P2	5	Bad	
	P3	4,5	Bad	
Bafing	P4	5	Bad	
	P5	5	Bad	

2. Assessment of water ecological quality

During the dry season, IBS index values (Table IV) indicate that station P1, located in the upstream section of the Sassandra River, has water of passable ecological quality. Stations P2 and P3, located in the middle and downstream sections of the Sassandra respectively, exhibit good and excellent ecological quality. The waters of the Bafing River are of good and excellent ecological quality at station P4 (downstream) and station P5 (middle section), respectively. During the rainy season, all stations surveyed show poor water quality, with the exception of station P1 in the upstream section of the Sassandra River, where the water quality is very poor.

V. Discussion

Overall, the waters of the Sassandra and Bafing rivers are of good quality in terms of physicochemical parameters. However, the high lead concentrations exceeding the 10 µg/L threshold observed in both rivers likely originate from airborne lead resulting from metallurgical recycling, coal combustion, and waste incineration in the area. Precipitation washes this airborne lead into the aquatic environments (Van den Hoven et al., 1999). Furthermore, the high phosphate concentrations in the Bafing River exceeding the 0.5 mg/L threshold established by the March 2001 water management standard (NF EN 1717) are likely attributable to increasing runoff from agroforestry areas and potentially from nickel mining operations in the Fougbésso zone, located within the river's catchment area. The stripping of large tracts of formerly agricultural land for this mining activity likely causes the release and subsequent drainage of phosphates into the Bafing River.

Additionally, the poor ecological quality of the Sassandra and Bafing river waters during the park's rainy season is likely due to soil runoff from the catchment area. These inputs, rich in organic and mineral matter, cause bottom sediment disturbance, resulting in high turbidity. This environment also favors the proliferation of pollution-tolerant taxa, such as Diptera, Hemiptera, and Odonata (Kressou, 2020).

VI. Conclusion and Recommendation

This seasonal study on the physicochemical and ecological water quality of the Bafing River and the Sassandra River within Mount Sangbé National Park (PNMS) aims to establish a baseline for the park's aquatic environments and to promote their value.

The physicochemical quality assessment reveals that the waters of the Sassandra and Bafing rivers within the park are generally of good quality. However, lead concentrations exceeding the 10 µg/L threshold were recorded in both rivers, and phosphate concentrations in the Bafing River were found to be high, exceeding the 0.5 mg/L threshold.

Ecological quality assessments based on macroinvertebrate communities indicate poor water quality in both the Sassandra and Bafing rivers during the rainy season.

The high lead concentrations in the park's waters pose a risk of lead bioaccumulation for both aquatic and terrestrial wildlife. Furthermore, forestry agents and ecologists working in the park should have access to safe drinking water to avoid ingesting lead, as long-term accumulation is linked to cancer. It is therefore essential to regularly monitor the park's water quality and to encourage upstream industries to install stabilization ponds, thereby preventing the direct discharge of effluents into the surrounding waters.

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