Composition and seasonal distribution of diatom in human-influenced rivers in tropical Africa: Nonhon and Gninhin rivers (Ivory Coast, West Africa)

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Abstract

This study aimed to describe the temporal and spatial distribution of diatoms communities of the rivers Nonhon and Gninhin that are impacted by agricultural and mining activities respectively. Sampling was carried out every 45 days from October 2020 to February 2022 at three stations on each rivers following two climatic seasons. Diatoms were sampled at the same time as physical and chemical parameters using qualitative and quantitative methods according to Standard NF EN 15972 (2011). Thirty-one taxa, 12 genera, 12 families, 5 orders and 2 classes were identified. Abundance varied between 18 x 105 Cells/L and 40 x 105 Cells/L and between 30 x 105 and 126 x 105 Cells/L respectively in Nonhon and Gninhin Rivers. In Nonhon River, extreme values of Shannon diversity index (1.42 and 2.14) were noted during dry season at stations NO1 and NO3 respectively. Maximum (0.90) and minimum (0.71) values of evenness index were recorded during rainy season at stations NO2 and NO3 respectively. Concerning Gninhin River, Shannon diversity index values fluctuated between 0.73 and 2 respectively at stations GN1 and GN2 during rainy season. Evenness values oscillated between 0.32 and 0.82 respectively at GN1 and GN2 during dry season. The lack of homogeneity of the appearance of taxa indicated the dominance of few taxa with high abundance, which is an indicator of the existence of environmental pressure. These results suggested the need for awareness among the local population about ecological standards for the conservation of the ecological integrity of the two rivers.

Key words: Composition, Dynamic, Diatoms, Rivers; West Africa

Résumé

Cette étude visait à décrire la distribution spatio-temporelle des communautés de diatomées des rivières Nonhon et Gninhin, impactées respectivement par les activités agricoles et minières. Des prélèvements ont été effectués tous les 45 jours, d'octobre 2020 à février 2022, à trois stations sur chaque rivière, suivant deux saisons climatiques. Les diatomées ont été échantillonnées de manière concomitante avec les paramètres physico-chimiques en utilisant des méthodes qualitatives et quantitatives conformément à la norme NF EN 15972 (2011). Au total, 31 taxons, 12 genres, 12 familles, 5 ordres et 2 classes ont été identifiés. L'abondance varie entre 18 x 10^5 cellules/L et 40 x 10^5 cellules/L dans la rivière Nonhon, et entre 30 x 10^5 et 126 x 10^5 cellules/L dans la rivière Gninhin. Dans la rivière Nonhon, des valeurs extrêmes de l'indice de diversité de Shannon (1,42 et 2,14) ont été observées pendant la saison sèche aux stations NO1 et NO3 respectivement. Les valeurs maximales (0,90) et minimales (0,71) de l'indice d'équitabilité ont été enregistrées pendant la saison des pluies aux stations NO2 et NO3 respectivement. Concernant la rivière Gninhin, les valeurs de l'indice de diversité de Shannon ont fluctué entre 0,73 et 2 aux stations GN1 et GN2 respectivement pendant la saison des pluies. Les valeurs d'équitabilité ont oscillé entre 0,32 et 0,82 aux stations GN1 et GN2 respectivement pendant la saison sèche. Le manque d'homogénéité dans la représentation des taxons indique la dominance de quelques taxons très abondants, ce qui témoigne de l'existence d'une pression environnementale. Il est impératif de sensibiliser la population locale aux normes écologiques pour la conservation de l'intégrité écologique de ces deux rivières.

Mots clés : Composition, Dynamique, Diatomées, Rivières ; Afrique de l'Ouest

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1-Introduction

River ecosystems dynamics is hierarchically organised in space (**Tudesque *et al.*, 2014**), and are influenced by multiple natural and thropogenic factors operating at different temporal and spatial scales, causing biotic assemblage variation depending on which factor is at play. For example, water pollution mainly due to human activities leads to many undesirable effects on ecosystem as well as human health **(Carr and Neary, 2008)**. Agricultural runoff and wastes from urban areas that get their way into different aquatic systems could lead to changes in the physical and chemical characteristics of the receiving water bodies **(Peters and Meybeck, 2000).** Aquatics ecosystems are important, as they provide numerous ecological services from water storage, maintenance of biodiversity and biochemical cycling (**Messager *et al.*, 2021**). Therefore, the need for proper monitoring and management of those aquatic ecosystems is crucial, as all life on earth depends on them. A more appropriate biomonitoring technique must thus be applied to assess water quality using these microscopic organisms, (**Matlala *et al.*, 2011**) with diatoms serving as indicators. Indeed, diatoms are the main primary producers and chemical modulators in freshwater aquatic ecosystems (**Mangadze *et al.*, 2015**) and represent an important carbon and energy source for secondary consumers (**Venkatachalapathy and Karthikeyan, 2015**). Because diatoms are very sensitive to environmental changes and/or disturbances such as eutrophication, acidification, land use and pollution, they are considered as powerful indicators of water quality in freshwater systems (**Bere and Tundisi, 2010 ; Wu *et al.*, 2012 ; Rimet *et al.*, 2015**). In addition, Diatoms are a major group of the algae and are one of the most common types in fresh water (**Wehr and Sheat, 2003**). They are usually at the base of aquatic food web are the most important factor for production of organic matter in aquatic ecosystem. Therefore, rivers require significant amounts of diatoms to have productive and sustainable fisherie.

Despite their importance in aquatic ecosystems, diatoms data are scarce, being limited to the studies of **Ouattara (2000)**, **Da (2007)**, **Salla (2015) and N'Guessan *et al.* (2018)** in tropical Africa. In Ivory Coast, the use of these organisms in monitoring the integrity of rivers is very limited by a lack of knowledge. Only available data are those of **N'Guessan *et al.* (2018).** None of his studies concerning diatom's structure has focused on Nonhon and Gninhin rivers despite various activities developed on their watershed. The purpose of the current study was to document diatom biodiversity and describe temporal and spatial distribution of diatom communities as well as physico-chemical factors that control their dynamics from a sustainable development perspective.

2-Materials and Methods

2.1-Study area and sampling sites

The study area with the the two rivers Nonhon and Gninhin is under two climatic conditions namely a dry season from November to February and a rainy season from from March to October. The peak rainfall is in September. Human activities in the study area are dominated by farming and mining (**Doffou, 2019**). Based on accessibility, the upstream-downstream gradient and influence of human activities, three sampling points were selected for each river (Fig 1). The characteristics of the sampling stations on the Nonhon and Gninhin rivers are set out in table I.

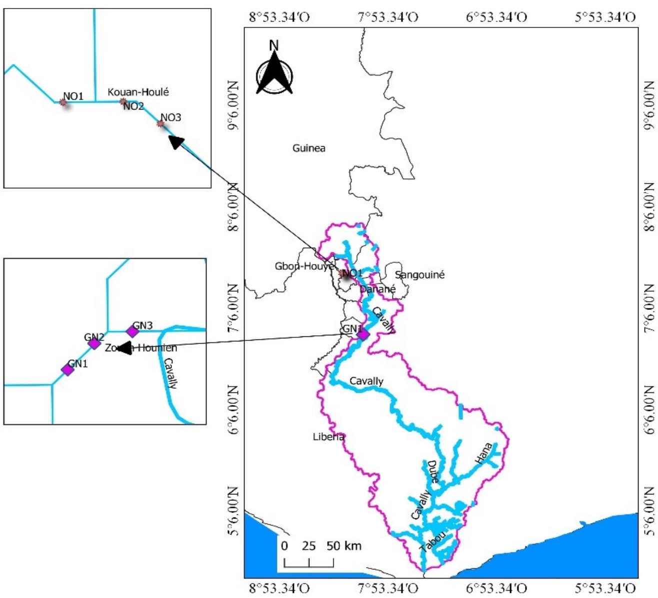

Figure 1: Maps of the Cavally watershed showing the sites of sampling stations on Nonhon (NO1, NO2, NO3) and Gninhin (GN1, GN2 and GN3) rivers in Ivory Coast.

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Table I: Characteristics of the sampling sites of the Nonhon and Gninhin rivers.

Rivers	Stations	Geographic coordinates		Canopy (%)	Position
		North Latitude	West Longitude		
Nonhon	NO1	7°26'53,088''	8°18'16,42788''	52,85	Upstream
	NO2	7°26'54,91212"	8°18'21,89988"	53,57	Intermediate
	NO3	6°50'15,87012"	8°18'21,89988"	67,14	Downstream
Gninhin	GN1	6°50'15,87012"	8°6'49,57812"	35,00	Upstream
	GN2	6°50'14,442"	8°6'57,042"	28,89	Intermediate
	GN3	6°50'15,864"	8°6'59,112"	55,56	Downstream

2.2-Sampling and analytical techniques of environmental parameters

Physical and chemical parameters of the water (temperature, pH, conductivity, dissolved oxygen, and transparency) were measured every 45 days from 9 a.m. to 2 p.m. from October 2020 to February 2022 at the different stations. These parameters were measured in situ using a Hach Lange HQ 40D type multiparameter powered on approximately 5 minutes before the measurements. The probes were then immersed in water, then selecting the desired function made it possible to obtain the parameter value on the display screen. Water transparency was measured using a Secchi disc. For nutrients and organic matter, a surface water sample was collected using 1-liter polyethylene bottles at each station and during each sampling campaign, and stored at 4°C in a glass container. The analyses were performed in the laboratory according to the following standards for ISO 7890-3 : 1988 (Nitrates), ISO 7150-1 : 1984 (Ammonium), ISO 6878 : 2004 (Phosphates), AFNOR NF T90-005 (Silice), ISO 15705 : 2002 (COD), ISO 5815-1 : 2019 (BOD5).

2.3-Diatoms sampling and analysis of biotic variables

Diatoms were sampled at the same time as physical and chemical parameters using qualitative and quantitative methods according to Standard NF EN 15972 (2011). Qualitative sampling was carried out using a 20µm mesh plankton net by filtering 40 L of water drawn using a 10 L capacity bucket. After filtration, the filtrate collected in the net collector was stored in a pillbox and fixed with Lugol then with formalin at a final concentration of 5%. Quantitative sampling was carried out by sedimentation of 10 L of water in a bucket. A water sample was stored in 120 mL capacity pillboxes then fixed with Lugol and formalin at a final concentration of 5%. After sampling, diatoms were subjected to specific preparations in order to better reveal details of the ornamentation (striations, pores) of the siliceous shell or frustule (**Rumeau and Coste 1988**). Diatoms were subsequently observed, photographed and measured under an Olympus BX40 microscope. Identification of these taxa was made as previously described (**Couté and Iltis, 1985; Krammer and Lange-Bertalot, 1991; Round *et al.*, 1990 ; Tomas, 1995).** Taxa were identified essentially according to the classification of **Van den Hoek *et al.* (1995),** updated using the website https://www.algaebase.org/search/species/.

Water samples (250 mL) intended for the determination of chlorophyll **a** were collected in polyethylene bottles, then wrapped in aluminum foil and stored in a cooler containing dry ice until the laboratory, where samples were filtered on Whatman GF/F filters with a 0.7 µm mesh using a vacuum pump. After each filtration, filters were immediately immersed in 15 mL of a 90% cool acetone solution in a dark glass bottle wrapped in aluminum foil and stored for 24 hours at 4°. Chlorophyll **a** was extracted by centrifugation of the mixture at 2000 rpm for 15 minutes. Then, the absorbance of the supernatant was measured at several wavelengths (665 and 750 nm) prior and after acidification using a spectrophotometer knowing that acidification destroys chlorophyll **a** without destroying the other pigments.

3-Data analysis

Data were subjected to various analyses as follows

3.1-Structural analyzes

Taxonomic richness and the total number of taxa collected at each site were determined. Biological diversity (*H'*) and evenness (*J'*) were calculated according to equations of Shannon (1949) and Pielou (1966) respectively. Abundance (N) of taxa was expressed as cells per liter (**Utermöhl 1958 ; Aktan *et al.*, 2005**) and determined according to the following formula:

D=N/(a/A) X V

where a = C_{40}× × (R40×)² × π

N : quantity of cells counted for a taxon;

a : surface area observed under the microscope;

C40x : number of fields observed at 40x; R40x: radius of the field at 40x (0.25 mm),

A : surface area of the sedimentation cup where the cells accumulate (490.8 mm²)

V: sample volume used for sedimentation

The chlorophyll biomass was obtained from the **Lorenzen** formula (**1967**).

3.2-Statistical analyses

Variability of physical and chemical parameters as well as biotic parameters were studied through univariate analyses. For each parameter studied, hypothesis of normality of data distribution was verified using Shapiro test (**Shapiro *et al.*, 1968**). Subsequently, data were subjected to Kruskall -Wallis non-parametric test for seasons and stations. Significance level was defined as $p < 0.05$. For these analyses, R software was used.

4-Results

4.1-Physical and chemical variables

Physical and chemical variables at sampling stations in Nonhon and Gninhin rivers during the period October 2020 to February 2022 are presented in **Seu-Anoï *et al.* (2024)**. Overall, physical and chemical characteristics of Nonhon River reflected spatial and seasonal variations (Tab.II). The minimum (23.2°C) and maximum (26.2°C) temperatures were recorded respectively at station NO2 during the dry season and station NO3 during the rainy season. The pH values vary between 2.87 (NO2; rainy season) and 11.12 (NO3; dry season). The minimum (17 µS/cm) and maximum (140 µS/cm) value of conductivity were observed respectively at NO1 (dry season) and NO2 (rainy season). The dissolved oxygen levels in the different stations have a range of variations between 0.69 mg/L (NO1, dry season) and 5.58 mg/L (NO2, rainy season). The maximum (77.1 cm) and minimum (2.6 cm) values of transparency (77.1 cm) were observed during the rainy season at station NO3. The high nitrate content (15.1 mg/L) and the low content of this parameter (4.9 mg/L) were observed during the rainy season at station NO1. Ammonium concentrations vary from 0.21 mg/L to 0.8 mg/L (NO3; rainy season). The silica contents vary between 4 mg/L (NO1; rainy season; dry season and NO2; rainy season) and 16 mg/L (NO3; rainy season). The maximum content (0.18 mg/L) of phosphate were obtained during the rainy season (NO3). The minimum content (0.04 mg/L) of this parameter was recorded at stations NO1 and NO3 (rainy season) and at station NO2 (dry season). The high value of COD was recorded during the rainy season at station NO2 and the low value was obtained at station NO1 in the dry season. Biochemical oxygen demand (BOD5) concentrations range between 5 mg/L (NO3; dry season) and 19.5 mg/L (NO2; rainy season).

Regarding the Gninhin river (Tab.III), the extremes temperatures values were recorded at station GN3 during the rainy season (25.90 °C) and the dry season (34.9 °C), respectively. Low (5.4) and high (10.24) pH values were recorded at station GN1 during the rainy season. The minimum and maximum conductivity values were obtained at stations GN1 (261 µS/cm) and GN3 (11.3 µS/cm), respectively, during the rainy season. High dissolved oxygen values were recorded at stations GN2 (5.95 mg/L) and GN3 (5.50 mg/L) during the dry season. The extremes transparency values were recorded at stations GN1 (0.01 cm) and GN2 (136.3 cm), respectively, during the dry season. The highest nitrate concentration was recorded at station GN3 during the dry season, while the lowest was recorded at station GN1 during the rainy season. The extreme values for ammonium concentrations were recorded at GN1 (0.08 mg/L) and GN3 (18 mg/L) during the rainy season. The highest and lowest silica concentrations were recorded at station GN3 during the rainy season (3 mg/L) and the dry season (18 mg/L), respectively. The extreme values for phosphate concentration were recorded at stations GN2 (0.05 mg/L) and GN3 (0.26 mg/L) during the rainy season. High COD values were recorded at all stations during the rainy season. Maximum BOD5 values were obtained at all stations during the dry season.

Spatial and seasonal variations of physical and chemical parameters were not significantly different in the two rivers (Kruskall-Wallis test, $p > 0.05$).

Table II. Spatial and seasonal variations of physico-chemical parameters in the Nonhon river in western Côte d'Ivoire (NO = Nonhon river; DS = dry season; RS = rainy season; 1, 2, 3 = Station number).

Nonhon river												
Stations	NO1 RS		NO1 DS		NO2 RS		NO2 DS		NO3 RS		NO3 DS	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Temperature (°C)	24.7	26.07	23.7	25.14	24.5	25.87	23.2	25.35	24.6	26.2	23.4	24.49
pH	5.76	8.75	6.2	10.75	2.87	8.56	6.6	10.29	6.57	8	7.08	11.12
Conductivity (µS/cm)	36	84	17	95.2	18	140	18	91.7	20	38	20	93.7
Dissolved oxygen (mg/L)	1.2	4.2	0.69	3.54	2.8	5.58	1.52	3.44	1.2	5.85	2.21	3.68
Transparency (cm)	3.1	73.5	8.1	46.2	12.6	67.6	17.2	44.7	2.6	77.1	26.4	47.1
Nitrates (mg/L)	4.9	15.1	4.8	11.6	5.3	13.7	5.1	9.2	6.1	14.1	5.7	10.4
Ammonium (mg/L)	0.36	0.7	0.26	0.33	0.29	0.78	0.29	0.41	0.21	0.8	0.3	0.52
Silice (mg/L)	4	13	4	11	4	12	7	14	5	16	5	14
Phosphates (mg/L)	0.04	0.1	0.05	0.05	0.05	0.14	0.04	0.1	0.04	0.18	0.06	0.08
DCO (mg/L)	17.3	38.9	13.6	16.2	19.2	40.8	14.1	20.8	15.5	40.6	14.6	16.9
DBO5 (mg/L)	7	14	5.5	9.5	6	19.5	6	12.5	6.5	17	5	10.7

Table III. Spatial and seasonal variations of physico-chemical parameters in the Gninhin river in western Côte d'Ivoire (GN = Gninhin river; DS = dry season; RS = rainy season; 1. 2. 3 = Station number).

Gninhin river												
Stations	GN1 RS		GN1 DS		GN2 RS		GN2 DS		GN3 RS		GN3 DS	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Temperature (°C)	26	29.6	25.96	29.53	26.5	31.7	29.61	30.04	25.9	31.52	30.04	34.9
pH	5.4	10.24	7.51	7.9	6.7	8.28	7.86	7.96	5.49	7.29	7.66	7.84
Conductivity (µS/cm)	51	261	31	134	59	111	26	74	11.3	172	36	85
Dissolved oxygen (mg/L)	0.4	4.36	3.56	3.77	0.7	2.81	3.14	5.95	2.2	4.7	2.66	5.5
Transparency (cm)	0.02	54	0.01	66.2	0.03	44	45.2	136.3	0.02	31	1.4	37.8
Nitrates (mg/L)	6.3	15.1	8.2	91	5.2	13.1	14.3	17.6	6.7	20.4	21.2	24.2
Ammonium (mg/L)	0.08	0.68	0.38	0.38	0.21	0.41	0.44	0.55	0.26	18	0.47	0.71
Silice (mg/L)	4	12	9	16	4	13	9	12	3	13	10	18
Phosphates (mg/L)	0.11	0.14	0.06	0.12	0.05	0.18	0.12	0.21	0.06	0.26	0.09	0.23
DCO (mg/L)	14.8	31.4	18	20.3	14.6	27.8	18.1	20.3	17.3	31	23.8	26.5
DBO5 (mg/L)	4	10	9.5	12.9	6.5	12.5	11.7	17.3	4	14.5	14.5	19.1

4.2-Diatom community composition

In the present study, 31 taxa belonging to 12 genera, 12 families, 5 orders and 2 classes were identified from all sampling sites (Tab.3). In both rivers, Bacillariophyceae class was the predominant diatom population with 94%. Mediophyceae class only represents 06% of the total population. *Pinnularia* (08 taxa), *Surirella* (05 taxa), Gyrosigma (03 taxa) were the predominant genera with the highest taxa richness recorded in the sampling sites during both seasons. In agricultural sites (Nonhon river), the community (21 diatomic taxa) was distributed between two classes namely Bacillariophyceae and Mediophyceae. Bacillariophyceae class was the highest contribution with a percentage of 82%. Mediophyceae represented only 8% percent of the total population. The genera *Achnanthales*, *Surirella*, *Stenopterobia*, *Achnanthales*, *Gyrosigma*, *Navicula*, *Pinnularia* appeared with the highest frequencies and *Stephanodiscus*, *Cyclotella*, *Fragilaria*, and *Pinnularia* were specific genera in this river. Taxa, notably *Cyclotella meneghiniana*, *Stephanodiscus astraea*, *Fragilaria crotonensis*, *Pinnularia viridis*, present in Nonhon river were supporting organic pollution. Moreover, the mining impacted sites (Gninhin River) with 25 diatomic taxa, were characterized by the presence of a single class consisting of Bacillariophyceae (100%) and predominated by *Craticula*, *Pinularia*, *Gyrosigma*, *Achnanthales*, *Stenopterobia*, *Surirella* with the highest frequencies (above 50%). The genera notably *Ulnaria*, *Craticula*, *Stauroneis*, *Sellaphora*, *Pinnularia*, *Sellaphora*, *Encyonema*, *Surirella*, obtained in this River were common in polluted waters. *Ulnaria ulna*, *Craticula cuspidata*, *Stauroneis anceps*, *Sellaphora pupula*, *Pinnularia* sp.3, *Sellaphora pupula* var. *bacillarioides*, *Encyonema silesiacum*, *Surirella capronii* were the taxa present only in this site. Taxa common to both rivers were *Pinnularia brauniana*, *Pinnularia nodosa*, *Pinnularia* sp.1, *Pinnularia* sp.2, *Pinnularia* sp.4, *Pinnularia* sp.5, *Navicula placentula*, *Gyrosigma acuminatum*, *Gyrosigma* sp.1, *Gyrosigma* sp.2, *Achnanthales tropica*, *Stenopterobia intermedia*, *Surirella tenera*, *Surirella* sp.1, *Surirella* sp.2, *Placoneis elginensis*. In the two rivers, the stations located in the upstream zone (NO1: Nonhon river and GN1: Gninhin river) record the lowest taxonomic richness with 9 and 13 taxa in Nonhon and Gninhin rivers respectively. On the other hand, stations located downstream (NO3: Nonhon river and GN3: Gninhin river) with 15 and 16 taxa respectively present the greatest taxonomic richness.

4.3-Diatoms abundance and biomass

Spatio-seasonal variation in total abundance of diatoms in Nonhon and Gninhin rivers is presented in Fig. 2. Across the two rivers, abundance varied between 18.10^5 Cell/L and 40.10^5 Cell/L in Nonhon river and between 30.10^5 and 126.10^5 Cell/L in Gninhin river. These extreme values were observed respectively during rainy and dry seasons in Nonhon river and during dry and rainy seasons in Gninhin river at all stations. In the two rivers explored, a clear domination of the Bacillariophyceae class was noted. Taxa that contribute to the growth of diatoms in Nonhon river during dry season were *Cyclotella meneghiniana*, *Pinnularia viridis*, *Pinnularia* sp.2, *Pinnularia* sp.4, *Navicula placentula*, *Gyrosigma acuminatum*, *Gyrosigma* sp.1, *Gyrosigma* sp.2, *Stenopterobia intermedia*, *Surirella* sp.2, *Surirella* sp.3. In Gninhin river, taxa responsible for dominance during rainy season are *Craticula cuspidatant*, *Craticula cuspidata*, *Sellaphora pupula*, *Pinnularia brauniana*, *Gyrosigma acuminatum*, *Gyrosigma* sp.1, *Gyrosigma* sp.2, *Encyonema silesiacum*, *Stenopterobia intermedia*, *Surirella tenera*, *Surirella* sp.2. In the two rivers explored, no significant difference in abundance was observed between the stations and between seasons (Kruskall-Wallis, test $p > 0.05$). Fig. 3 illustrates spatio-seasonal evolution of chlorophyll **a** biomass within the two rivers studied. In those rivers, maximum and minimum values were recorded at all stations respectively during rainy and dry seasons. No significant difference in chlorophyll **a** biomass was observed between stations and between seasons (Kruskall-Wallis, test $p > 0.05$).

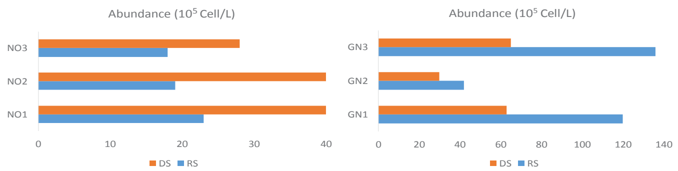

Figure 2: Abundance of diatoms communities in the Nonhon (stations NO1, NO2, NO3) and Gninhin (stations GN1, GN2, GN3) rivers.

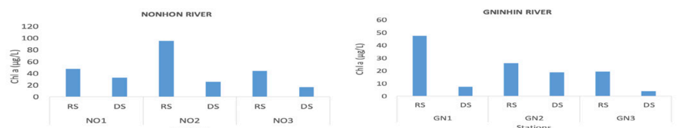

Figure 3: Chlorophyll a biomass in Nonhon (stations NO1, NO2, NO3) and Gninhin (stations GN1, GN2, GN3) rivers.

4.5-Diversity evaluation

The spatial-seasonal variations of Shannon diversity and evenness index in Nonhon and Gninhin rivers are presented in Fig. 4. In Nonhon river, values oscillated between 1.42 and 2.14 for Shannon diversity and between 0.71 and 0.90 for Evenness index. Extreme values of Shannon diversity index were noted during dry season at stations NO1 and NO3. Maximum and minimum values of evenness index were recorded during rainy season at stations NO2 and NO3 respectively. Concerning Gninhin river, values of Shannon diversity index fluctuated between 0.73 and 2 bit/Cell respectively at stations GN1 and GN2 during rainy season. Evenness values oscillated between 0.32 and 0.82 bit/Cell respectively at stations GN1 and GN2 during dry season.

No significant difference in spatial and seasonal variation of Shannon diversity and evenness index was observed for the two rivers (Kruskall-Wallis, test $p > 0.05$).

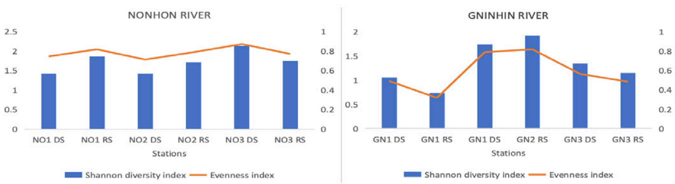

Figure 4: Shannon diversity and Evenness index of diatoms communities in Nonhon (stations NO1, NO2, NO3) and Gninhin (stations GN1, GN2, GN3) rivers.

5-Discussion

5.1-Diatomic community

A total of 31 diatom taxa were identified which was lower than numbers reported in the literature. **Ndjouondo *et al.* (2023)** reported 43 species in Amenda, North-west cameroon, whereas **Shibabaw *et al.* (2021)** report 169 diatom species in the Gilgel Gibe watershed in Southwest Ethiopia. One of the reasons for low diversity might be the environmental factors due to anthropogenic pressure. Indeed, the agricultural and mining activities carried out around Nonhon and Gninhin rivers respectively impact their functioning. This would prevent the presence of taxa sensitive to pollution. In Kebena and Akaki rivers (Addis Abeba, Ethiopia), **Beyene *et al.* (2009)** made the same observation. In Nonhon river, taxa were distributed between two classes which are Mediophyceae and Bacillariophyceae. Gnihin river is characterized by the presence of a single class consisting of Bacillariophyceae (100%). This result could be explained by the different sources of anthropogenic pressure as noted in the work of **Serre-Fredj *et al.* (2023)**. Taxa including *Cyclotella meneghiniana*, *Stephanodiscus astraea*, *Fragilaria crotonensis*, *Pinnularia Viridis,* present in Nonhon river and *Ulnaria ulna*, *Craticula cuspidata*, *Stauroneis anceps*, *Sellaphora pupula*, *Pinnularia* sp.3, *Sellaphora pupula* var. *bacillarioides*, *Encyonema silesiacum*, *Surirella capronii* present only in Gnihin river are characteristic of disturbed waters. This result could be explained by the agricultural and mining activities carried out around the two rivers which impact their functioning. The same observations were made by **Battarbee *et al.* (2001)**. According to them, the presence of diatoms in water can be explained by numerous factors such as light intensity, quantity of nutrients, turbidity and chemical conditions of the water (pH, conductivity, dissolved organic carbon). Additionally, in the two rivers, stations located in the upstream zone (NO1 and GN1) record the lowest species richness with 04 and 09 taxa whereas stations located downstream (NO3 and GN3) present the greatest species richness with 12 and 15 taxa. The reason for taxa richness variation among upstream and downstream stations could be due to the diatom species response to environmental variables **(Beyene *et al*., 2014).** Hence, low taxa richness may indicate presence of hostile environment (chemical and physical pressure) unsuitable for occurrence of diatoms with narrow environmental optima. Consequentially, only diatoms with broad range of tolerance to environmental conditions would exist in that specific site **(Soininen *et al.*, 2007).** The same observation was made by **Alfinito and Lange-Bertalot (2013).**

5.2-Seasonal and spatial variation of diatoms abundance, diversity and evenness

In Nonhon river, on one hand, densities were generally higher during dry season at all stations. On the other hand, lowest values were recorded during rainy season also at all stations. High densities observed during dry season at all stations could be due to the fact that during this season, water inputs due to soil leaching are reduced and residence time of water becomes sufficiently long. These undoubtedly have an effect of increasing the growth potential of diatoms **(Sheng-Xiu *et al.*, 2009)**. The low densities recorded at all stations in the rainy season could be due to several factors acting in synergy: (1) high amount of organic matter, (2) high speed of water flow which would encourage a reduction in proliferation of micro-algae, (3) dilution effect and (4) high grazing rate. These phenomena could explain the drop in diatom density recorded during this study in Nonhon river. The opposite trend was observed at Gninhin river. Highest values are were noted during rainy season while the lowest are were recorded during dry season at all stations. High values observed during rainy season could be explained by high concentrations of nutrient salts, particularly phosphate and ammonium, during this season in Gninhin river. This results from the fact that in addition to light energy requirements, the presence of nutrients was essential for diatom photosynthesis to occur. Indeed, under optimal conditions, diatoms absorb nutrients for their proliferation (**Brzezinski, 1985**). In addition, during periods of heavy rain, the strong flow of water from Cavally river entering in Gninhin river could induce an enrichment of this ecosystem with diatoms. These results corroborate the observations of **Angelier (2000)** and **Suroy (2013)** according to which the development of diatoms is linked to changes in the conditions of their environment and to the speed of the current in an aquatic ecosystem. Highest value of diversities observed during dry season at station NO3 (Nonhon river) and at station GN2 (Gninhin river) during rainy season could be explained by the stability of the water column. The lower evenness values obtained during rainy season at station NO3 (Nonhon river) and station GN2 (Gninhin river) in dry season were due to the proliferation of Bacillariophyceae restraining the development of other diatom groups **(Merican *et al.,* 2006).** In general, diatom diversity in Nonhon and Gninhin rivers was similar to that observed in other aquatic systems **(Shaimaa *et al.,* 2018)**.

Conclusion

The taxa richness and Shannon and Weaver Index (H) showed that Nonhon and Gninhin rivers in the study sites has have a relatively high diversity of diatoms because water quality is suitable for the living aquatic life and is slightly affected by the pollutants that are released to it. Evenness Index (E) which recorded high values and lack of species homogeneity with high densities, indicates also environmental stress. It is necessary to carry out a study aimed at implementing an ecological restoration plan designed to restore the biological connectivity of these aquatic ecosystems.

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