

Characterization of the Physico-Chemical Parameters of Two Marshes and the Distribution of Aquatic Macrophytes in the Littoral Region of Cameroon

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Abstract

The objective of this study was to characterize the physico-chemical parameters of two swamps receiving wastewater from soap factories and the distribution of their macrophytes in the localities of Bonaberi and Bomono Ba Mbengue in the Littoral Region of Cameroon. A floristic inventory was carried out in 5 m × 5 m quadrats with 15 quadrats per site. A total of 30 quadrats were used in the two study sites. Physical parameters such as temperature, pH, electrical conductivity and salinity were measured *in situ*, while chemical analyses to determine the (nitrate, phosphate, bio-chemical, oxygen demand and iron contents) were carried out in the Laboratory with water samples collected from the two marshes. A total of 65 species of macrophytes divided into 58 genera and 32 families were recorded. The flora is dominated by *Commelina bengalensis* (6.9%), *Costus afer* (4%), *Commelina diffusa* (3.8%), *Asystasia gangetica* (3.7%). The Bomono Ba Mbengue site had a higher specific richness (40 species) compared to that of Bonaberi (33 species). It appears from the ANOVA test that there is a significant difference between the pH values (11.62 ± 1.17), salinity ($591.67 \text{ g/L} \pm 123.56$) and conductivity ($1283.67 \text{ }\mu\text{S/cm} \pm 214.43$) obtained in the marsh waters of Bonaberi and those of Bomono Ba Mbengue which are respectively 6.65 ± 0.35 ; $12.67 \text{ g/L} \pm 1.15$ and $21 \text{ }\mu\text{S/cm}$. The physico-chemical parameters of the wastewater collected in the Bonaberi swamp are particularly higher, reflecting a higher degree of pollution than that of Bomono Ba Mbengue. This study contributes to the management and con-

ervation of coastal wetlands.

Keywords

Pollution, Soap Effluents, Macrophytes, Douala IV, Littoral-Cameroon

1. Introduction

Wetlands are areas where water is the primary determining factor in the environment for plant and associated animal life (Tieligounon *et al.*, 2021). Wetlands are sometimes referred to as unique environments because they constitute entities distinct from terrestrial and aquatic ecosystems (Bonis *et al.*, 2014; RAMSAR, 2021). They act like real sponges that release water just as they absorb it (Mascarenhas & Méllo, 2016). Previous studies demonstrate that, in most regions of the world, wetlands are undergoing a continuous decline in their area and quality consequently, the ecosystem services they provide to populations are compromised (Priso *et al.*, 2014). Population growth, the rise of industrialization and the transformation of human society related to the development of agriculture with the increasing use of phytosanitary products (chemical fertilizers and pesticides) are factors that have favored the pollution of aquatic ecosystems (Taffouo *et al.*, 2017). In Cameroon, as in most developing countries, watercourses in the urban area are subject to untreated pollutant discharges such as domestic wastewater and industrial effluents. Soap effluents which degrade the quality of water while modifying the biodiversity of the ecosystems which constitute part of these pollutants (Beyene *et al.*, 2009; Tchinda *et al.*, 2018). Human activities are therefore the major cause of ecosystem degradation (Priso *et al.*, 2014; Noukeu *et al.*, 2016). Watercourses are thus subject to physical and chemical disturbances which are at the origin of an increasing degradation of water quality (Beyene *et al.*, 2009). Soap factories generally produce small quantities of wastewater that cause local impacts in the surrounding waters. Indeed, soap factories in Cameroon are industrial installations which produce a wide range of hygiene products including soaps, detergents and cosmetics. These products require the use of chemical substances such as surfactants, bleaching agents and perfumes (Noukeu *et al.*, 2016), which can affect aquatic environments and the health of populations living near the soap factories. The release of these chemicals into water has harmful consequences on flora and fauna, particularly aquatic macrophytes (Priso *et al.*, 2017). This is the case of the soap factories in the localities of Bonaberi (Douala IV) and Bomono Ba Mbengue (in the district of Dibombari) located respectively near and at a considerable distance from a swamp (508 meters for Bomono marsh and Bonaberi marsh, which is only 113 meters). These swamps receive soap effluents which could affect the distribution and composition of the aquatic macrophyte communities found there and consequently, an intensification of eutrophication. Indeed, plants participate in the biotic and abiotic phenomena which take place in ecosystems and appear as visible markers of environmental disturbances (Sauberer *et al.*,

2004; RAMSAR, 2021). They can only partially escape an environment which would be unfavourable to them by “dispersing in space and time” according to Dibong & Ndjouondo (2014). The main role of macrophytes in wetlands is to provide oxygen and surfaces for the growth of biofilms, as well as to use nutrients from polluted water (Ramade, 2008; Mascarenhas & Mélo, 2016). Thus, plants are considered as one of the biological elements to be analyzed in order to assess the ecological state of waterways (Priso *et al.*, 2014). Indeed, the city of Douala, the economic capital of Cameroon, is facing many environmental challenges related to rapid industrialization and increasing urbanization. Among these challenges, the pollution of surface water by industrial effluents, particularly those from soap factories, represents a major concern for the preservation of aquatic biodiversity. Aquatic macrophytes, biological indicators of the quality of aquatic ecosystems, are particularly sensitive to these environmental changes (Taffouo *et al.*, 2017). The following hypothesis will be verified: swamps located near soap factories have high physico-chemical characteristics and a low distribution and abundance of macrophytes compared to those far from soap factories. The objective of this study is to evaluate the physico-chemical characteristics of the waters of two marshes receiving wastewater from soap factories as well as the distribution of their macrophytes in the Districts of Bonaberi and Dibombari.

2. Materials and Methods

2.1. Study Site

The locality of Bomono Ba Mbengue is located in the Dibombari district, Moungo Division, Littoral Region of Cameroon. It is found on latitudes 4°8'39" N and longitudes 9°35'20" E (P.C.D., 2012). While the Bonaberi Swamp, is located on the right bank of the Wouri River, Douala IV. The Bonaberi Swamp is located in the Wouri Division in the Littoral Region-Cameroon. It is found on: Latitude: 4°04'40" North, Longitude: 9°40'33" East (Priso *et al.*, 2017). The Dibombari District, created in 1955, is one of the 13 districts that make up the Moungo Division (Noukeu *et al.*, 2016). The Bonaberi and Dibombari sub Division have varied reliefs that influence their urban and rural development. Bonaberi is characterized by an urban topography, with often flat areas near the Wouri River, while hills and slopes are found on the outskirts, affecting urbanization and access to infrastructure. On the other hand, Dibombari has a more rugged relief, with mountainous areas that favor subsistence agriculture and limit urban expansion. The soils of Dibombari are hydromorphic in nature around the rivers and ferralitic with a clayey-sandy texture on the plains (P.C.D., 2012). These two districts benefit from an equatorial climate characterized by high temperatures and abundant rainfall throughout the year. Temperatures generally range between 24°C and 32°C, fostering rich biodiversity. The districts of Bonaberi and Dibombari have varied vegetation marked by limited green spaces, but include gardens and fruit tree plantations. There are also areas of dense tropical forest, industrial oil palm plantations, and a mangrove forest area. The floral diversity in these areas is es-

essential for maintaining local biodiversity and for agricultural practices. However, increasing urbanization and human activities threaten these ecosystems, requiring conservation efforts (Figure 1).

2.2. Sampling

2.2.1. Collection of Floristic Data

The choice of the localities Bomono Ba Mbengue (in the District of Dibombari) and Bonaberi (in the District of Douala IV) for this study is justified by several reasons: these two localities are home to at least one soap factory and marshy areas which served as a target during this study. These two Districts are also subject to untreated pollutant discharges such as industrial effluents.

Data collection was carried out during the year 2025. A floristic inventory was carried out using the 5 m × 5 m (25 m²) quadrat system as recommended by Priso *et al.* (2014) and Tchinda *et al.* (2018). In the Bomono Ba Mbengue site, 15 quadrats were carried out and 15 quadrats too for the Bonaberi site. Each quadrat corresponds to one survey, making a total of 30 surveys for the 2 sites. These floristic surveys consisted of drawing up an exhaustive list of all plant species present with notation of the abundance-dominance coefficients of each species as defined by the scale of Braun-Blanquet *et al.* (1952) taken up by Massens (1997), which range from the index “+” to the index “5”. This scale gives a distribution of individuals of a species as follows (Priso *et al.*, 2017):

- +: number of individuals with a very low degree of coverage, the Average Coverage (AC) is 0.5%;
- 1: number of sufficiently abundant individuals with a low degree of coverage, AC = 3%;
- 2: very abundant individuals covering at least 1/20 of the survey surface, AC = 15%;
- 3: species with any number of individuals covering between 1/4 and 1/2 of the survey area, AC = 37.5%;
- 4: abundant individuals or not, but covering 1/2 to 3/4 of the survey surface, AC = 62.5%;
- 5: number of any individuals covering more than 3/4 of the survey area, AC = 87.5%. These abundance-dominance indices make it possible to calculate for each species its average coverage (AC) which is the average percentage of occupancy of this species in a given environment.

2.2.2. Physicochemical Characterization of the Water at Each Site

For each site, several water samples were taken at different points in each marsh between 9 a.m. and 11 a.m. during the rainy season. Water samples for laboratory analyses were collected at the various sites during the floristic inventory period. These water samples were collected in pre-labeled 0.5-liter polyethylene plastic bottles placed in an insulated cooler. A total of 6 water samples were collected, 3 samples per site, for physicochemical analyses in the laboratory.

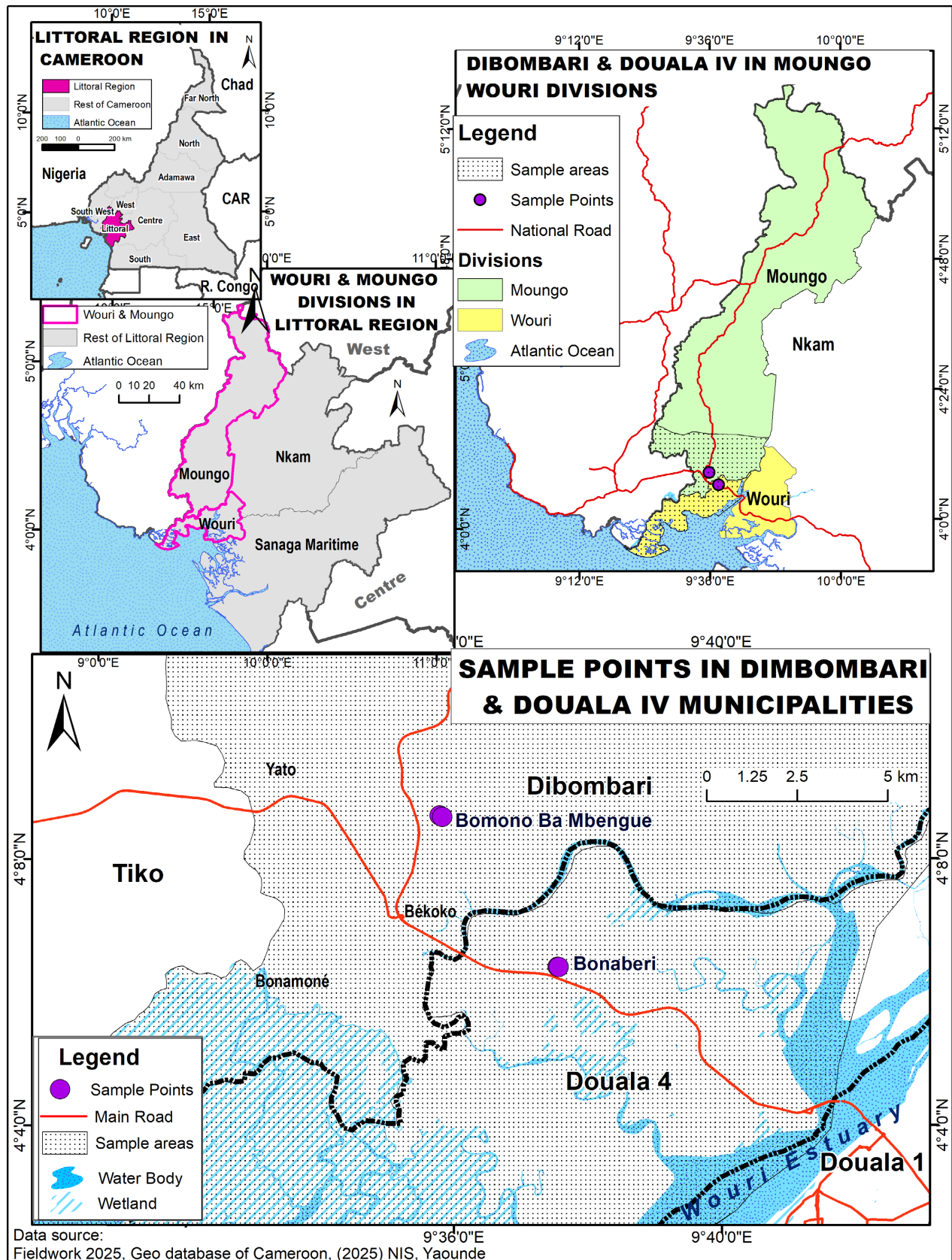


Figure 1. Location of the study area.

2.2.3. Analysis of Physicochemical Parameters

The physico-chemical parameters taken into consideration for water analysis were: temperature, conductivity, pH, nitrates, phosphates, BOD5, salinity and iron. For each site, parameters such as: temperature, pH, conductivity and salinity were measured “in situ” by immersing the electrodes of a multiparameter brand EC Wm 32 ep. in the marsh water (Rodier *et al.*, 1996). This device, by a control button, distinguished the values of the different parameters read on the screen; °C for temperature, µS for conductivity and ppm or g/L for salinity. In the laboratory, nitrate ions were determined by the cadmium reduction method using a Hach DR/2010 spectrophotometer. The determination of phosphate ions was done using the “molybdovanadate” method. The determination of biochemical oxygen demand was carried out using the “manometric” method using a Hach brand BOD5 incubator (model 2173B). The Biochemical Oxygen Demand (BOD5) was quantified after five days of incubation at 20 °C and the unit is given in mg/L. Iron is measured by atomic absorption spectrophotometry (Barkai *et al.*, 2014) at the Waste Water Research Laboratory of the University of Yaoundé 1.

2.2.4. Floristic Analyses

The qualitative floristic analysis was carried out using the general floristic list of the various inventories. The analyses focused mainly on floristic diversity.

The accumulation curves by the rarefaction method allow, from observed data, to obtain an estimate of the cumulative specific richness as a function of the sampling effort provided (Colwell *et al.*, 2004). The rarefaction curves which reflect the sampling effort of the inventoried flora were obtained using the R software by the survey/species matrix which gives the abundance and specific richness as a function of the surveys of each marsh.

- **Average recovery and Shannon-Weaver index**

The **average coverage (AC)** is the percentage that a species occupies in an environment:

$$AC_i = P_i / \text{Total number of floristic surveys},$$

the presence index (P_i) corresponds to the total coverage of individuals

$$(P_i = AC_i / \sum AC).$$

- **The Shannon-Weaver index (H')** indicates the diversity or specific richness of the environment, it is therefore determined by the following relationship:

$$H' = -\sum P_i \times \ln(P_i) \text{ (Priso et al., 2014).}$$

- **Pielou Fairness Index**

$$\text{Pielou's Fairness index noted } R = H' / H'_{\text{max}}.$$

H'_{max} being the maximum diversity ($\log_2 S$) where S is the number of species. It tends towards 0 when almost all the numbers are concentrated on a single species. It is equal to 1 when all the species have the same abundance.

- **Simpson's Index**

Simpson's D index is:

$$D = \sum Ni(Ni - 1)/N(N - 1) \text{ or } D = \sum P^2.$$

This index represents the probability that two individuals chosen at random from a sample belong to the same species (Priso *et al.*, 2017).

- **Sorensen similarity index**

The Sorensen similarity index is used to assess the floristic affinity between two ecological environments. It is greater than 50% when there is floristic affinity between two environments and less than 50% otherwise. It is calculated using the following formula:

$$K_S = \frac{2c}{a + b} \times 100$$

With (a = number of species in environment A, b = number of species in environment B and c = number of species common to the two ecological environments). It allows us to understand the similarities between plant communities (Priso *et al.*, 2017).

In this work, we also took into consideration:

- **The frequency**

There frequency which is the number of surveys in which a species is observed, it represents the number of times that a species is observed in the 25 m². It is expressed according to the following formula:

$$F = (A/N) \times 100$$

with A = Number of records where species A is present and N = number of records.

2.3. Data Analysis

The floristic data and physico-chemical parameters obtained were recorded, classified and then analyzed using Excel spreadsheet and R software version 3.3.3. The characterization of the flora was done on the basis of diversity indices, which required the “Biodiversity R” package integrated into R software. Multivariate analyses, including principal component analyses (PCA) and factorial analyses of mixed data were carried out to assess the existing correlations between the different physicochemical variables on the one hand and between these variables and the different sites on the other hand. Analysis of variance (ANOVA) was applied to the different physicochemical variables studied and comparisons of means were carried out by the Tukey HSD test with a confidence interval of 5% ($p \leq 0.05$).

3. Results

3.1. Characteristics of Macrophytes in the Marshes of the Study Area

A total of 65 species divided into 58 genera and 32 families were identified in the two sampled marshes (Figure 2). The most diverse families in terms of species richness are Acanthaceae, Poaceae with 5 species, Amaranthaceae, Fabaceae and Asteraceae with 4 species, Commelinaceae, Convolvulaceae and Cyperaceae with

3 species each. The most abundant Poaceae in terms of species abundance-dominance are: *Oplismenus hirtellus*, *Panicum virgatum* (73% each), *Cynodon dactylon*, *Hymenachne amplexicaulis* (47% each), *Panicum maximum* (27%). The most abundant Commelinaceae are: *Commelina benghalensis* (87%), *Commelina diffusa*, *Palisota ambigua* (27% each). The Araceae are: *Cyrtosperma senegalensis* (100%), *Anchomanes difformis* (60%), *Xanthosoma sagittifolium* (7%). The Amaranthaceae are: *Alternanthera sessilis* (73%), *Alternanthera repens* (33%).

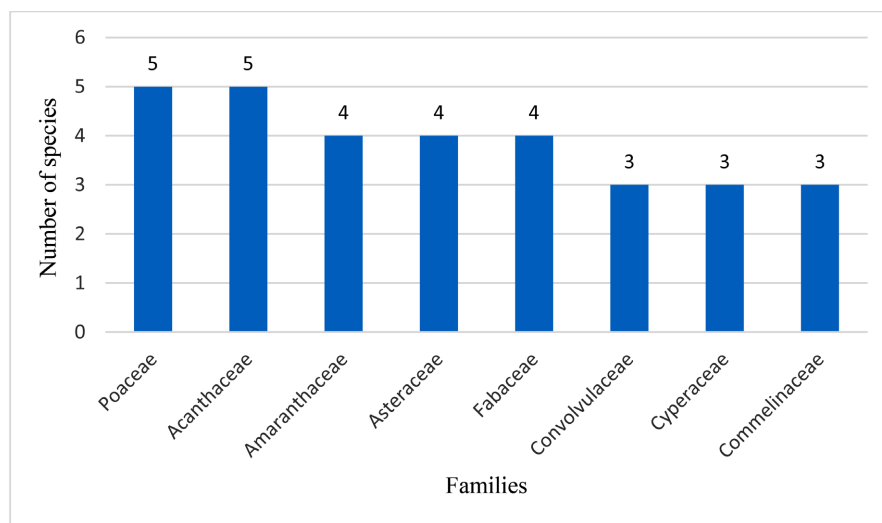


Figure 2. Most represented families in terms of the number of species in the study area.

3.1.1. Macrophyte Diversity Index of Different Marshes

The Bomono Ba Mbengue marsh has a higher species richness (40 species) compared to that of Bonaberi (33 species). Similarly, the families and genera (which are 24 and 37 respectively) in the Bomono Ba Mbengue marsh are more diverse compared to that of Bonaberi (22 and 28 respectively). The Shannon diversity indices (3, 56 bits), Pielou (0.94) and Simpson (0.97) obtained in the marshes of Bomono Ba Mbengue are higher compared to those of the marshes of Bonaberi which are respectively 3.23 bits, 0.92 for and 0.95. It also emerges that the Sorensen index obtained from the two marshes (Bonaberi located near the soap factory and Bomono Ba Mbengue distant from the soap factory) of the study area is 27% (**Table 1**).

Table 1. Floristic composition and diversity index of the marshes in the study area.

| Sites | Specific richness | Gender number | Family number | Shannon | Pielou | Simpson | Sorensen |
|-------------------|-------------------|---------------|---------------|---------|--------|---------|----------|
| Bomono Ba Mbengue | 40 | 37 | 24 | 3.56 | 0.94 | 0.97 | |
| Bonaberi | 33 | 28 | 22 | 3.23 | 0.92 | 0.95 | 27% |
| Study site | 65 | 58 | 32 | 3.91 | 0.94 | 0.98 | |

- **Sampling effort of different marshes**

The accumulation curves by the rarefaction method of the Bomono Ba Mben-

gue and Bonaberi marshes tend almost towards a plateau. The accumulation curves of the two marshes, although they tend towards a plateau, continue to increase (Figure 3).

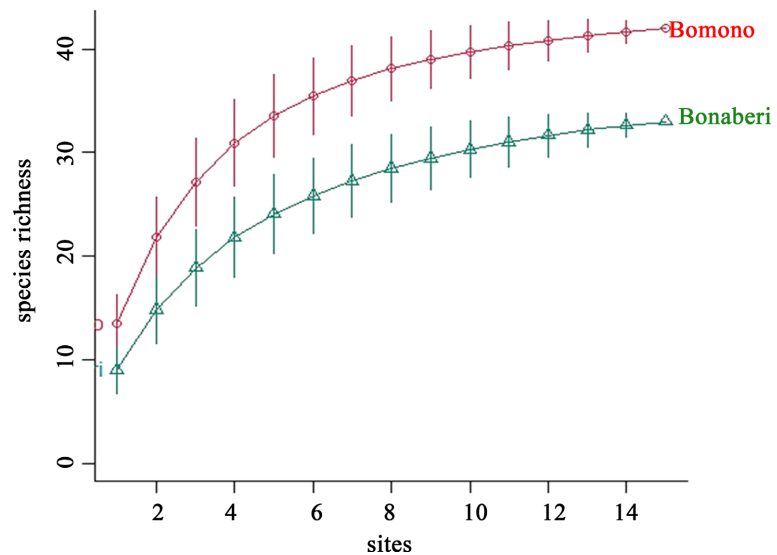


Figure 3. Species accumulation curve of the study area.

3.1.2. Abundance-Dominance of Taxa in the Study Area

The floristic inventory carried out in the Bomono Ba Mbengue and Bonaberi marshes revealed the most abundant species (Table 2). The most abundant species in the Bomono Ba Mbengue swamp were: *Cytosperma senegalensis* (29.6%), *Costus afer* (25.1%), *Amaranthus viridis* (20%), *Barleria cristata* (19.62%), *Anchomanes difformis* (18.54%), *Eremomastax speciosa* and *Oplismenus hirtellus* (15% each). In terms of frequency, there is a predominance of *C. afer*, *Asystasia gangetica* and *C. senegalensis* (with a frequency of 100% each), followed by *Commelina benghalensis* and *Nymphaea alba* (87% each), *Nephrolepis bisserata* and *O. hirtellus* (73% respectively) and *A. difformis* (60%). The most abundant species in the Bonaberi marshes were: *Dianthera secounda* (82.5%), *Onocleonea struthiopteris* (38.8%), *Cynodon dactylon* (37.9%), *Aeschynomene sensitiva* (32.8%), *Hymenachne amplexicaulis* (32.81%), *Ipomoea aquatica* (29.8%), *Alchornea cordifolia* (26.9%), *Thelypteris interrupta* (26.3%), *Vachellia farnesiana* (26.38%), *Alternanthera sessilis* (23.40%), *C. diffusa* (22.1%), *Panicum virgatum* and *P. maximum* (18.8% respectively) and *Pentodon pendantrus* (19.7%). The most predominant species in terms of frequency were: *P. virgatum*, *I. aquatica* and *V. farnesiana* (87% respectively), *C. benghalensis*, *C. diffusa* (80% each) and *A. sessilis* (73%). Woody species (e.g. *Mangifera indica*) were inventoried at a diameter of less than 1 cm.

3.2. Physico-Chemical Characteristics of the Water at Each Site

- **Temperature, Potential Hydrogen (pH), Conductivity, Salinity**

It appears from the ANOVA test that there is a significant difference between

Table 2. Average Coverage and frequency of species in the Bonaberi and Bomono Ba Mbengue marshes.

| Family | Species | Average Recovery | | Frequency | |
|----------------|---------------------------------|------------------|-------------------|-----------|-------------------|
| | | Bonaberi | Bomono Ba Mbengue | Bonaberi | Bomono Ba Mbengue |
| Acanthaceae | <i>Asystasia gangetica</i> | - | 9.23 | - | 100 |
| | <i>Barleria cristata</i> | - | 19.62 | - | 20 |
| | <i>Dianthera secounda</i> | 82.5 | 9 | 33 | 20 |
| | <i>Edinoflora sp</i> | 7 | - | 7 | - |
| | <i>Eremomastax speciosa</i> | - | 15 | - | 60 |
| Amaranthaceae | <i>Alternanthera sessilis</i> | 23.40 | | 73 | |
| | <i>Alternanthera repen</i> | - | 10.5 | - | 33 |
| | <i>Amaranthus viridis</i> | - | 20 | - | 53 |
| | <i>Cyatula prostata</i> | - | 9 | - | 47 |
| Anacardiaceae | <i>Mangifera indica</i> | 0.5 | - | 7 | - |
| Apocynaceae | <i>Alstonia bonei</i> | 15 | 4.75 | 13 | 47 |
| Araceae | <i>Anchomanes difformis</i> | - | 18.54 | - | 60 |
| | <i>Cyrtosperma senegalensis</i> | - | 29.6 | - | 100 |
| | <i>Xanthosoma sagittifolium</i> | - | 3 | - | 7 |
| Asteraceae | <i>Ageratum conyzoides</i> | - | 3.9 | - | 33 |
| | <i>Cyathillium cinereum</i> | - | 7 | - | 20 |
| | <i>Eclipta prostrata</i> | 9 | - | 27 | - |
| | <i>Mikania micrantha</i> | - | 5.33 | - | 40 |
| Asteraceae | <i>Struchium sparganophorum</i> | - | 2.16 | - | 27 |
| Arecaceae | <i>Elaeis guineensis</i> | 15 | 4.75 | 13 | 33 |
| Cleomaceae | <i>Cleome ruidosperma</i> | - | 2 | - | 53 |
| Commelinaceae | <i>Commelina benghalensis</i> | 16.8 | 8.53 | 87 | 87 |
| | <i>Commelina diffusa</i> | 22.1 | 7.8 | 80 | 27 |
| | <i>Palisota ambigua</i> | - | 3 | - | 27 |
| Convolvulaceae | <i>Ipomea aquatica</i> | 29.8 | 8.5 | 73 | 7 |
| | <i>Ipomea batatas</i> | 15 | 5 | 27 | 33 |
| | <i>Ipomea involucrata</i> | 9 | 7.5 | 13 | 27 |
| Costaceae | <i>Costus afer</i> | 15 | 25.1 | 7 | 100 |
| Cucurbitaceae | <i>Bryonia alba</i> | 17.8 | - | 53 | - |
| Cyperaceae | <i>Cyperus difformis</i> | 12.6 | - | 33 | - |
| | <i>Cyperus esculentus</i> | - | 1.33 | - | 33 |
| | <i>Cyperus papyrus</i> | 15 | - | 20 | - |

Continued

| | | | | | |
|------------------|------------------------------------|-------|-------|----|----|
| Euphorbiaceae | <i>Alchornea cordifolia</i> | 26.9 | 7.22 | 33 | 53 |
| Fabaceae | <i>Aeschynomene sensitiva</i> | 32.8 | - | 13 | - |
| | <i>Grona triphola</i> | - | 7.75 | - | 33 |
| | <i>Mimosa invisa</i> | 15 | - | 20 | - |
| | <i>Vachellia farnesiana</i> | 26.38 | - | 87 | - |
| Gentianaceae | <i>Anthocleista schweinfurthii</i> | 15 | - | 7 | - |
| Irvingiaceae | <i>Irvingia gabonensis</i> | 7 | - | 7 | - |
| Lamiaceae | <i>Clerodendrum paniculatum,</i> | - | 10.58 | - | 47 |
| | <i>Purerea trifolia</i> | 15 | - | 13 | - |
| Maranthaceae | <i>Marantha arundinacea</i> | - | 8.4 | - | 13 |
| Melastomataceae | <i>Melastoma malabathricum</i> | - | 4.4 | - | 40 |
| | <i>Tristemma mauritianum</i> | - | 9 | - | 20 |
| Meliaceae | <i>Carapa procera</i> | - | 3.23 | - | 7 |
| Nephrolepidaceae | <i>Nephrolepis bisserata</i> | - | 10.91 | - | 73 |
| Nymphaeaceae | <i>Nymphaea alba</i> | - | 8.88 | - | 87 |
| | <i>Nymphaea lotus</i> | - | 9.95 | - | 7 |
| Onagraceae | <i>Ludwigia hyssopiphylla</i> | 12 | - | 27 | - |
| Onocleaceae | <i>Onocleonea struthiopteris</i> | 38.8 | - | 13 | - |
| Phyllanthaceae | <i>Phyllanthus amarus,</i> | - | 2.37 | - | 20 |
| Poaceae | <i>Cynodon dactylon</i> | 37.9 | - | 47 | - |
| | <i>Hymenachne amplexicaulis</i> | 32.81 | - | 47 | - |
| | <i>Oplismenus hirtellus</i> | - | 15 | - | 73 |
| | <i>Panicum maximum</i> | 18.8 | - | 27 | - |
| | <i>Panicum virgatum</i> | 18.8 | - | 73 | - |
| Rubiaceae | <i>Pentodon pendants</i> | 19.7 | - | 47 | - |
| Sphenocleaceae | <i>Sphenoclea zeylanica</i> | 15 | - | 40 | - |
| Thelypteridaceae | <i>Thelypteris interrupta</i> | 26.3 | - | 13 | - |
| Urticaceae | <i>Laportea ovuliphora,</i> | - | 6.35 | - | 67 |
| Vitaceae | <i>Cissus oraloides</i> | - | 6.1 | - | 20 |

The presence of the sign – means the absence of the species.

the pH values (11.62 ± 1.17), salinity (591.67 ± 123.56 g/L) and conductivity (1283.67 ± 214.43 μ S/cm) obtained in the marsh waters of Bonaberi and those of Bomono Ba Mbengue which are respectively 6.65 ± 0.35 ; 12.67 ± 1.15 g/L and 21 μ S/cm. On the other hand, there is no significant difference between the temperatures of the marshes of Bomono Ba Mbengue ($25.53^\circ\text{C} \pm 0.57^\circ\text{C}$) and those of Bonaberi ($24.3^\circ\text{C} \pm 3.39^\circ\text{C}$) (Figure 4).

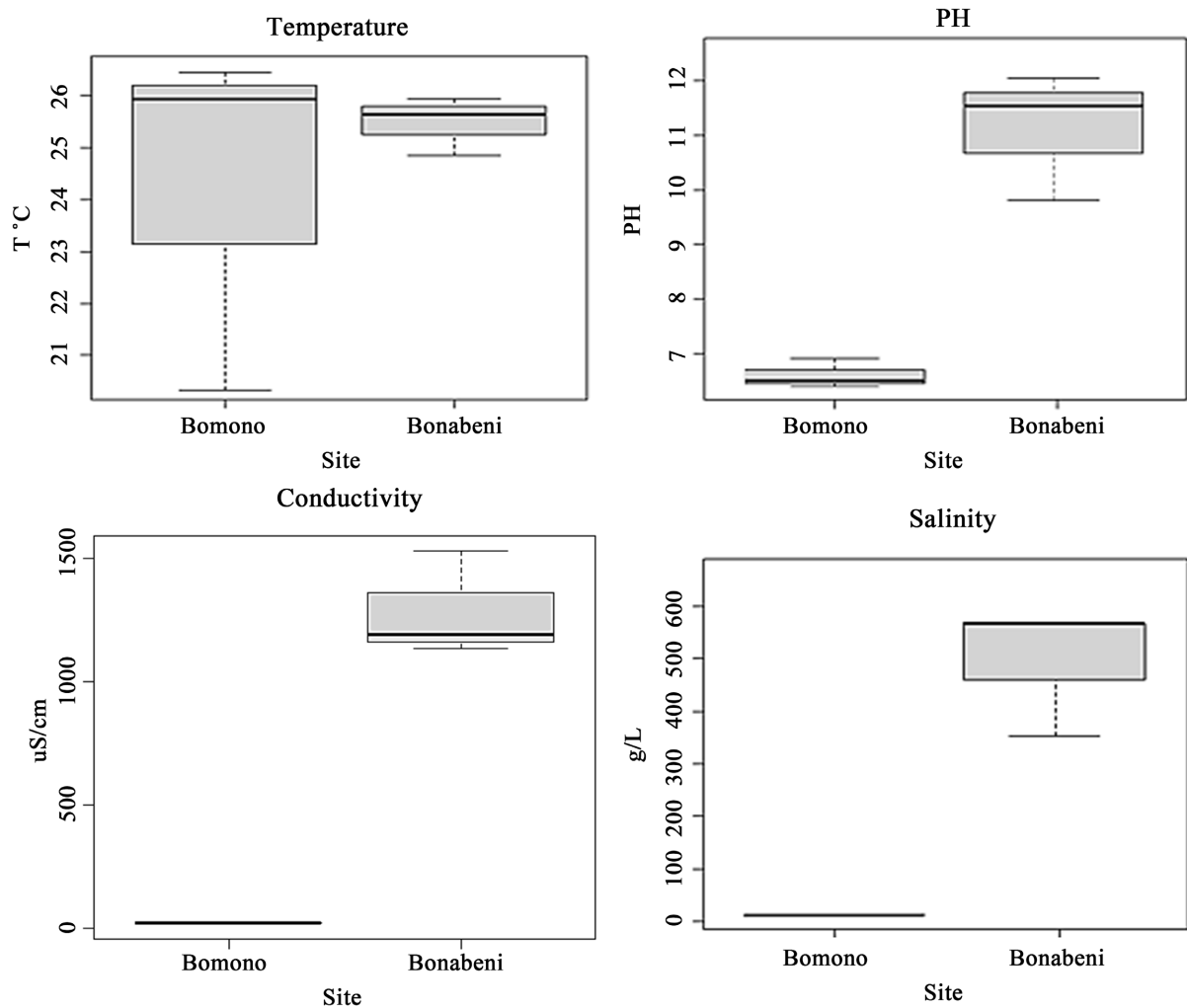


Figure 4. Physico-chemical parameters at different sites.

- **Nitrates, Phosphates, Iron and Biochemical Oxygen Demand.**

Figure 5 shows the average of the Nitrates, Phosphate, Biochemical Oxygen Demand and Iron (Fe^{2+}). The ANOVA test performed shows that there is a significant difference between the values of NO_3^- (3543.60 ± 2834.85 mg/L), PO_4^{3-} (11.85 ± 11.92 mg/L), BOD_5 (45.00 ± 22.91 mg/L) and Fe^{2+} (24.07 ± 15.72 mg/L) from the Bonaberi marshes and those obtained at Bomono Ba Mbengue respectively of 8.53 ± 0.70 mg/L; 1.26 ± 1.13 mg/L; 16.67 ± 2.87 mg/L, 1.11 ± 0.21 mg/L.

3.3. Similarities between the Physicochemical Parameters and the Different Sites in the Study Area

In order to highlight the relationships that may exist between the different parameters studied in the two swamps, a principal component analysis (PCA) was carried out (**Figure 6**). The principal component analysis of the different physico-chemical variables in the Bomono Ba Mbengue and Bonaberi marshes shows that the two axes that describe the correlations between the physicochemical variables represent nearly 83.33% of the total inertia with respectively 67.13% for axis 1

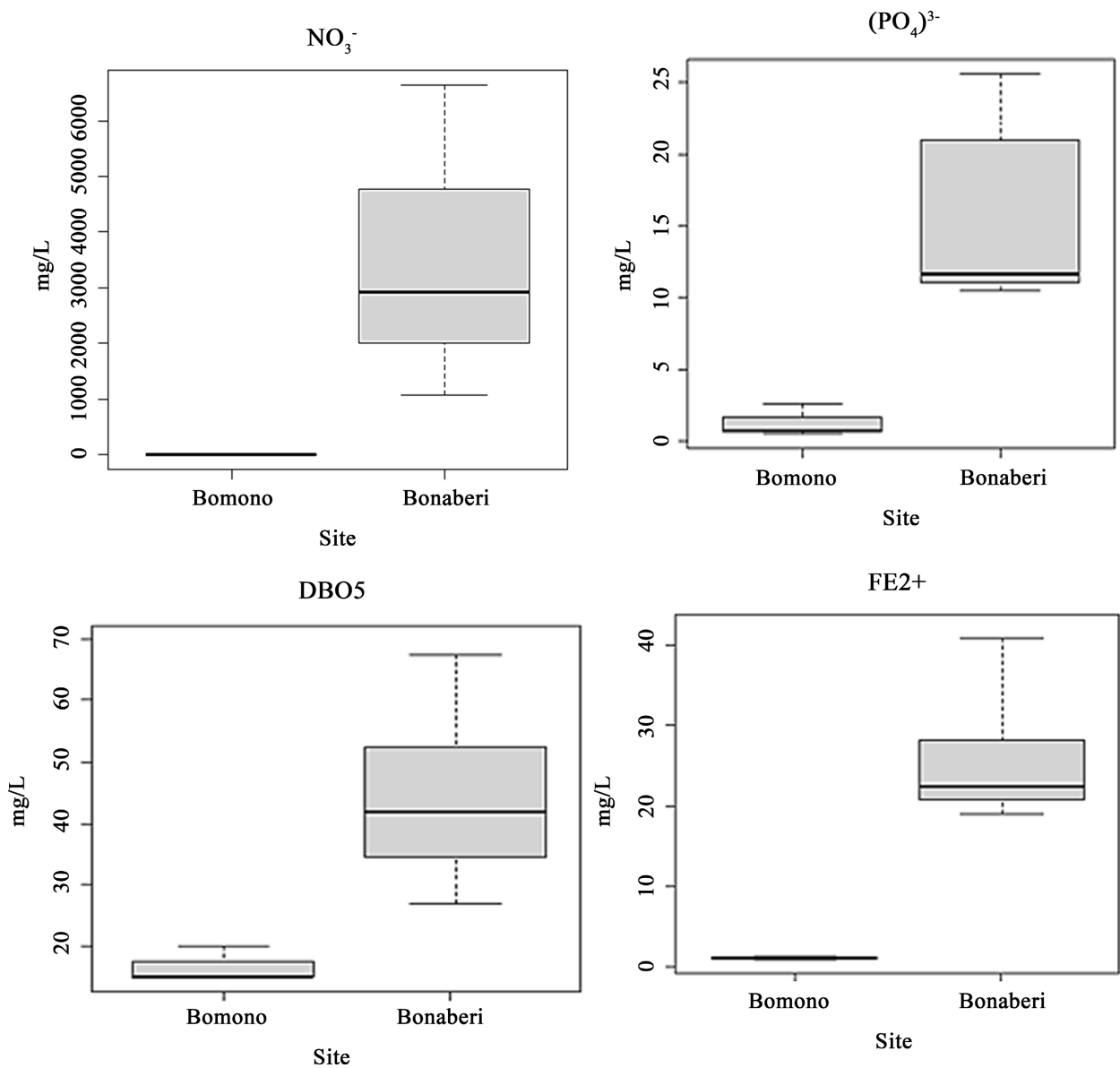


Figure 5. Chemical parameters at different sites.

(dimension 1) and 16.70% for axis 2 (dimension 2). All variables are concentrated on axis 1 and have a significant contribution to the explanation of this axis: nitrates, conductivity, phosphates, BOD5, pH, temperature, Fe²⁺. This PCA shows that the parameters are highly correlated. The strongest correlation is observed between BOD5 and Fe²⁺, BOD5 and phosphates; between nitrates, conductivity, pH, Conductivity is also correlated with salinity and weakly correlated with temperature.

The multivariate analysis to highlight the correlation between the physico-chemical parameters and the different sampled sites shows that nitrates, conductivity, iron, salinity, phosphates are strongly correlated with the Bonaberi site, on the other hand the BOD5 is weakly correlated with the two sites. However, pH and temperature are strongly correlated with the Bomono site (Figure 7).

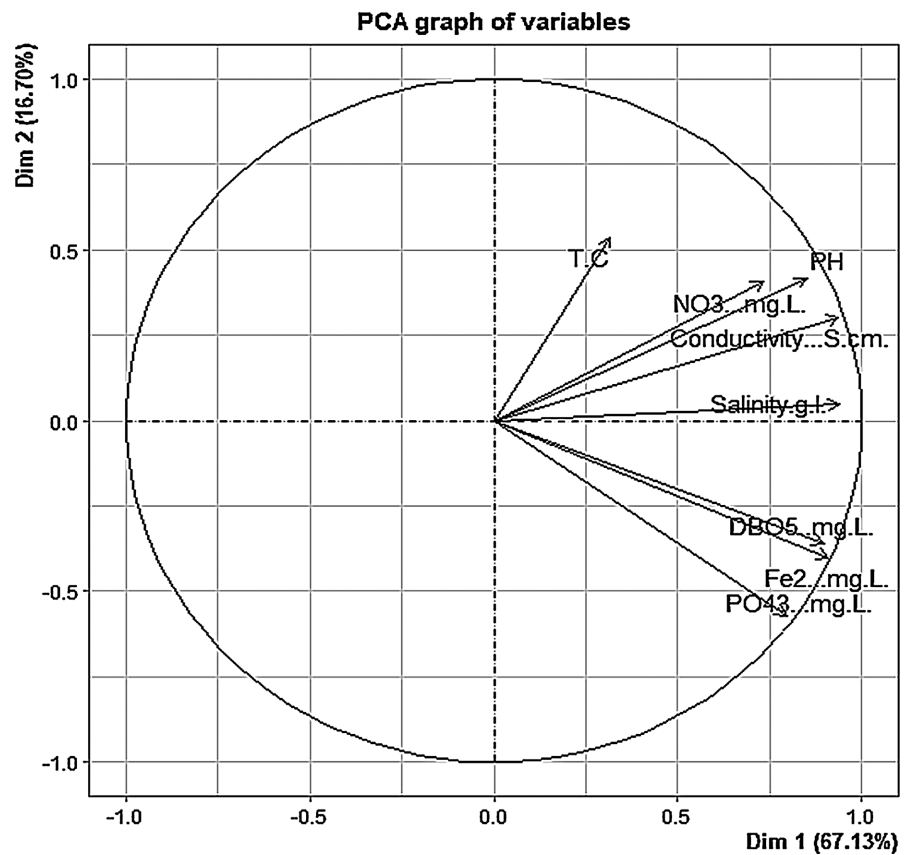


Figure 6. Correlation between the physicochemical parameters of soap effluents from the study area.

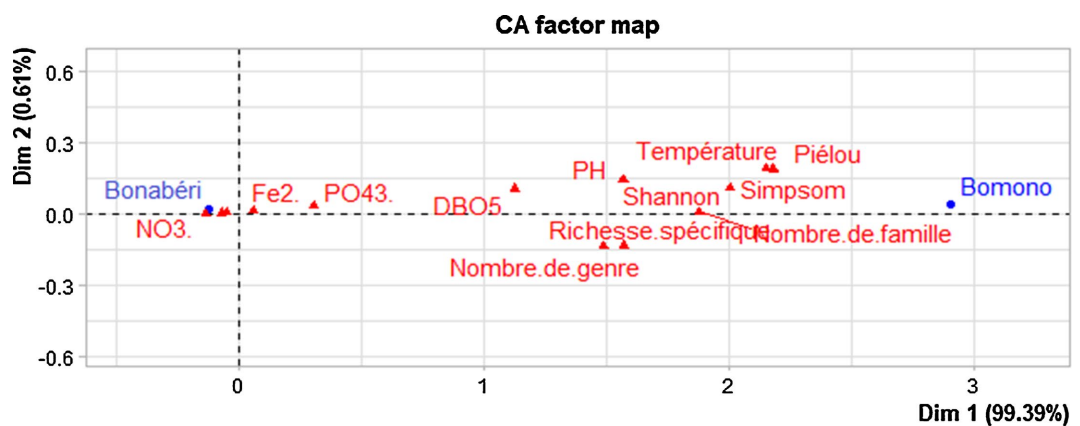


Figure 7. Correlation between physicochemical parameters and different sites in the study area.

3.5. Correlation between Diversity Indices and Physico-Chemical Parameters of the Marshes in the Study Area

The specific richness, the number of families, genus, diversity indices (such as Shannon, Pielou and Simpson) and the physical parameters (pH, temperature) are strongly correlated with the Bomono Ba Mbengue swamp, on the other hand the chemical parameters such as BOD5, nitrates, iron and phosphate are strongly correlated with the Bonaberi swamp (Figure 8).

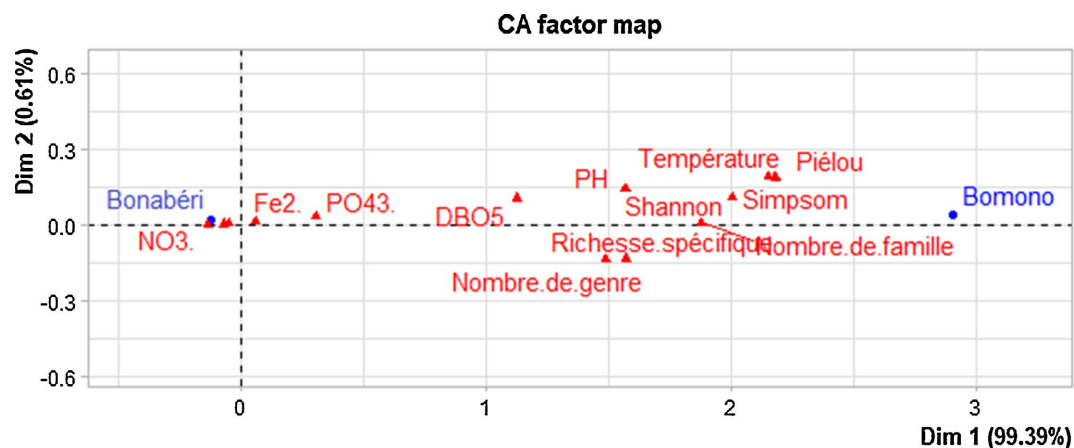


Figure 8. Correlation between diversity indices and physicochemical parameters of the two marshes.

4. Discussion

Physicochemical characteristics of water

The analyses of the physico-chemical parameters highlighted significant differences between the two sites. Indeed, the pH, salinity and conductivity values obtained at Bonabéri are very high (respectively 11.62 ± 1.17 , 591.67 ± 123.56 g/L and 1283.67 ± 214.43 $\mu\text{S}/\text{cm}$) compared to the standard which is respectively 6.5 - 8.5 (World Health Organization, 2006; Bruxelles Environnement, 2011; Tchinda *et al.*, 2018), 200g/L and 1200 $\mu\text{S}/\text{cm}$ (Mohamed *et al.*, 2024). This shows that the waters of the Bonabéri marshes are unusable for agriculture because a high electrical conductivity makes water considered unusable in irrigated areas because it has an impact on the development of organisms and on chemical balances, depending on the affinity of each organism with the concentration of ions (Taffou *et al.*, 2017). Comparing the values of electrical conductivity and salinity in the analyzed wastewater with the standards for the quality of water intended for irrigation allows us to deduce that the waters of the Bomono marshes would be suitable for watering market garden crops which are most often grown along the watercourse. The pH value observed in Bomono would be linked to the strong presence of fixed macrophytes. Indeed, the humic acid which comes from the decomposition of dead macrophytes would contribute to lowering the pH (Atanle *et al.*, 2012). Hade (2007) reported that when the pH is high, ammoniacal nitrogen (NH_4^+) becomes toxic while for a pH below 8, ammoniacal nitrogen has little influence on the flora. There is no significant difference between the temperatures of the soap effluents of Bomono Ba Mbengue ($25.53^\circ\text{C} \pm 0.57^\circ\text{C}$) and those of Bonabéri (24.3 ± 3.39). These values are very close to the ambient temperature, this could be explained by the close connection between the temperature of the water and that of the ambient environment as well as possible discharges of waste water as is the case with waste water from soap factories. These results are similar to those of Mohamed *et al.* (2024) who found temperatures between 29°C and 32°C in surface water and groundwater at the level of two continental wetlands in Mauritania. The ANOVA test performed shows that there is a significant differ-

ence between the values of NO_3^- (3543.60 ± 2834.85 mg/L), PO_4^{3-} (11.85 ± 11.92 mg/L), BOD5 (45.00 mg/L ± 22.91) and Fe^{2+} (24.07 ± 15.72 mg/L) of the Bonaberi marshes and those obtained at Bomono Ba Mbengue which are respectively 8.53 ± 0.70 mg/L; 1.26 ± 1.13 mg/L; 16.67 ± 2.87 mg/L; 1.11 ± 0.21 mg/L. The values of nitrates, phosphorus and BOD5 obtained at Bonaberi are higher than those found at Bomono and also higher than the threshold set by [World Health Organization \(2006\)](#) which are respectively: nitrate < 1 mg/l, 0.03 mg/l of phosphate and < 30 mg/l of O_2 . This result indicates that the waters studied are subject to a risk of pollution by nitrates, and this is much more accentuated at Bonaberi. The dissolved phosphate level in both sites is above the threshold of 0.03 mg/l, which would indicate eutrophication of these environments but much more accelerated in the Bonaberi marshes which directly receives wastewater from soap factories as well as that of nearby households. The practice of agriculture with the use of chemical fertilizers (market gardening and food crops) in the surrounding area should also constitute a significant source of phosphate transported into these various marshes by runoff water ([Tchinda et al., 2018](#)). This also shows that most of the PO_4^{2-} measured in these marshes would have an exogenous origin. The high values of the BOD5 content in Bonaberi compared to Bomono constitute a direct indicator of the presence of a significant quantity of biodegradable organic matter in the water leading to excessive consumption of oxygen by microorganisms for its decomposition. Organic pollution therefore leads to eutrophication ([Tieligounon et al., 2021](#)). The high iron values in Bonaberi compared to Bomono also indicate pollution due to soap effluents which are directly drained into these marshes compared to those of Bomono, it can also be said that the Bonaberi marsh is subject to pollution by nitrates and phosphates. Analyses of the physico-chemical parameters obtained in the two marshes show that the waters of the Bomono marshes are less polluted compared to those of Bonaberi. This notable difference can be attributed to the distance of the Bomono Ba mbengue marshes, located at a significant distance from the soap factory (508 meters), unlike the Bonaberi marsh, which is only 113 meters from the latter including the households located nearby.

Floristic diversity of marshes

The results of the floristic richness observed within the analyzed marshes show a total of 65 identified species. The Acanthaceae and Poaceae families are particularly distinguished by their high representation, testifying to a specific diversity that is both rich and varied. The accumulation curves by the rarefaction method of the marshes of Bomono Ba Mbengue and Bonaberi tend towards practically a plateau. This suggests that the specific richness seems to be total in these two types of marshes, also showing that the sampling is approaching a state of satisfaction. The accumulation curves of the two marshes indicate that these two sites are very diverse because the more we sample, the more new species we collect. The Shannon, Pielou and Simpson diversity indices reveal a particularly high floristic richness in the Bomono Ba Mbengue swamps compared to that of Bonaberi, thus tes-

tifying to a site that is not only distinguished by its number of species, but also by a harmonious balance in the relative abundance of the different species present. These results reinforce the results of Priso *et al.* (2014) as well as Dibong & Ndjouondo (2014), who had observed a similar gradient in the distribution of macrophytes along the Kambo and Kondi rivers. On the other hand, the Sorensen index, which displays a value of 27%, indicates a low similarity between the two sites, suggesting that the effluents from the activities of the Bonaberi soap factory could have a significant impact on the biodiversity of the marsh. This very low value (<50%), underlines that the floristic funds are distinct at these different water points (Priso *et al.*, 2014). This diversity would be largely attributed to their capacity for adaptation and propagation, influenced by various climatic factors and by the dispersion caused by both water currents and human activity (Bonis *et al.*, 2014). In addition, previous research has highlighted that Poaceae are among the plants most tolerant to pollution, particularly that caused by heavy metals (Tchinda *et al.*, 2018). In particular, the Bomono Ba Mbengue swamp stands out with 40 species, surpassing Bonaberi, which has only 33 species. The work of Priso *et al.* (2014) indicates that the most polluted sites generally harbor the fewest macrophytes. The results of the floristic inventories show that certain species are sensitive to water pollution and stand out for their frequency of appearance and their abundance-dominance in the different swamps studied. These species can be described as indicator species of pollution of the swamps in the study area. Thus, the most abundant species in Bomono Ba Mbengue are: *Costus afer* and *Cyrtosperma senegalensis* and a predominance of species such as, *Costus afer* (100%), *Asystasia gangetica* (100%), *Cyrtosperma senegalensis* (100%), *Commelina benghalensis* and *Nymphaea alba* (87%), *Nephrolepis bisserata* and *Oplismenus hirtellus* (73%) which undoubtedly dominate the plant landscape, while in Bonaberi, species such as *Dianthera secunda* and *Onoclonia struthiopteris* also show a strong presence, although their recovery values are lower. There is also a predominance of species such as *Panicum virgatum*, *Ipomoea aquatica* and *Vachellia farnesiana* (87%), *Commelina benghalensis*, *Commelina diffusa* (80%) and *Alternanthera sessilis* (73%). The Bomono Ba Mbengue marsh is distinguished from that of Bonaberi by its floristic diversity. Many studies have shown that the Poaceae family is among the families most tolerant to pollution, particularly by heavy metals (Anoliefo *et al.*, 2008). These results corroborate those of Tchinda *et al.* (2018) and those of Promesse-ssie *et al.* (2021) who also noted that the dominant species of the floristic inventory belong mainly to the Commelinaceae family and constitute an indicator of pollution of aquatic environments. Similarly, Noukeu *et al.* (2016) by characterizing the impact of agri-food industries on receiving environments find that Poaceae and Commelinaceae appear as two families most represented in the fermenteries of Cameroon located in the city of Douala.

Principal component analysis of the different physicochemical variables in the Bomono Ba Mbengue and Bonaberi marshes reveals that the parameters are highly correlated. The strong correlation may be due to common water pollution

from various sources but also to interdependent physicochemical interactions between the parameters themselves. Indeed, organic pollution that affects BOD5 and nutrient inputs such as nitrates and phosphates most often comes from identical human activities (Mohamed *et al.*, 2024). Thus, temperature and high pH directly influence the biodegradation (BOD5) of organic matter present in the water, while conductivity reflects the presence of dissolved ions from practically the same pollution sources (Tieligounon *et al.*, 2021) such as wastewater from soap factories, surrounding households and agricultural runoff. These wastewaters can also jointly introduce salts and heavy metals such as iron into the water and the higher the salinity in the water the more conductive it is (Mohamed *et al.*, 2024). All these physicochemical parameters are strongly correlated with the Bonaberi marsh showing that this site is highly polluted compared to that of Bomono Mba Mbengue. Furthermore, the specific richness, as well as the diversity indices (Shannon, Pielou, Simpson) are strongly correlated with the Bomono Mba Mbengue site showing that it is not only rich in species but also very diverse in terms of distribution of individuals and therefore less polluted. These results show that the physicochemical parameters the distribution of macrophytes that the absence or presence of a species in a swamp is inherent to the composition of the environment in nutrients (Taffouo *et al.*, 2017). This study was conducted only during the rainy season, which differs from the work of Tchinda *et al.* (2018) and Tieligounon *et al.* (2021) who worked in both the rainy and dry seasons.

5. Conclusion

The analyses of this study show that soap effluents, wastewater from surrounding households and agricultural runoff contain large quantities of nitrates, phosphorus, salts and heavy metals which are found in the different swamps, but much higher in the Bonaberi marsh compared to that of Bomono Ba Mbengue. High temperatures and pH directly influence the biodegradation (BOD5) of organic matter present in the water. This suggests that these effluents should not be discharged into aquatic environments without treatment. Similarly, the distance between swamps and sources of pollution influences the degree of nutrients introduced into the marsh. Furthermore, diversity indices are strongly correlated with the Bomono Mba Mbengue site showing that it is not only rich in species but also very diverse in terms of individual distribution and therefore less polluted. Therefore, these wetlands remain highly vulnerable to pollution and degradation, requiring urgent and clear-sighted integrated management, protection and conservation measures.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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