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Diatoms and Water Quality of the Isalowe River in the Yangambi Biosphere Reserve/ D.R. Congo

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ABSTRACT

This study focused on the bioassessment of water quality of the Isalowe River in the Yangambi Biosphere Reserve using diatoms. The samples were taken from this river after measuring the physicochemical parameters (pH, temperature, conductivity and dissolved oxygen). The identification of diatoms revealed 194 specific taxa divided into 43 genera and belonging to 20 families. The species of Eunotia genus are the most abundant (35.99 %) such as Eunotia rhomboidea Hustedt, Eunotia intermedia (Krasske ex Hustedt) Norpel & Lange-Bertalot, Eunotia fallax A. Cleve in the course set. At the station level, species of the Eunotia genus are the most abundant at the source and in the environment (41.28% and 48.41% respectively). At the mouth, we have species of the genus Neidium which predominate (24.98%) with N. affine and N. sp. The Shannon index values obtained showed great diversity at each station (source, environment and mouth). The Equitability Index revealed an equipartition of individuals within species. The spatial distribution varies from one station to another. The Spearman correlation coefficient revealed the impact of physicochemical parameters on the abundances and specific richness at the station level. Using the Shannon Index (H'), it was revealed that, in general, the waters of the Isalowe River are in poor ecological condition and heavily polluted. The same observation was made at the source and at the mouth. In the middle, the waters are in a poor ecological state and very polluted. These results are due to the anthropogenic activities carried out in this river (cassava retting, artisanal palm oil extraction, dishes, laundry, bathing and fields).

Introduction

The degradation of water resources is essentially caused by point and diffuse pollution as well as by the modification of its physicochemical characteristics (Malmqvist and Rundle, 2002). Anthropogenic disturbances have a very strong impact on aquatic biodiversity (Sweeney *et al*., 2004). Indeed, autoecological processes are mainly responsible for the distribution of organisms colonizing aquatic environments (Vannote *et al*., 1980; Dolédec *et al*., 1999). Induced more or less directly by human activities, community modifications can also come directly from the introductions and/or disappearance of species (Malmqvist and Rundle 2002; Bollache *et al*., 2004). Thus, throughout the world, there are numerous bodies of water irreversibly damaged by pollution and/or eutrophication (Zohary *et al*., 1996).

Vulnerability is, however, observed in tropical lake ecosystems. This fact requires more vigilance and hydrobiological investigations in Africa with a view to searching for factors that could be specific to it. Phytoplankton are the base of the food chain in these continental waters. It can form blooms due to the proliferation of one or a few species when hydroclimatic conditions are favorable and, particularly with the risk of imbalance of an entire ecosystem. These blooms appear following several physicochemical factors such as the high concentration of nutrients, high light and the hydrodynamics of the ecosystem (Kilham and Kilham 1984; Reynolds *et al*., 1993; Reynolds, 1998; Dusenberry et al., 1999). Thus they can cause numerous health, ecological and economic consequences.

In the ecology of lotic systems, algae play a major role in primary productivity, in the formation of habitats and the food chain, and the evaluation of water quality according to their sensitivity to pollution (Kolkwitz and Marsson, 1902; Prygiel and Coste, 1993; Morin, 2006).

The major challenge is to know the effects of anthropogenic degradation on diatomic communities in the ecology of freshwater aquatic systems. However, for biomonitoring the health of waterways, these microscopic beings have been relatively less exploited than fish or invertebrates (Whitton *et al*., 1991, Rosen 1995, Whitton and Kelly, 1995, Whitton *et al*. Rott, 1996, Prygiel *et al*., 1999b, Hill *et al*., 2000a).

Knowledge of the ecology of thousands of species of diatoms has enabled their widespread use as biological indicators of the quality of running waters in Europe. They are widely used to evaluate more or less precisely the influence of physicochemical parameters of water such as pH (Battarbee and Charles, 1986; Charles *et al*., 1991), pollution (Sladecek, 1986), salinity (Servant-vildary and Roux, 1990 and Gasse, 2002), etc. Diatoms can fossilize under favorable conditions after cell death due to some special biological characteristics, including their siliceous skeleton.

This is how they can allow the reconstruction of aquatic paleo-environments in their depositional sites (Stager and Anfang-Sutter, 1999 and Nguestop *et al*., 2004). They are used in the diagnosis of drowning in forensic medicine (Ludes and Coste, 2004). Sometimes invasive, these organisms are increasingly used in criminology, genetics, hydrology, nanotechnology, paleoecology as well as for the production of biofuels (Ector, 2017). The insecticidal activity of diatomite and the essential oil of Ammoide verticillata on the stored sheath pest Tribolium confusum in the Tissemsilt region was the subject of a study by Alia (2023).

Several factors such as temperature, nutrient concentration, dissolved oxygen, transparency influence the growth of algae. Any change in these parameters in the hydrosystem affects the specific richness and relative abundance of algae because they are sensitive (Morin, 2006). This therefore shows a strong link between water quality and the algae biodiversity of the environment.

In Central Africa in general and in the Democratic Republic of Congo in particular, there is little research on diatoms. Researchers give little importance to these microorganisms and are more interested in higher plants. However, some investigations have been carried out in the waterways of the DR Congo, the results of which have been published by certain authors. We can count some research carried out in the 20th century by: Duvigneaud & Symoens (1949), Kufferath (1956b), Cholnoky (1970), Compère & Symoens (1987), Compère & Symoens (1988), Compère (1989), Compère (1995) and Golama (1992; 1996). Interest in algal flora began with the Belgian-Congolese Boyekoli Ebale Congo expedition in 2010 covering 250 km of the Congo River and some tributaries between Kisangani and Bumba (Cocquyt and Taylor, 2015; Cocquyt and Taylor, 2016; Karthick *et al*., 2016; Cocquyt and Lokele (2019) recently identified a species Geissleria lubiluensis from the Lobilo River in the Yangambi region.

The present study is based on the study of diatoms from the Isalowe River, a river in the Yangambi Biosphere Reserve which experiences strong pressure from surrounding populations with a certain impact on the quality of its waters. To this end, it was necessary to (1) determine the specific composition and abundance of diatoms identified from each sampling site; (2) evaluate the correlation between some physicochemical parameters as well as the specific richness and abundance of species.

II. Environment, Materials and Method

The present investigation took place in the Yangambi Biosphere Reserve (RBY). The RBY is located approximately 100 km and 62 km, respectively west and north of the city of Kisangani. Its surface area is estimated at 225,000 hectares (INEAC, 1939). Its geographical coordinates are between 24°18’ and 25°08’ East longitudes and 00°43’ and 01°08’ North latitudes. Altitudes vary between 400 and 500 m. Located in the equatorial zone, the RBY experiences a Koppen Af type climate (Kombele, 2004; Beguin, 1958). It receives an annual average of 1,750 mm of rain. The annual average temperature is 24.9°C (Kombele, 2004). The reserve is watered over its entire extent by streams and rivers flowing either into the Congo River in the South-West, into the Aruwimi River in the North, or into the Lindi River in the East. The environment was the subject of floristic and agronomic studies carried out during the colonial era by the National Institute for Agronomic Studies in Congo (INEAC).

The materials used in this study were collected in the Isalowe stream at an altitude varying from 379 to 404 m (cf. figure 1). The samples to be studied were taken upstream of the rivers (source) between the source and the mouth (middle) and at the mouth of this river in the dry season between 2015 and 2016. Some physicochemical parameters were measured including temperature, electrical conductivity, pH and dissolved oxygen content at each sampling station. The samples taken were of the phytoplankton type (using a 10µm mesh plankton net), epilithon (on stones), epiphyton (on aquatic plants), epipsammon (on sand), benthos (at the bottom of the river) and epixylon (on submerged dead wood). The samples thus collected were preserved in labeled plastic jars after fixation with 70% ethyl alcohol. Each sample was coded LND0001, LND0002… of which the first two letters are the initials designating the collector and the third letter is the initial of the word “diatom”; the numbers are the order numbers. They were brought to the algology laboratory of the Faculty of Sciences of the University of Kisangani to undergo hot oxidation of the organic matter with 30% peroxide (digestion of the protoplasm and external organic coating of the cells to remain with the siliceous skeleton) and centrifugation. The cleaned diatom samples were mounted between slides and coverslips using Naphrax (AFNOR, 2003).

The observation and counting of diatoms (500 frustules per sample) were carried out using an OLYMPUS C9 optical microscope equipped with a 100 immersion lens. Species were determined using literature on pre-existing diatomic flora following the morphological criteria described by Compère (1975), Krammer and Lange-Bertalot (1986-1991), Golama (1996) and websites such as algaebase as well as Diatoms of North America. Taxa not determined at the species level are identified by sp1, sp2….

The geographic coordinates of the sampling stations are as follows:

- 00°48’17.1’’ N and 24°29’76.2’’ E: the source;
- 00°48’46’’ N and 24°30’64’’ E: the middle
- 00°45’40.4’’ N and 24°28’97.9’’: the mouth

III. Data Analysis

Counts were expressed as relative abundance of each species (ARS). To evaluate the diversity of diatoms in the surveyed stations, we determined the specific richness (RS), the H' index of Shannon and Weaver (1949) and the equitability E. The H' index and the equitability E have allowed respectively to account for the numerical importance of the taxa and to estimate the equidistribution of numbers between the taxa present in order to compare the diversity of the diatomic populations of the different stations (Dajoz, 2000). Principal component analysis (PCA) and correspondence factor analysis (CA) were carried out using PAST 4.03 software with data on physicochemical parameters and the relative abundance of diatoms having, in at least one harvest, a minimum 2% cumulative relative abundance. The PCAs thus carried out made it possible to ascertain the effects of the physico-chemical variables on the one hand, and to establish the taxonomic differences between the stations on the other hand. CA was used to reveal the different assemblages of diatoms taking into account samples collected at different stations. Spearman's rank correlation (rs) was used to measure the degree of connection between the physicochemical and biological parameters using PAST 4.03 software.

The level of water pollution is determined in relation to the Shannon index values mentioned in the following table:

Table 1 Correspondence between the values of the Shannon index and the level of pollution (Simboura and Zenetos, 2002)

Ecological status	Value of H'	Classification of pollution
Bad	0 < H' ≤ 1,5	Very polluted
Poor	1,5 < H' ≤ 3	Heavily polluted
Medium	3 < H' ≤ 4	Moderately polluted
Good	4 < H' ≤ 5	Transition zones
Very good	H' > 5	Reference site

IV. Results and Discussions

4.1. Physical Chemistry of Water

The results of the physicochemical analyzes of the different stations of the Isalowe River are recorded in Table 2.

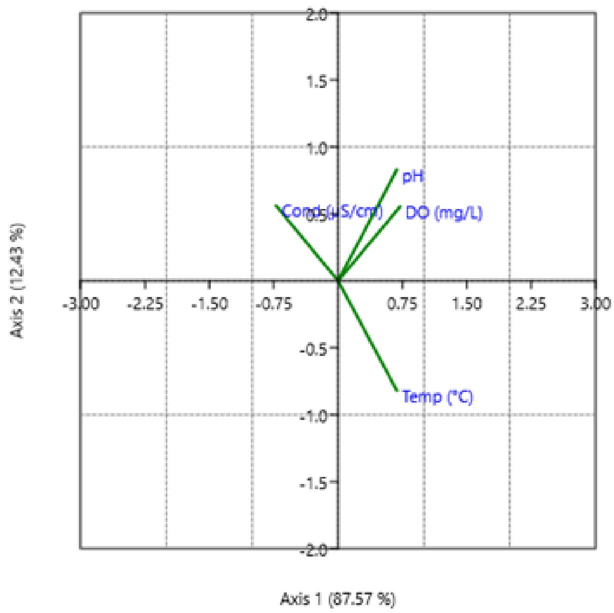
Table 2 Physico-chemical parameters of the Isalowe River

Stations	Temp (°C)	pH	Cond (µS/cm)	DO(mg/L)
Source	23.95±0.07	5.13±0.04	17.00±0.99	4.35±0.14
Middle	24.35±0.21	5.44±0.64	16.42±0.96	5.50±0.57
Mouthpeace	25.95±0.32	5.36±0.24	15.39±2.28	5.41±0.10
River	24.00±1.15	5.53±0.37	17.27±0.38	5.28±0.75

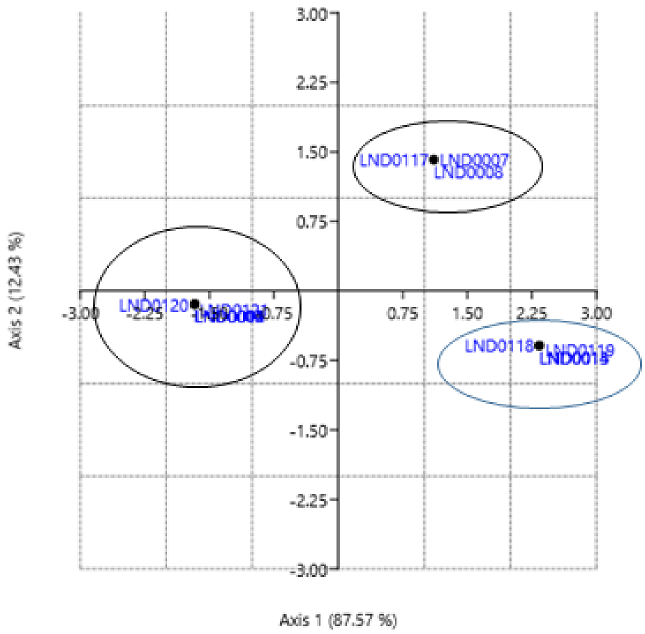
The physicochemical parameters of Isalowe water vary from one sampling site to another. The recorded temperatures vary between 23.95 and 25.95°C (an average of 24°C), the highest being those of the waters of the mouth while those of the source have the lowest temperature. The high temperature at the mouth is justified by the exposure of the waters to the sun of the mouth without plant cover while the source is in the middle of the forest of the reserve under plant cover. As for pH, these waters are generally acidic with values between 5.13 to 5.44 (i.e. a pH of 5.53 on average), the waters of the source being more acidic while those of the environment are less acidic. For electrical conductivity, the degree of mineralization observed in the water, it varies from 15.39 to 17.00 µS/cm being higher at the source while it is lower at the mouth with an average of 17.27 µS/cm for the entire river showing low mineralization. Regarding the dissolved oxygen content, there are values oscillating between 4.35 and 5.50 mg/L (i.e. an average content of 5.28 mg/L for the entire river) being higher in the waters of the environment following their exposure and the mixing of waters when we have less at the source. Ebang Menye et al. (2012) found values ranging from 21 to 25 °C in the Mfoundi River (Yaoundé, Cameroon). The slight difference observed could be explained by local climatic variations. The dissolved oxygen content shows a saturation rate of 55.60%. For these authors, the low dissolved oxygen saturation rates can be explained by the degradation of organic matter coming from waste water. In temperate conditions, in North Africa and precisely in Morocco, the parameters recorded in the waters of Oued Hassar showed strong mineralization with conductivity values varying between 3470 and 7210 µS/cm due essentially to the high contents in chlorides. Dissolved oxygen contents vary between 2.52 mg/L to 24.34 mg/L (Fawzi et al., 2001).

The results thus obtained are justified by the rise in temperature which is a parameter which influences all other physico-chemical parameters such as dissolved oxygen, pH, conductivity and others (Lavoie *et al*., 2008). The physico-chemistry of these waters reveals eutrophication because there is little mineralized material following the low temperature under the plant cover and, consequently, full of organic and acidic matter.

The PCA was carried out with 6 variables including 2 biotic and 4 physico-chemical from the different sampling stations. Axes 1 and 2 are retained because they represent 99.95% of the highest explained variability (figure 2 a and b). The two physicochemical parameters such as pH, dissolved oxygen content (DO) and mineralization (electrical conductivity: cond) correlate positively with respect to the first axis (87.57% inertia) while they correlate negatively with the temperature (Temp) relative to the same axis. It determines the water quality in the different stations of the Isalowe river. pH, dissolved oxygen and temperature correlate positively with respect to axis 2 (12.43% inertia) but they correlate negatively with mineralization with respect to the same axis. The distribution of different parameters in different stations on the plane of two axes show a spatial variation of these physicochemical variables at these stations considering the two axes (figure 2b). In fact, considering the samples, they form three groupings, the first of which consists of samples LND0001, LND0002, LND0003, LND0004, LND0005, LND0010 and LND0011 collected in the waters of the source. The second grouping consists of samples LND007, LND008 and LND0177 from the middle waters. The third grouping is formed LND0013, LND0014, LND0118 and LND0119 collected in the waters of the mouth.



a. Physico-chemical variables (axis 1 and 2 : 99.95 %)



b. Stations (axes 1 and 2 : 99.95 %)

Fig.2a PCA of physicochemical variables of water. b. PCA of samples collected at the different stations

4.2. Diatomic flora

The diatomic flora of the Isalowe River includes 194 specific taxa divided into 43 genera and 20 families. At the station level, we observe a spatial variation in species richness from the source to the mouth varying from 48 to 147 specific taxa belonging to different genera and families. At the source there are 147 species grouped into 34 genera and 17 families. In the middle, 48 specific taxa divided into 16 genera and 12 families. At the mouth, 97 species were counted grouped into 38 genera and 18 families.

Table 3 contains the different taxa identified at the stations and river. The Eunotiaceae Kützing family is the most abundant containing (29.38%) with the most abundant species *Eunotia rhomboidea* Hustedt, *Eunotia intermedia* (Krasske ex Hustedt) Norpel & Lange-Bertalot, *Eunotia fallax* A. Cleve. The Pinnulariaceae D. G. Mann represent 20.62% with the dominant species *Pinnularia brauniana* (Brunow) Studnicka. The Naviculaceae Kützing family comprises 8.76% of all species with the species *Eolimna subminuscula* (Manguin) Gerd Moser, Lange-Bertalot & Metzeltin, *Navicula cryptotenella* Lange-Bertalot, *Nupela neglecta* Ponader, R.L.Lowe & Potapova. The Diadesmidaceae D. G. Mann represent 5.67% of all individuals with the most abundant species *Luticola mutica* (Kützing) D.G.Mann. The Mereschkowsky Neidiaceae make up 5.15% of the total, with *Neidium affine* (Ehrenberg) Pfitzer as the dominant species. The other families are less abundant with less than 5% relative abundance.

At the river level, species of the genus Eunotia are the most abundant (35.99%) (*E. rhomboidea* Hustedt and E. intermedia (Krasske) Nörpel & Lange-Bertalot). They are followed by *Neidium affine* (Ehrenberg) Pfitzer (8.28%) and species of the *Pinnularia* genus (5.02%) (*P. brauniana* (Grunow) Studnicka) (see figure 3).

At the station level, species of the *Eunotia* genus are the most abundant (41.28%) at the source (*E. rhomboidea* Hustedt, *E. intermedia* (Krasske) Nörpel & Lange-Bertalot and *E. fallax* A. Cleve). At this station, we also have the species *Neidium affine* (11.79%) and *Pinnularia* spp (5.39%). In the middle, it is still the species of the genus *Eunotia* which predominate (48.41%), *Neidium affine* (Ehrenberg) Pfitzer (11.79%), *Neidium* sp (7.95%), *Pinnularia* spp (6.23%) (*P. brauniana* (Grunow) Studnicka) and *Frustulia saxonica* Rabenhorst (7.62%). At the mouth, species of the genus *Neidium* remain the most abundant (24.98%), cases of *N. affine* (Ehrenberg) Pfitzer (11.79%) and *N.* sp. There are also species of the *Eunotia* genus (15.77%), species of the *Neidium* genus (24.48%) such as *N. affine* and *N.* sp and *Pinnularia* sp (8.09%) (see figure 4).

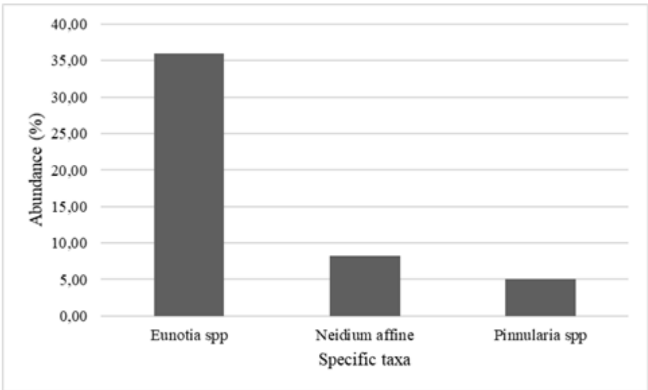


Fig. 3 River specific relative abundances (n ≥ 5).

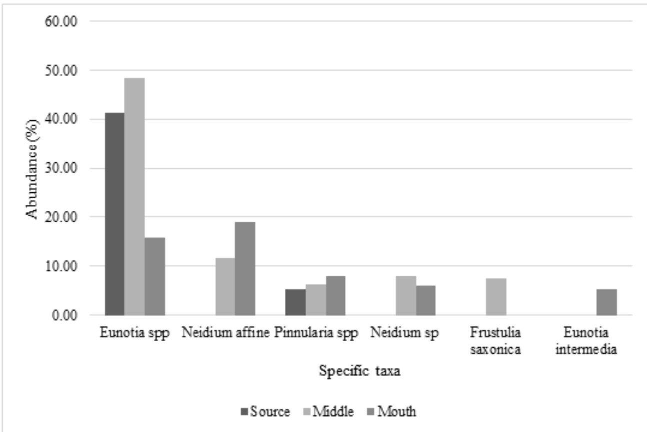
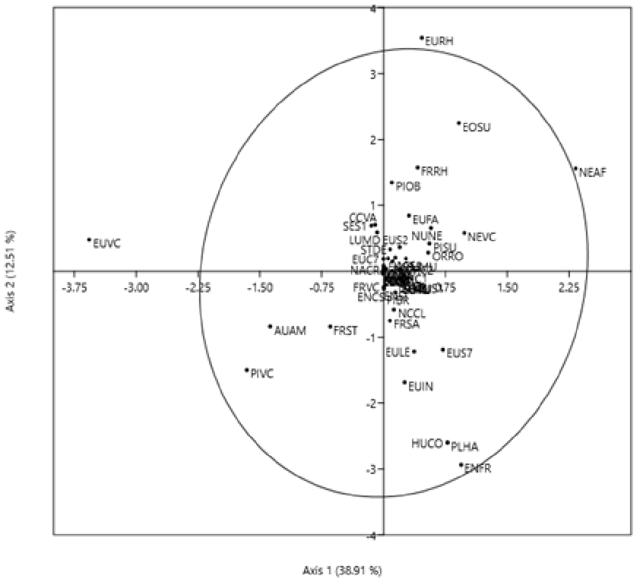


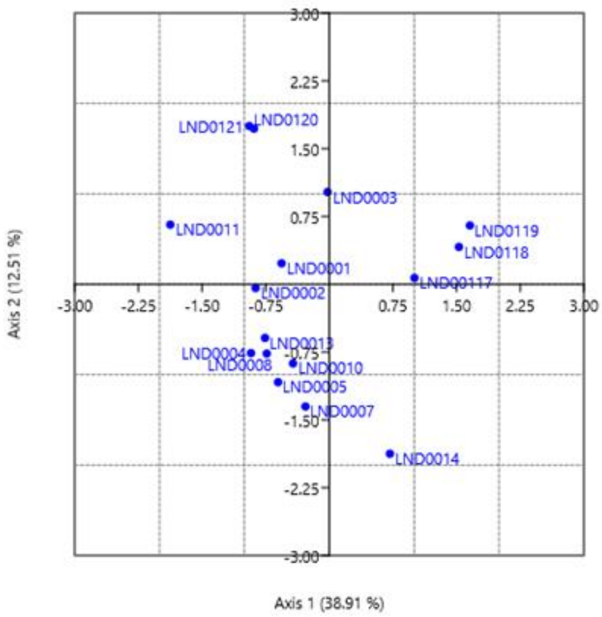
Fig. 4. Stations specific relative abundances (n ≥ 5)

The Shannon index varies from 1.273 to 3.084, an average of 2.166, showing great diversity in the waters of this river. At the station level, the results showed great diversity compared to all stations. In fact, at the source, we have a value of 2.980, 2.009 in the middle and 3.171 at the mouth. The equitability index varies from 0.4651 to 0.7893 (i.e. an average of 0.6305) revealing an equal distribution of individuals within species. Regarding the stations, it is 0.6463 at the source, 0.4876 in the middle and 0.6641 at the mouth.

The spatial distribution of diatoms was determined using CA performed using diatom species with cumulative relative abundances greater than or equal to 2%, with the first two axes representing 51.42% of the explained variability (Figure 3 a and b). The first assembly is formed of samples LND0120 and LND0121 with the species *Encyonopsis frequentis* (ENFR), *Eunotia leonardii* (EULE), *Eunotia* sp7 (EUS7), *Humidophila contenta* (HUCO) and *Placoneis hambergii* (PLHA) While the second assembly brings together the samples LND0117, LND0118 and LND0119 with the species *Aulacoseira ambigua* (AUAM), *Fragilariforma strangulata* (FRST) and *Neidium affine* (NEAF). The third assemblage is composed of samples LND0001 and LND0002 with the species *Aulacoseira ambigua* (AUAM), *Chammaepinnularia* cf. sp1 (CHC1) and sp2 (CHC2), *Eunotia fallax* (EUFA), *Fragilariforma strangulata* (FRST), *Luticola mutica* (LUMU) and *Orthoseira roeseana* (ORRO). The fourth assemblage consists of samples LND0004, LND0005, LND0007, LND0008, LND0010 and LND0013 *Actinella* sp1 (ACS1), *Craticula cuspidata* var. *ambigua* (CCVA), *Encyonopsis frequentis* (ENFR), *Eolimna subminuscula* (EOSU), *Eunotia fallax* (EUFA), *Eunotia minor* (EUMI), *Eunotia rhomboidea* (EURH), *Eunotia* sp2 (EUS2), *Fragilariforma strangulata* (FRST), *Frustulia rhomboides* (FRRH), *Frustulia saxonica* (FRSA), *Luticola mutica* (LUMU), *Luticola muticoides* (LUMD), *Navicula cryptotenella* (NACL), *Neidium affine* (NEAF), *Nupela neglecta* (NUNE), *Orthoseira roeseana* (ORRO), *Pinnularia obscura* (PIOB) , *Pinnularia subacoricola* (PISU), *Stauroneis phoeniceron* (STPH) and *Stenopterobia delicatissima* (STDE). The rest of the samples are isolated.



a. Taxons spécifiques (axes 1 et 2 : 51,42 %)



b. Echantillons (axes 1 et 2 : 51,42 %)

Fig. 3 a. Component Factor Analysis (CA) of specific diatom taxa (cumulative relative abundance ≥ 2%) collected in the Isalowe river. b. CA of samples from different sites described by their diatom communities.

The variability of these results in relation to the different stations could also be explained by the physico-chemical parameters which are not the same at all stations. It is also worth mentioning that the photosynthetic productivity of diatoms strongly depends on light acclimation processes (Valle *et al*., 2014; Wilhelm *et al*., 2014). Golama (1996) observed *Eunotia* taxa more abundant in acidic and low conductivity waters in and around Kisangani. Menye *et al*. (2012) found in the Mfoundi River in Yaoudé in Cameroon an abundance of *Nitzschia palea* in stations Mf5 (which supervises the Société Anonyme de Brasserie de Cameroun) with 66% of individuals and station Mf6 (located downstream of the point of discharge of effluents from the Cameroon Oil Depots Company and Cameroon Wine Manufacturing Company) which has 53% of individuals. Tahraoui *et al*. (2024), found 62 different taxa (or 62%) along the Casablanca–El Jadida coastal axis. In the same country, the study carried out in the Oued Hassar river (Fazwi *et al*., 2001), the abundances vary from one station to another. This is how in the stations (Sidi Brahim, Sidi Hajaj and Cascades), there is dominance of diatomic populations such as *Nitzschia palea* (i.e. 71%) and it exceeds 45%. For other stations such as source Hassar psychiatric hospital Oued Mouilleh *N. palea* presents higher abundances in the three stations, while *N. inconspicua*/ *N. frustulum* develop more, especially in the second station where their relative abundance reaches 58.5 %. The dominant species in the stations are *Achnanthes minutissima*, *Achnanthes inflata* and especially *Achnanthes kolbei*. In their study carried out in the streams of the Massif Ardenais in Belgium, Loncin *et al*. (1998) obtained the results according to which the genus *Eunotia* generally represents more than 80% of the population, with mainly *E. bilunaris, E. exigua E. rhomboidea and E. tenella. Eunotia exigua* clearly dominates in all the stations studied and throughout the year, a species generally accompanied by *E. rhomboidea*, except in the western branch of the Robinette where it is more often associated with *E. bilunaris. P. tricornutum, Nitzschia palea, Thalassiosira weissflogii, Navicula phyllepta, Plagiogrammopsis vanheurckii, Planothidium delicatulum, Biremis lucens, Fragilaria subsalina* were identified by Lavaud (2024). The study carried out by Gallut *et al*. (2024) revealed spatial (phytoplankton communities in heterogeneous harbor) and temporal variability of phytoplankton communities (variable from one year to another). These results can be explained by the presence of certain nutrient salts as well as the increase or decrease in salinity and temperature and depending on the circulation of water masses. In a study of the relationship between the carbonate system and the phytoplankton community in the Gulf of Guinea-Africa, it was proven that the physical (temperature, salinity) and chemical (total alkalinity, dissolved inorganic carbon, pH) parameters influenced, in general, less than 50% of the phytoplankton population of the Gulf coastal zone and in particular, the population of Bacillariophyta when the variability of physicochemical parameters increases (Koffi *et al*., 2024). Salam *et al*. (2024) counted 189 species of diatoms whose specific richness and abundance vary according to the season in Marine Protected Areas in Senegal where, for all stations and seasons combined, Bacillariophytes represented 189 species. The species richness, unlike the abundance of phytoplankton, was greater during the dry season with 207 species compared to 161 during the rainy season (Salam *et al*., 2024). Khaoula *et al*. (2023) identified 24 species of phytoplankton including

31% diatoms in Lake Tonga in Algeria. Amaral *et al*. (2024) identified 221 diatom species at the infrageneric level. *Pinnularia* was the most representative genus in terms of number of species (28 spp.), followed by *Eunotia* (25 spp.), *Gomphonema* (17 spp.), *Nitzschia* (14 spp.) and *Navicula* (11 spp.) in the river Cascavel in the south of Brazil.

The differences observed are explained by the regions and seasons of study as well as other parameters such as the nutrient and organic matter contents, the speed of water flow having a negative impact on the colonization of the substrates which have an influence on the diversity, relative abundance and assemblages of diatoms as well as their spatial distribution (Biggs and Close, 1989; Clausen and Biggs, 1997; Leland and Porter, 2000). In addition, the influence of pollution on the health state of rivers cannot be explained only by indicators of specific diversity. It is also necessary to consider the specific composition of the organisms concerned and to know their autoecology well (Archibald, 1972; Cox, 1988). Water turbulence is a parameter that has a major impact on the taxonomic composition of diatom communities in rivers. Consequently, to maximize the ability to measure the level of organic pollution and eutrophication using diatoms, it was necessary to choose a type of facies – the lotic facies – to homogenize the type of communities encountered (Kelly et al., 1998). The type of substrate on which benthic diatoms develop is also a physical parameter that structures the composition of communities (Rimet, 2020).

4.3. Diatoms and water quality

The results of Spearman's rank correlation ($p < 0.05$) obtained from the biotic variables (specific richness and specific relative abundance) of samples from the different stations and the physicochemical parameters. They revealed that the two biotic variables correlated positively with electrical conductivity (rs= 0.5). These same variables correlate negatively with pH and dissolved oxygen (DO) content (rs = 1) as well as temperature (rs = 0.5). These results show that the mineralization of organic matter is favorable to the richness (RS) and specific relative abundance (SRA) of diatoms in the waters of this river (Table 4).

Table 4 Spearman rank correlation coefficients of diatom biotic variables and physicochemical parameters of water

	SR	SRA (%)	Temp (°C)	pH	Cond (µS/)	DO (mg/)
SR						
SRA (%)	1					
Temp (°C)	-0,5	-0,5				
pH	-1	-1	0,5			
Cond (µS/cm)	0,5	0,5	-1	-0,5		
DO (mg/L)	-1	-1	0,5	1	-0,5	

Level of water pollution is determined in relation to Shannon index values. It can be deduced that, based on the average value of this index (2.1662), that the waters of the Isalowe River are in a poor ecological state and heavily polluted. At the station level, the waters of the source and those of the mouth are in a poor ecological state and heavily polluted (average H' of 2.2801 and 2.2220 respectively). In the middle, they are in a poor ecological state and very polluted. These ecological states and pollution of the waters of this stream and at its various stations are justified by the anthropogenic activities (retting of cassava, artisanal extraction of palm oil, washing dishes, laundry, bathing and fields) of the surrounding populations.

The differences observed are due to the climates (temperate and tropical) which determine the physicochemical parameters of the rivers in each region. The species richness and specific relative abundance of diatoms depend on decomposing organic matter which adapts to pollution. For this purpose, we encounter α-meso/polysaprobous species such as *Nitzschia palea*, *Gomphonema parvulum*, *G. gracile*, *Hantzschia amphioxys*, *Pinnularia subcapitata* at the different stations where the waters are eutrophic as reported by Leland and Porter (2000). Menye *et al*. (2012) mention α-meso/polysaprobous species such as *Nitzschia palea*, *N. mutica*, *N. geoppertiana*, *Pinnularia subcapitata* and *Gomphonema parvulum* var. *lagenula* frequently observed in stations Mf2 and Mf6 in the eutrophic or even hypereutrophic waters of the hydrosystems of the Mfoundi River. According to these authors, the abundances of *Nitzschia palea* have a positive correlation with conductivity, ammonium ions, orthophosphates and oxidizability, alkalinity and hardness of water. Blinn *et al*. (2004) and Morin (2006) reported these results in the hydro-ecoregions of Australia and France. The results obtained from the Shannon and Piélou diversity indices reflect low diversity and an unequal distribution of individuals within phytoplankton communities in the Marine Protected Areas of Senegal (Salam *et al*., 2024). Tahraoui *et al*. (2024) observed a spatiotemporal evolution of the diversity (H’) and equitability (E) indices showing pronounced seasonal fluctuations without much analogy between the different sites sampled.

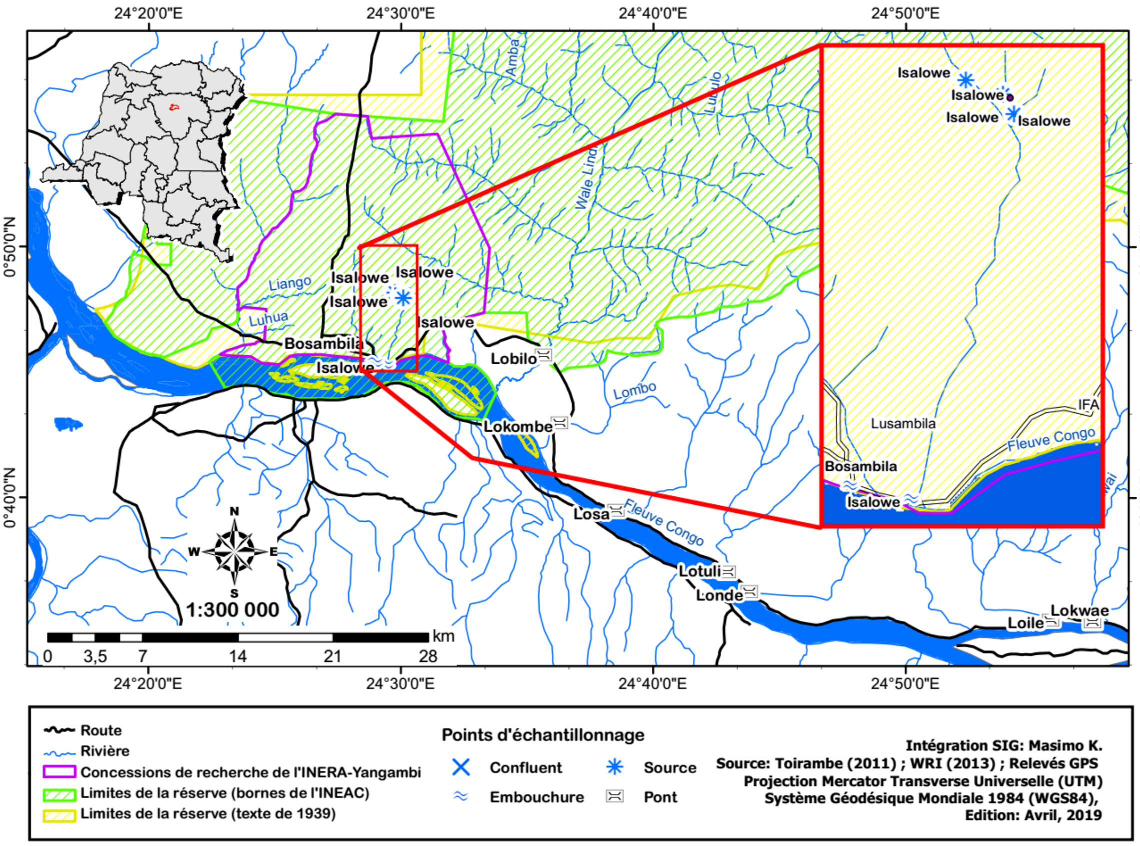


Fig. 1 Rivers and sampling points

Table 3. Diversity of diatoms at the stations and the river

Stations	Genus	Families	Source	Middle	Mouth
Achnanthes inflate	*Achnanthes*	Achnanthaceae			+
Achnantidium exiguum	*Achnanthidium*	Achnanthidiaceae	+		
Actinella sp1	*Actinella*	Eunotiaceae	+	+	+
Adlafia sp1	*Adlafia*	Naviculaceae	+		+
Aulacoseira ambigua	*Aulacoseira*	Aulacoseiraceae	+		+
Aulacoseira granulate	*Aulacoseira*	Aulacoseiraceae	+		
Brachysira serians	*Brachysira*	Brachysiraceae			+
Caloneis sp1	*Caloneis*	Pinnulariaceae	+		
Capartogramma crucicula	*Capartogramma*	Pinnulariaceae	+		
Cavinula lilandae	*Cavinula*	Naviculaceae	+	+	+
cf. Chamaepinnularia sp1	*Chamaepinnularia*	Cavinulaceae	+		
cf. Chamaepinnularia sp2	*Chamaepinnularia*	Pinnulariaceae	+		
Chamaepinnularia soehrensis	*Chamaepinnularia*	Pinnulariaceae	+		
Cocconeis schroederi	*Cocconeis*	Pinnulariaceae	+		
Craticula cuspidata var. ambigua	*Craticula*	Cocconeidaceae			+
Craticula sp1	*Craticula*	Stauroneidaceae			+
Cyclotella meneghiniana	*Cyclotella*	Stauroneidaceae			+
Cymbopleura amphicephala	*Cymbopleura*	Stephanodiscaceae	+		
Cymbopleura sp1	*Cymbopleura*	Cymbellaceae			+
Desmogonium sp1	*Desmogonium*	Cymbellaceae	+		+
Desmogonium sp2	*Desmogonium*	Eunotiaceae	+		+
Encyonema silesiacum	*Encyonema*	Eunotiaceae	+		+
Encyonema cf. silesiacum	*Encyonema*	Cymbellaceae	+		
Encyonopsis frequentis	*Encyonopsis*	Cymbellaceae	+		+
Eolimna sp1	*Eolima*	Cymbellaceae	+		
Eolimna subminuscula	*Eolima*	Naviculaceae	+	+	+
Eunotia bilunaris var. mucophila	*Eunotia*	Naviculaceae		+	
Eunotia cf. bilunaris	*Eunotia*	Eunotiaceae	+		
Eunotia cf. fallax	*Eunotia*	Eunotiaceae	+	+	+
Eunotia epithemioides	*Eunotia*	Eunotiaceae	+		
Eunotia fallax	*Eunotia*	Eunotiaceae	+	+	+
Eunotia intermedia	*Eunotia*	Eunotiaceae			+
Eunotia intricans	*Eunotia*	Eunotiaceae			+

Eunotia cf. intricans	*Eunotia*	Eunotiaceae			+
Eunotia leonardii	*Eunotia*	Eunotiaceae	+		+
Eunotia cf. logicollis	*Eunotia*	Eunotiaceae	+		
Eunotia minor	*Eunotia*	Eunotiaceae	+	+	+
Eunotia cf. minor	*Eunotia*	Eunotiaceae			+
Eunotia cf. monodon	*Eunotia*	Eunotiaceae	+		
Eunotia naegelii	*Eunotia*	Eunotiaceae	+		
Eunotia cf. parallela	*Eunotia*	Eunotiaceae	+		
Eunotia paludosa	*Eunotia*	Eunotiaceae			+
Eunotia parabidens	*Eunotia*	Eunotiaceae	+		
Eunotia cf. pectinalis	*Eunotia*	Eunotiaceae	+		
Eunotia pierrefuseyi sp. nov.	*Eunotia*	Eunotiaceae			+
Eunotia rabenhorstii	*Eunotia*	Eunotiaceae	+	+	
Eunotia rhomboidea	*Eunotia*	Eunotiaceae	+	+	+
Eunotia aff. rhomboidea	*Eunotia*	Eunotiaceae	+		
Eunotia cf. rhomboidea	*Eunotia*	Eunotiaceae	+	+	
Eunotia rudis	*Eunotia*	Eunotiaceae	+	+	
Eunotia sp1	*Eunotia*	Eunotiaceae	+	+	+
Eunotia sp2	*Eunotia*	Eunotiaceae	+	+	+
Eunotia sp3	*Eunotia*	Eunotiaceae	+		+
Eunotia sp4	*Eunotia*	Eunotiaceae	+	+	
Eunotia sp5	*Eunotia*	Eunotiaceae	+		
Eunotia sp6	*Eunotia*	Eunotiaceae	+		
Eunotia sp7	*Eunotia*	Eunotiaceae	+	+	+
Eunotia sp8	*Eunotia*	Eunotiaceae			+
Eunotia sp9	*Eunotia*	Eunotiaceae		+	+
Eunotia sp14	*Eunotia*	Eunotiaceae	+		
Eunotia sp15	*Eunotia*	Eunotiaceae	+		
Eunotia sp16	*Eunotia*	Eunotiaceae	+		
Eunotia sp17	*Eunotia*	Eunotiaceae	+		
Eunotia sp18	*Eunotia*	Eunotiaceae	+		+
Eunotia sp19	*Eunotia*	Eunotiaceae		+	
Eunotia sp25	*Eunotia*	Eunotiaceae		+	
Eunotia sp37	*Eunotia*	Eunotiaceae		+	
Eunotia sp38	*Eunotia*	Eunotiaceae		+	
Eunotia sp39	*Eunotia*	Eunotiaceae		+	
Eunotia sp40	*Eunotia*	Eunotiaceae		+	
Eunotia sp41	*Eunotia*	Eunotiaceae		+	
Eunotia sp42	*Eunotia*	Eunotiaceae		+	
Eunotia sp43	*Eunotia*	Eunotiaceae		+	
Eunotia sp44	*Eunotia*	Eunotiaceae		+	
Eunotia sp45	*Eunotia*	Eunotiaceae		+	
Eunotia sp47	*Eunotia*	Eunotiaceae			+
Eunotia sp48	*Eunotia*	Eunotiaceae	+		
Eunotia sp50	*Eunotia*	Eunotiaceae			+
Eunotia tenella	*Eunotia*	Eunotiaceae			+
Eunotia zygodon	*Eunotia*	Eunotiaceae	+		+
Fragilaria vacheriae	*Fragilaria*	Fragilariaceae			+
Fragilariforma sp1	*Fragilariforma*	Eunotiaceae	+		
Fragilariforma strangulata	*Fragilariforma*	Fragilariaceae	+	+	+
Fragilariforma virescens	*Fragilariforma*	Fragilariaceae			+
Frustulia cf. vulgaris	*Frustulia*	Fragilariaceae			+
Frustulia rhomboids	*Frustulia*	Amphipleuraceae	+	+	+
Frustulia saxonica	*Frustulia*	Amphipleuraceae	+	+	+
Geissleria lubiluensis sp. nov.	*Geissleria*	Amphipleuraceae	+		
Geissleria sp2	*Geissleria*	Naviculaceae			+
Gomphonema augur var. turris	*Gomphonema*	Naviculaceae	+		
Gomphonema gracile	*Gomphonema*	Gomphonemataceae	+		
Gomphonema cf. gracile	*Gomphonema*	Gomphonemataceae	+		
Gomphonema parvulum	*Gomphonema*	Gomphonemataceae	+		+
Gomphopleura amphicephala	*Gomphopleura*	Gomphonemataceae			+
Hantzschia amphioxys	*Hantzschia*	Gomphonemataceae			+
Humidophila cf. gallica	*Humidophila*	Bacillariaceae			+
Humidophila contenta	*Humidophila*	Diadesmidaceae	+		+
Humidophila contenta var. constricta	*Humidophila*	Diadesmidaceae	+		+
Humidophila gallica	*Humidophila*	Diadesmidaceae	+		

Iconella cf. ebalensis	*Iconella*	Surirellaceae	+		+
Luticola cf. goeppertiana	*Luticola*	Diadesmidaceae	+		
Luticola mutica	*Luticola*	Diadesmidaceae	+	+	+
Luticola cf. mutica	*Luticola*	Diadesmidaceae	+		
Luticola muticoides	*Luticola*	Diadesmidaceae		+	+
Luticola sp1	*Luticola*	Diadesmidaceae	+		
Luticola sp3	*Luticola*	Diadesmidaceae	+		+
Luticola sp4	*Luticola*	Diadesmidaceae			+
Mayamaea sp	*Mayamaea*	Naviculaceae			+
Melosira sp1	*Melosira*	Melosiraceae			+
Navicula cryptocephala	*Navicula*	Naviculaceae	+		+
Navicula cf. cryptotenella	*Navicula*	Naviculaceae			+
Navicula cryptotenella	*Navicula*	Naviculaceae	+		+
Navicula cf. kotschyi	*Navicula*	Naviculaceae	+		
Navicula lapidosa	*Navicula*	Naviculaceae	+		
Navicula radiosa	*Navicula*	Naviculaceae			+
Neidium affine	*Neidium*	Naviculaceae	+	+	+
Neidium cf. affine	*Neidium*	Neidiaceae	+		
Neidium ampliatum	*Neidium*	Neidiaceae			+
Neidium cf. ampliatum	*Neidium*	Neidiaceae	+		
Neidium apiculatum	*Neidium*	Neidiaceae	+		
Neidium cf. dialitatum	*Neidium*	Neidiaceae	+		
Neidium gracile	*Neidium*	Neidiaceae			+
Neidium iridis	*Neidium*	Neidiaceae	+		
cf. Neidium sp2	*Neidium*	Neidiaceae	+		
cf. Neidium sp3	*Neidium*	Neidiaceae			+
Nitzschia palea	*Nitzschia*	Neidiaceae	+	+	+
Nitzschia cf. palea	*Nitzschia*	Bacillariaceae			+
Nitzschia palea var. tenuirostris	*Nitzschia*	Bacillariaceae	+		
Nitzschia sp1	*Nitzschia*	Bacillariaceae			+
Nitzschia terrestris	*Nitzschia*	Bacillariaceae	+		
Nupela neglecta	*Nupela*	Bacillariaceae	+	+	
cf. Nupela neglecta	*Nupela*	Naviculaceae	+		
Nupela wellneri	*Nupela*	Naviculaceae	+	+	+
Orthoseira roeseana	*Orthoseira*	Naviculaceae	+	+	+
Pinnularia acoricola	*Pinnularia*	Orthoseiraceae		+	
Pinnularia cf. acoricola	*Pinnularia*	Pinnulariaceae	+		
Pinnularia acrosphaerea	*Pinnularia*	Pinnulariaceae	+		+
Pinnularia amabilis	*Pinnularia*	Pinnulariaceae	+		+
Pinnularia cf. amabilis	*Pinnularia*	Pinnulariaceae		+	
Pinnularia borealis	*Pinnularia*	Pinnulariaceae			+
Pinnularia brauniana	*Pinnularia*	Pinnulariaceae		+	+
Pinnularia gibba	*Pinnularia*	Pinnulariaceae	+		+
Pinnularia cf. gibba	*Pinnularia*	Pinnulariaceae	+		+
Pinnularia cf. gracilis	*Pinnularia*	Pinnulariaceae			+
Pinnularia gibba var. parva	*Pinnularia*	Pinnulariaceae			+
Pinnularia gracilis	*Pinnularia*	Pinnulariaceae	+		
Pinnularia graciloides	*Pinnularia*	Pinnulariaceae	+		
Pinnularia hudsonii sp. nov.	*Pinnularia*	Pinnulariaceae	+		
Pinnularia interrupta	*Pinnularia*	Pinnulariaceae			+
Pinnularia maior	*Pinnularia*	Pinnulariaceae	+	+	+
Pinnularia mesolepta	*Pinnularia*	Pinnulariaceae			+
Pinnularia microstauron	*Pinnularia*	Pinnulariaceae	+	+	+
Pinnularia obscura	*Pinnularia*	Pinnulariaceae	+		+
Pinnularia cf. schoenfelderi	*Pinnularia*	Pinnulariaceae	+		
Pinnularia sp1	*Pinnularia*	Pinnulariaceae	+		
cf. Pinnularia sp1	*Pinnularia*	Pinnulariaceae	+		
Pinnularia sp4	*Pinnularia*	Pinnulariaceae	+		+
Pinnularia sp5	*Pinnularia*	Pinnulariaceae	+		
Pinnularia sp6	*Pinnularia*	Pinnulariaceae	+		
Pinnularia sp9	*Pinnularia*	Pinnulariaceae	+		
Pinnularia sp16	*Pinnularia*	Pinnulariaceae	+		
Pinnularia sp25	*Pinnularia*	Pinnulariaceae			+
Pinnularia subacoricola	*Pinnularia*	Pinnulariaceae	+	+	+
Pinnularia cf. subacoricola	*Pinnularia*	Pinnulariaceae	+		+
Pinnularia subcapitata	*Pinnularia*	Pinnulariaceae		+	+
Pinnularia cf. subcapitata	*Pinnularia*	Pinnulariaceae	+		

Pinnularia cf. subcapitata var. elongata	*Pinnularia*	Pinnulariaceae	+		
Placoneis elginenis	*Placoneis*	Cymbellaceae	+		
Placoneis hambergii	*Placoneis*	Cymbellaceae	+	+	+
Placoneis cf. hambergii	*Placoneis*	Cymbellaceae	+		
Sellaphora pupula	*Sellaphora*	Sellaphoraceae		+	+
Sellaphora cf. pupula	*Sellaphora*	Sellaphoraceae	+		+
Sellaphora seminilum	*Sellaphora*	Sellaphoraceae	+		
Sellaphora cf. seminilum	*Sellaphora*	Sellaphoraceae	+		
cf. Sellaphora seminulum	*Sellaphora*	Sellaphoraceae	+		
Sellaphora sp1	*Sellaphora*	Sellaphoraceae	+		+
cf. Sellaphora sp1	*Sellaphora*	Sellaphoraceae			+
Sellaphora sp2	*Sellaphora*	Sellaphoraceae	+		
Sellaphora sp3	*Sellaphora*	Sellaphoraceae	+		
Stauroneis kriegeri	*Stauroneis*	Sellaphoraceae	+		
Stauroneis phoenicenteron	*Stauroneis*	Sellaphoraceae			+
Stauroneis smithii	*Stauroneis*	Stauroneidaceae		+	
Stauroneis sp2	*Stauroneis*	Stauroneidaceae	+		
Staurosirella cf. africana	*Stauroneis*	Stauroneidaceae	+		
Stenopterobia delicatissima	*Staurosirella*	Stauroneidaceae	+	+	+
Stenopterobia sigmatella	*Stenopterobia*	Surirellaceae	+		
Stenopterobia sp1	*Stenopterobia*	Surirellaceae			+
Surirella linearis	*Surirella*	Surirellaceae			+
Surirella nervosa	*Surirella*	Surirellaceae	+		
Surirella sp1	*Surirella*	Surirellaceae	+		

References

1) AFNOR (2003). Water quality. Guide for routine sampling and pre-treatment of river benthic diatoms. Standards NF EN 13946, 16 p

2) Alia, Y. (2024). The insecticidal activity of diatomite and the essential oil of Ammoide verticillata on the pest of stored sheaths Tribolium confusum in the Tissemsilt region. Master's thesis. Ecology and environment. Protection of ecosystems. Faculty of Science and Technology. Department of Natural and Life Sciences. Tissemsilt University. Algeria. 42-55.

3) Amaral, M W W, Medeiros, G, Sampaio, S C, Dos Reis, R R, Ludwig, T A V & Bueno, N C (2024). Taxonomic of epilithic diatoms and teratological forms under the presence of metals in surface sediment. Vol. 674 N° 3. Phytotaxa. P. 237 – 273. DOI: 10.11646/Phytotaxa.647.3.3.

4) Archibald, R.E.M. (1972). Diversity in some South African diatom associations and its relation to water quality. Water Res., 6, 1229-1238

5) Beguin, H. (1958). Human geography of the Bengamisa region, Brussels, INEAC Publication, scientific series, 74, 69 p.

6) Biggs, B.J.F.and Close, M.E. (1989). Periphyton biomass dynamics in gravel bed rivers: the relative effects of flow and nutrients. Freshwater Biol., 22, 209-231.

7) Blinn D.W., Halse, S.A., Pinder, A.M., Shiel, R.J. et McRae, J.M. (2004). Diatom and micro-invertebrate communities and environmental determinants in the western Australian wheatbelt: a response to salinization. Hydrobiologia, 528, 229-248.

8) Clausen, B. et Biggs, B.J.F. (1997). Relationships between benthic biota and hydrological indices in New Zealand streams. Freshwater. Biol.. New Zealand. 38, 327-342.

9) Cox, E. J. (1988). Microdistributional patterns of freshwater diatoms in relation to their use as bioindicators. 10th Diatom-Symposium 1988: 521–528.

10) Dajoz R. (2000). Summary of ecology. Dunod. Paris. France. 615 pp.

11) Fawzi, B., Chlaida, M., Oubraim, S., Loudiki, M., Sabour, B. and Bouzidi, A. (2001). Application of certain diatomic indices to a Moroccan river: Oued Hassar. Rev. Sci. Water.

University of Quebec - INRS-Water, Earth and Environment (INRS-ETE). Quebec. Canada. 14, 73-89.

12) Gallut, C., Liret, C. Le Moal, M., Pondaven, P. Banovski-Klein, C. Pichon, C. J., Plus, M. Schweibold, L., Sourisseau, M. and Schnell, N. K.. (2024). Objectif Plankton: a participatory science program for the study of plankton diversity. The inventory of biodiversity today, new methods and discoveries, ISTE Editions, pp.43-58, Biology, 978-1-78406-986-543. hal-04612703.

13) Golama S.K.A. (1996). Bacillariophyceae, Desmidiaea and Euglenophyceae from the Kisangani region (Zaire). Royal Academy of Overseas Sciences. Class of Natural and Medical Sciences. Mémoires in-8°, New Series 23(3): 232 pp.

14) National Institute for Agronomic Studies in Congo (NIAC) (1940). Annual report for the 1939 financial year, special issue 1940 and 1941, 301 p.

15) Kelly, M.G., Cazaubon, A., Coring, E., Dell'Uomo, A., Ector, L., Goldsmith, B., Guasch, H., Hurlimann, J., Jarlman, A., Kawecka, B., Kwandrans, J., Laugaste, R., Lindstrom, E.A., Leitao, M., Marvan, P., Padisak, J., Pipp, E., Prygiel, J., Rott, E., Sabater, S., Van Dam, H., Vizinet, J., (1998). Recommendations for the routine sampling of diatoms for water qualtiy assessments in Europe. Journal of Applied Phycology 10, 215–224.

16) Khaoula, B. & Riham, M S C (2023). Study of the dynamics and identification of phytoplankton populations in the continental waters of Lake Tonga (PNEK). SNV.STU. Algeria read online at http://dspace.univ-guelma.dz/jspui/handle/123456789/15493.

17) Koffi KU, Konan ES, Hassoun AER and Kouadio Y. 2024. Relationship between the carbonate system and phytoplankton community in the Gulf of Guinea-Africa. Front. Mar. Sci. 11:1286338.
DOI: 10.3389/fmars.2024.1286338

18)Kombele B. (2004). Diagnosis of soil fertility in the Congolese Central Basin. Case of the Yakonde and Yangambi series. Doctoral thesis, University Faculty of Agricultural Sciences of Gembloux. Gembloux. Belgium. 464.
19)Krammer K. et H. Lange-Bertalot (1986-1991). Süβwasserflora von Mitteleuropa. Bacillariophyceae, 2/1 : Naviculaceae, 876 p. ; 2/2 : Nitzschiaceae, Epithemiaceae, Surirellaceae, 596 p.; 2/3 : Centrales, Fragilariaceae, Eunotiaceae, 576 p.; 2/4: Achnanthaceae, 437 p. G. Fischer, Stuttgart, Germany.
20)Lavaud, J. (2024). Functional ecophysiology of planktonic and benthic diatoms: from the photosystem to the ecosystem. Biodiversity and Ecology. Université de La Rochelle, La Rochelle. France. 278 p.
21)Leland, H.V. et Porter, S.T. (2000). Distribution of benthic algae in the Illinois River basin in relation to geology and land use. Freshwater Biol., 44, 279-301.
22)Morin, S. (2006). In situ bioindication of the effects of metal pollution on benthic diatom communities: in situ and experimental approaches. Doctoral Thesis, Univ. Bordeaux 1, France, 302 p.
23)Rimet, F. (2020). Diatoms: taxonomy, ecology and tool for the management of aquatic environments. Biodiversity and Ecology. Savoie Mont-Blanc University. France. 82p.
24)Salam, A. M. A., BA, N., Mbaye, M.S., Diop, D., Diouf, N., Diouf, J., Gueye, M., Sane, S. and Noba, K. (2024). Characterization of the diversity and abundance of phytoplankton in the Marine Protected Area of Sangomar/Senegal. Int. J. Biol. Chem. Sci. 18(1): 197-205. DOI: https://dx.doi.org/10.4314/ijbcs.v18i1.16. Available online at http://www.ifgdg.org.
25)Shannon C.E. and Weaver, W. 1949. The mathematical theory of communication, Univ. Illinois Press, Urbana, Illinois, USA, 117 p.
26) www.algaebase.org.
27) https://diatoms.org.