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RESEARCH ARTICLE

ENVIRONMENTAL CHARACTERIZATION OF THE BANDAMA RIVER ESTUARY IN AZAGNY NATIONAL PARK (IVORY COAST, WEST AFRICA)

Koné Touplé Sibiri*[1], Kouyaté Kassoum[2], Soro Tieligounon Ali[2], Kamelan Tanoh Marius[3], Etilé Raphaël N'doua[3] and Kouamélan Essétchi Paul[3]

[1]Animal Biology and Cytology Laboratories, Department of Natural Sciences, NANGUI ABROGOUA University, 02 PO BOX 801 Abidjan 02, Côte d'Ivoire; [2]Department of Sciences and Technologies, ALASSANE OUATTARA University of Bouaké, PO BOX 18 Bouaké 01, Côte d'Ivoire; [3]Laboratory of Natural Environments and Biodiversity Conservation, Department of Biosciences, FÉLIX HOUPHOUËT-BOIGNY University, 22 PO BOX 582 Abidjan 22, Côte d'Ivoire

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***Corresponding author:**
Koné Touplé Sibiri

ABSTRACT

The hydrosystems of the Bandama River estuary are influenced by domestic, agricultural, mining, and fishing activities. The aim of this study is to characterize the physicochemical environment of the waters of the Bandama River estuary located in Azagny National Park. Physicochemical parameters were measured monthly, from March 2019 to February 2020, using multiparameter and miniphotometer measurements. Statistical analysis of the collected physicochemical data indicates both spatial and seasonal variation. The hydrosystems of the Bandama River estuary have an ideal temperature (28.29± 0,081°C) and good oxygenation (6.3± 0,59 mg/L). This hydrosystem, salty (9.53± 4,3 ‰), has high conductivity values (201.94 ± 91,81µS/cm). Magnesium and manganese concentrations are higher upstream in the Bandama River estuary. However, nitrate, nitrite, orthophosphate, total phosphorus, ammonium and ammonia are highly concentrated downstream during the short rainy season and the long dry season.Chemicals used in human activities around Azagny National Park contribute to significantly altering the physicochemical parameters of the Bandama River estuary hydrosystem. These conditions would pose an ecological risk to the survival of certain living beings in this aquatic ecosystem.

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INTRODUCTION

The Bandama River is one of the main rivers in Côte d'Ivoire. It is entirely located in Côte d'Ivoire. It rises in the north of the country, at an altitude of 480 m between the towns of Korhogo and Boundiali (Aboua *et al*., 2010). At its outlet, the Bandama River joins the Ébrié Lagoon to the east, via the Azagny Canal, and follows its course to flow into the ocean (Koffi *et al*., 2015). The Bandama River estuary is an area where fishing activity is very intense and remains the main activity of the population (Wognin *et al*., 2007). However, this area constitutes the preferred zone for several fish species, which find ideal conditions there to reproduce, feed, and develop (Kamelan *et al*., 2022). Furthermore, these hydrosystems of great ecological and economic importance receive water from agricultural areas loaded with agricultural inputs (pesticides, fertilizers, etc.), domestic discharges linked to its proximity to residential areas and residues of chemical products used for fishing (Gnagbo *et al*., 2016). These infiltrations are not without consequences on the physicochemical quality of the hydrosystems of the Bandama River estuary. Indeed, the Bandama River has been the subject of several studies. Most of the studies carried out on the Bandama River have focused on the freshwater area of the river. These studies mainly focus on the physicochemistry, specific composition and ecology of fish in the Bandama River (Paugy and Lévêque, 1977 ; Mérona, 1981 ; Aboua *et al*., 2010 ; Koné *et al*., 2021 ; Soro *et al*., 2021 ; Kamelan *et al*., 2022). In the absence of reference data on the physicochemistry of the Bandama River estuary, it becomes imperative to establish an environmental characterization of this hydrosystem, in order to effectively contribute to the conservation of this ecosystem and the design of a plan for sustainable management of their biodiversity.

METHODOLOGY

Study Setting: The estuarine zone of the Bandama River is located in Grand-Lahou, between latitudes 5°17 and 5°90 North, and longitudes 4°47 and 4°57 West. At its outlet, the Bandama River joins the Ébrié Lagoon to the east, via the Azagny Canal, and follows its course to flow into the ocean (Koné *et al*., 2021). The estuarine section studied constitutes the natural western boundary of Azagny National Park. Three stations were selected, following the upstream-downstream gradient. These are the Point O (Ba1), Avickam Lodge (Ba2), and Ségui (Ba3) stations (Fig 1).

perform Principal Component Analysis (PCA) to ordinate the stations based on environmental parameters.

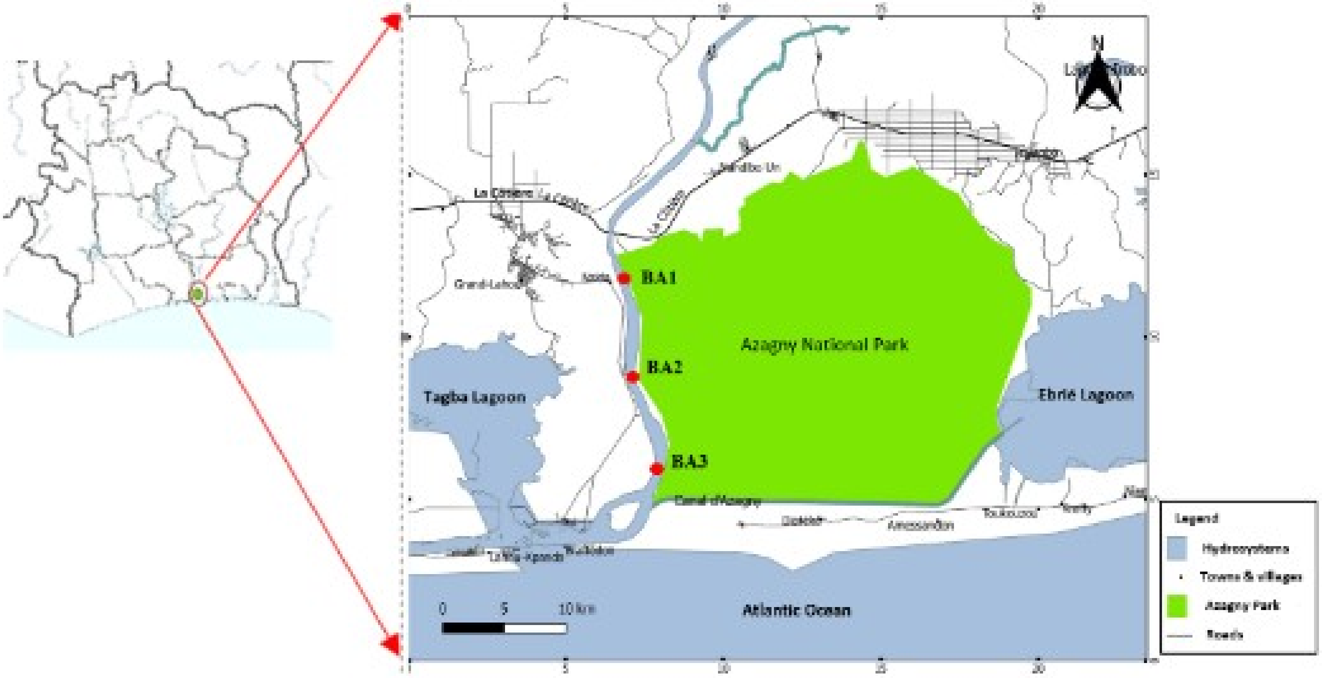

Fig 1. Environmental parameter measurement points in the Bandama River estuary in Azagny National Park (Koné et *al*, 2021)

Sampling and Processing of Environmental Variables

Measurement of Physicochemical Parameters : Physicochemical parameters were measured monthly from March 2019 to February 2020. The sampling strategy aimed at covering all hydrological and climatic seasons. At each sampling station, parameters such as temperature, dissolved oxygen, pH, conductivity, and salinity were measured using an AQUAred multi-parameter AQUAmeter. These measurements were carried out according to the methods of Rodier *et al.* (2009). For each parameter, three *in situ* measurements were taken at each station. The three measurements were taken first between 7:00 and 8:00 a.m., then between 12:00 and 1:00 p.m., and finally between 3:00 and 4:00 p.m. Water depth and transparency were assessed using a weighted rope and a Secchi disk, respectively. The flow rate was measured three times by timing the movement of a 50 cl plastic water bottle, half full of water, over a specified distance of 10 m (McMahon *et al.*, 1996). Ionic compounds (nitrite, nitrate, orthophosphate, total phosphorus, alkalinity, ammonium, ammonia and magnesium) and manganese were measured after sampling 250 ml of water. They were measured in mg/L, using HANNA brand "search" digital miniphotometers and HANNA kits containing reagents for measuring these chemical compounds.

Data Processing and Statistical Analysis: Mean, minimum, and maximum values were determined to synthetically describe the physicochemical variables. The ANOVA test was performed to test the significance of the variation between the mean values of the environmental variables at a significance level of 5%. The different representations with the letters a, b, or c in common did not differ significantly (ANOVA, $p > 0.05$). These statistical analyses were performed using Statistica 7.1 software. XLSTAT software was also used to

RESULTS

The average temperature recorded in this study was 28.29 ± 0.081°C. It ranged from 27.85 ± 1.73°C at station Ba2 to 28.85 ± 2.23°C at station Ba3 (Figure A1). These average temperature values showed no significant spatial variation (ANOVA, $p = 0.08$). Seasonally, the temperature ranged from 27.46 ± 0.001°C during the short rainy season to 29.23 ± 0.88°C during the long dry season (Figure 2A2). The canal waters were significantly warmer (ANOVA, $p = 0.01$) during the long dry season. The average pH was 6.31 ± 1.10. Spatially, pH varies between 6.20 ± 0.021 at station Ba2 and 6.41 ± 2.09 at station Ba3. pH does not vary significantly from one station to another (Anova, $p = 0.06$) (Figure 2B1). Seasonally, pH ranges between 7.53 ± 0.74 in the short dry season and 6.03 ± 0.001 in the long rainy season. pH is significantly (Anova, $p = 0.01$) more basic during the short dry season (Figure 2B2). The average oxygen of the hydrosystems is 6.3 ± 0.59 mg/L. Spatially, oxygen values range from 5.7 ± 1.32 mg/L at station Ba2 to 6.62 ± 0.74 mg/L at station Ba1. The water is significantly (Anova, $p = 0.006$) more oxygenated at station CA2 (Figure 2C1). Seasonally, values vary from 5.4 ± 0.16 mg/L in the short rainy season to 6.89 ± 0.001 mg/L in the long dry season. The water is significantly (Anova, $p = 0.02$) more oxygenated in the long dry season than in the short rainy season (Figure 2C2). Conductivity values, with an average of 201.94 ± 91.81 µS/cm, oscillate spatially between 70.94 ± 11.81 µS/cm (station Ba1) and 400.6 ± 51.81 µS/cm (station Ba3). Conductivity is significantly (Anova, $p = 0.01$) higher at station Ba3 than at station Ba1 (Figure 3A1). Seasonally, conductivity varies from 86.1 ± 10.72 µS/cm in the short rainy season to 354.57 ± 16.72 µS/cm in the long dry season. Electrical conductivity is significantly (Anova, $p = 0.01$) higher in the long dry season than in the short rainy

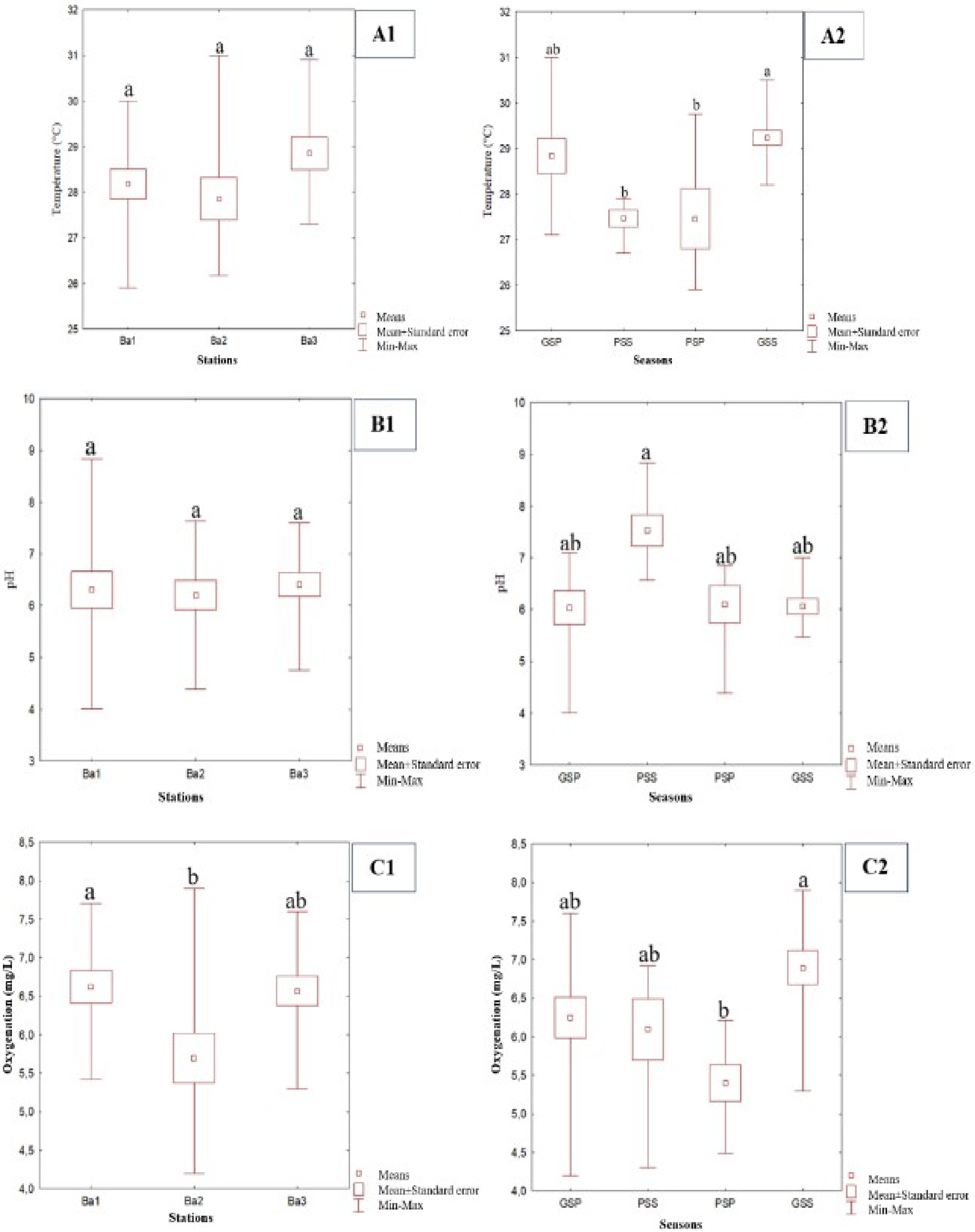

Fig 2 : Spatial and temporal variations of temperature (A), pH (B) and oxygen (C) in the hydrosystems of the Bandama River estuary from March 2019 to February 2020. (Ba1 = Point O ; Ba2 = Avickam lodge ; Ba3 = Ségui ; GSP = long rainy season ; PSP = short rainy season; GSS = long dry season ; PSS = short dry season ; the mean values of parameters having a letter (a, b or c) in common do not differ significantly (ANOVA, p > 0.05))

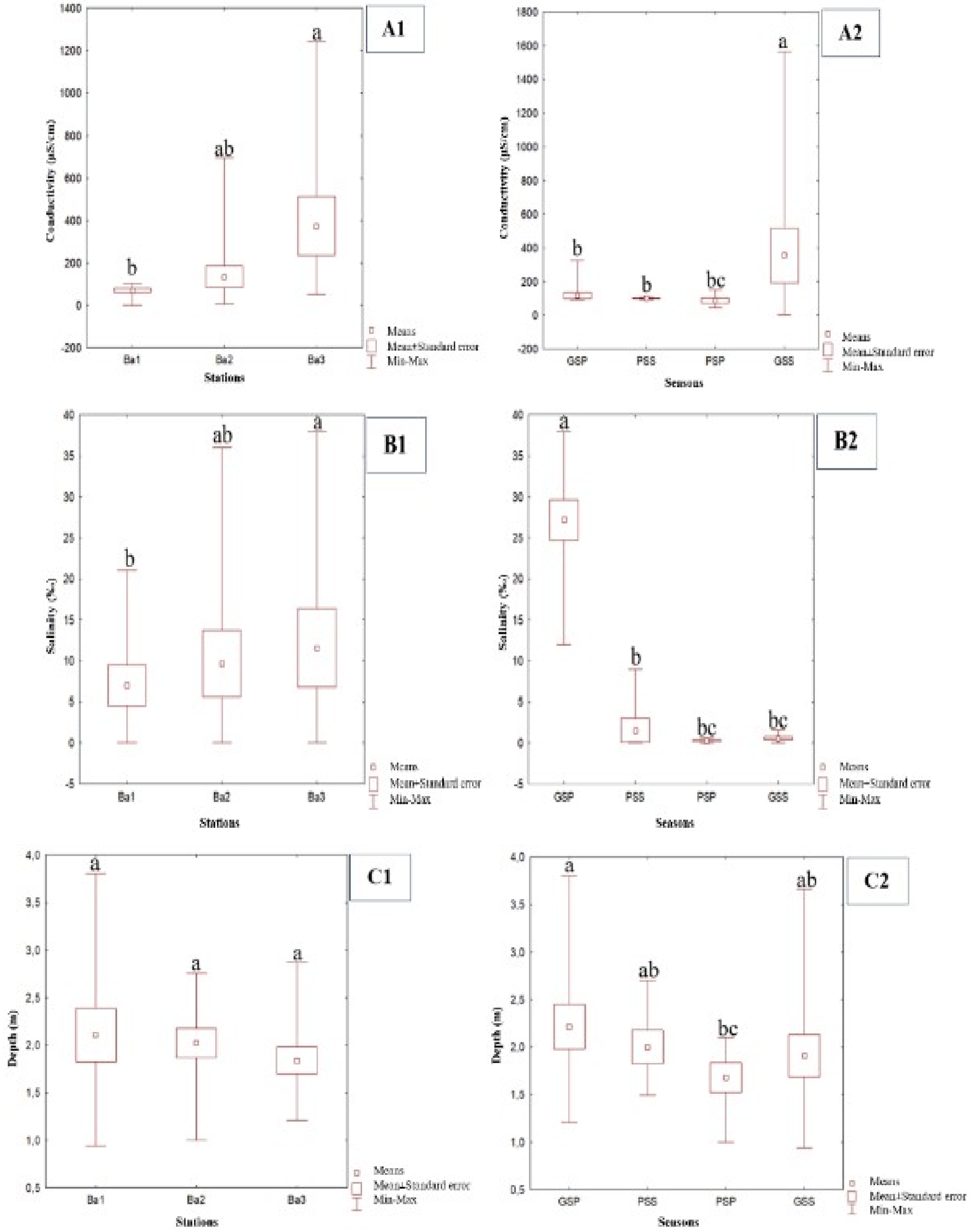

Fig 3: Spatial and temporal variations of conductivity (A), salinity (B) and depth (C) in the hydrosystems of the Bandama River estuary from March 2019 to February 2020 (Ba1 = Point O ; Ba2 = Avickam lodge ; Ba3 = Ségui ; GSP = long rainy season ; PSP = short rainy season; GSS = long dry season ; PSS = short dry season ; the mean values of parameters having a letter (a, b or c) in common do not differ significantly (ANOVA, p > 0.05))

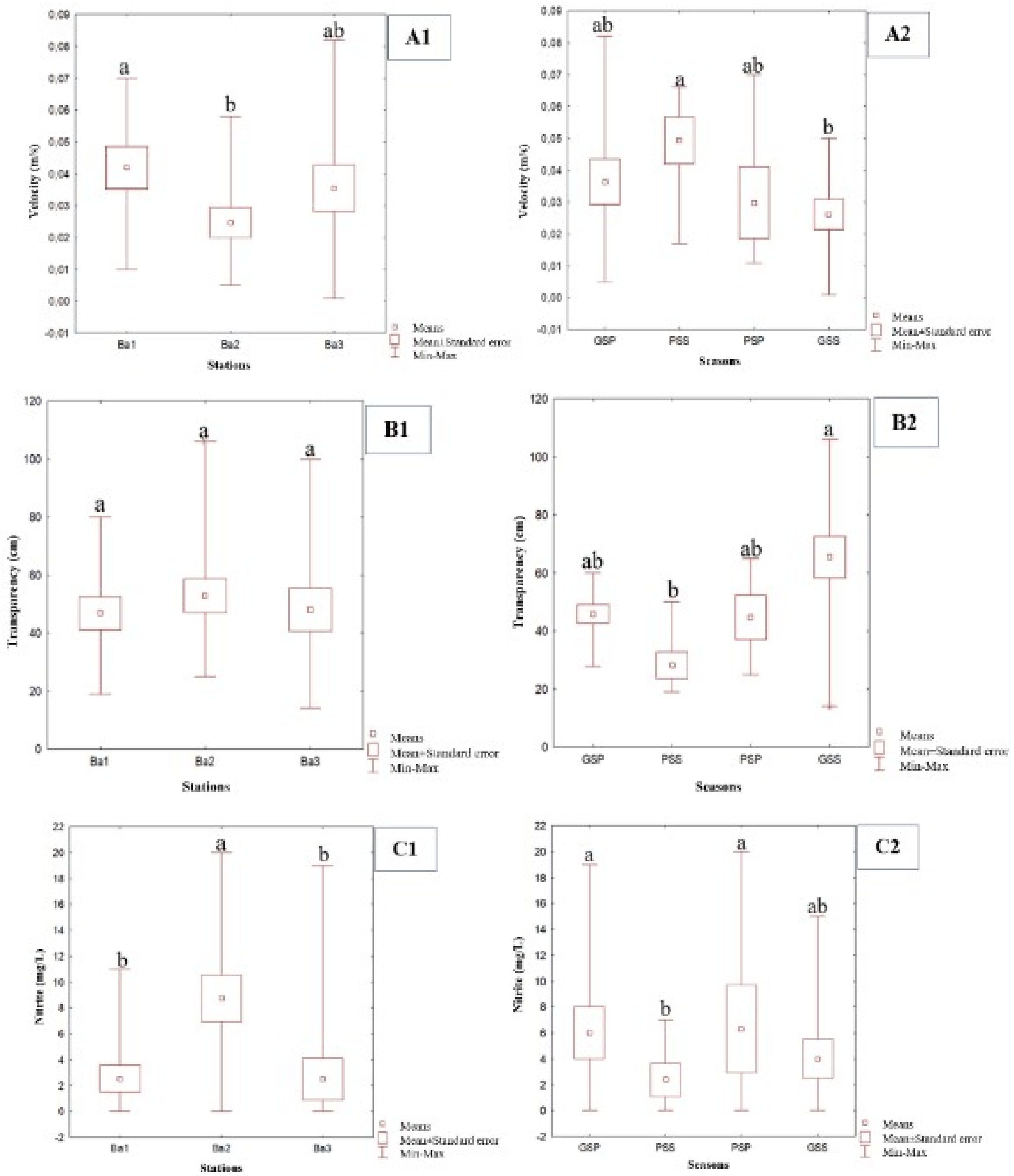

Fig 4 : Spatial and temporal variations in velocity (A), transparency (B) and nitrite (C) in the hydrosystems of the Bandama River estuary from March 2019 to February 2020. (Ba1 = Point O ; Ba2 = Avickam lodge ; Ba3 = Ségui ; GSP = long rainy season ; PSP = short rainy season; GSS = long dry season ; PSS = short dry season ; the mean values of parameters having a letter (a, b or c) in common do not differ significantly (ANOVA, p > 0.05))

season (Figure 3A2). The average salinity is 9.53 ± 4.3 ‰. From a spatial point of view, it is minimal (6.98 ± 0.03 ‰) at station Ba1 and maximal (11.57 ± 6.14 ‰) at station Ba3. These values are significantly (Anova, p = 0.02) higher at station Ba3 than at station Ba1 (Figure 3B1). At the seasonal level, salinity oscillates between 0.23 ± 0.07 ‰, in the short rainy season, and 27.17 ± 8.98 ‰, in the long rainy season. The salinity averages are significantly higher (Anova, p = 0.01) in the long rainy season than during the short rainy season and the long dry season (Figure 3B2). The average depth is 1.99 ± 0.52 m. The depth varies between 1.84 ± 0.19 m at station Ba3 and 2.11 ± 0.97 m at station Ba1. Spatially, the waters are significantly deeper (Anova, p = 0.01) at station Ba1 and less so at station Ba3 (Figure 3C1). Over time, the depth varies between 1.68 ± 0.49 m, in the short rainy season, and 2.22 ± 0.05 m, in the long rainy season. The waters are significantly (Anova, p = 0.01) deeper in the long rainy season (Figure 3C2). Water velocity averages 0.034 ± 0.23 m/s. Spatially, it ranges from 0.025 ± 0.001 m/s (Ba2) to 0.042 ± 0.001 m/s (Ba1). Velocity is significantly (Anova, P = 0.01) higher at station Ba1 (Figure 4A1). Seasonally, velocity varies from 0.049 ± 0.022 m/s in the short dry season to 0.026 ± 0.006 m/s in the long dry season. Velocities are significantly higher (Anova, P = 0.04) in the short dry season and lower in the long dry season (Figure 4A2). With an average of 49.23 ± 1.04 cm, in space, transparency varies from 46.82 ± 1.54 cm at station Ba1 to 52.83 ± 2.48 cm at station Ba2. Transparency does not vary significantly between stations (Anova, p = 0.06)

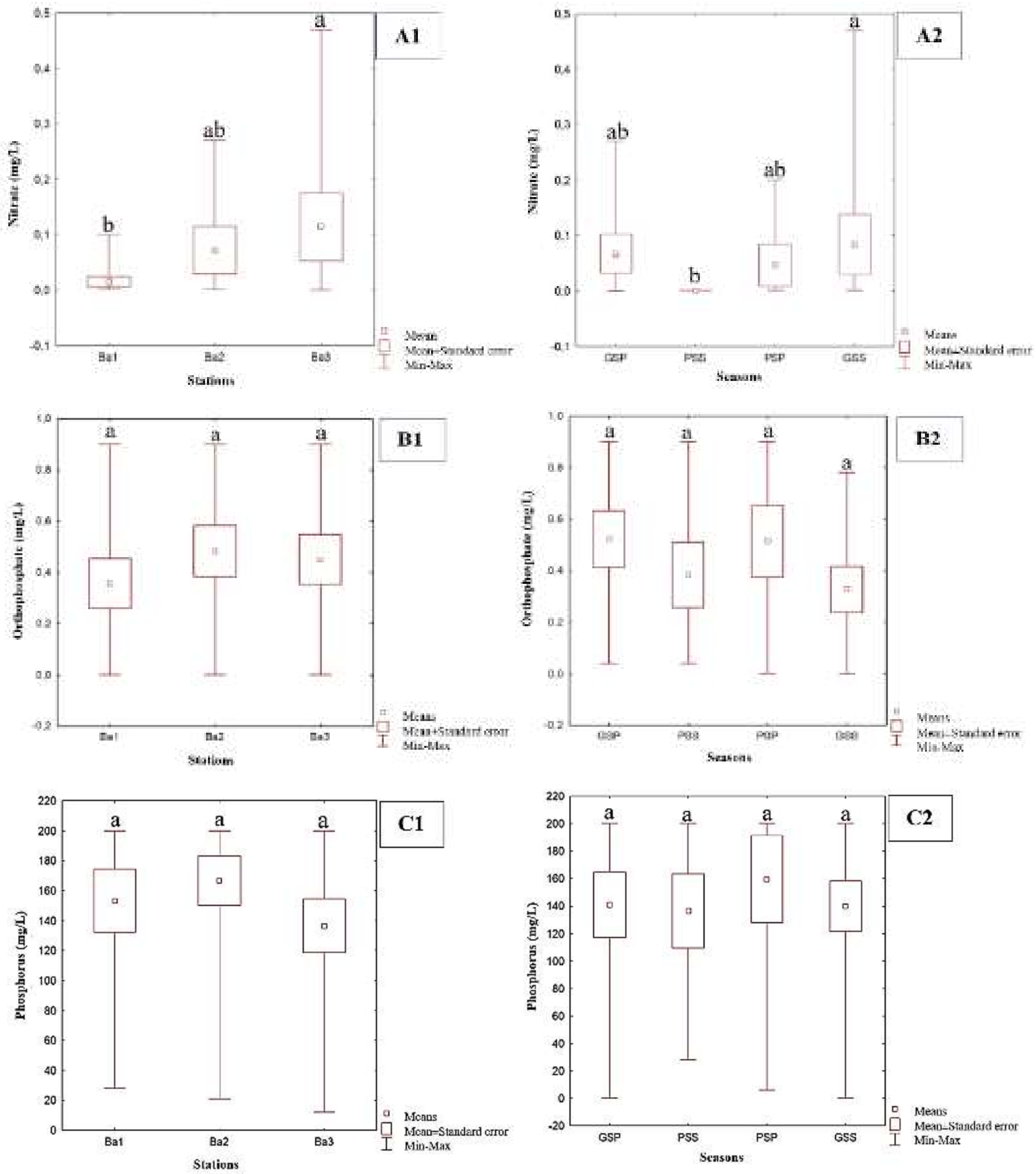

Fig. 5. Spatial and temporal variations of nitrate (A), phosphate (B) and phosphorus (C) in the hydrosystems of the Bandama River estuary from March 2019 to February 2020 (Ba1 = Point O ; Ba2 = Avickam lodge ; Ba3 = Ségui ; GSP = long rainy season ; PSP = short rainy season; GSS = long dry season ; PSS = short dry season ; the mean values of parameters having a letter (a, b or c) in common do not differ significantly (ANOVA, p > 0.05))

(Figure 4B1). At the seasonal level, it oscillates between 28.17 ± 0.001 cm in the short dry season and 65.42 ± 6.75 cm in the long dry season. The waters are significantly more (Anova, p = 0.01) transparent in the long dry season and less in the short dry season (Figure 4B2). The average nitrite concentration is 4.53 ± 1.77 mg/L. In space, the nitrite concentration oscillates between 2.55 ± 3.06 mg/L at station Ba1 and 9.10 ± 5.06 mg/L at station Ba2. Nitrite concentrations are significantly (Anova, p = 0.01) higher at station Ba2 (Figure 4C1). Over time, the nitrite concentration is minimal (2.4 ± 0.001 mg/L) in the short dry season and maximal (6.33 ± 2.07 mg/L) in the short rainy season. Nitrite concentrations are significantly lower (Anova, p = 0.02) in the short rainy season (Figure 4C2). The average nitrate concentration is 0.059 ± 0.004 mg/L. Spatially, nitrate concentrations range from a trace value below 0.001 mg/L at station Ba1 to 0.11 ± 0.009 mg/L at station Ba3. These concentrations are significantly (ANOVA, p = 0.01) high at stations Ba3 (Figure 5A1). Temporally, nitrate concentrations vary from 0.001 ± 0.0001 mg/L in the short dry season to 0.084 ± 0.04 mg/L in the long dry season. Nitrate concentrations are significantly (ANOVA, p = 0.01) higher in the long dry season and lower in the short dry season (Figure 5A2). With an average of 0.43 ± 0.31 mg/L, orthophosphate concentrations ranged in space between 0.36 ± 0.12 mg/L at station Ba1 and 0.48 ± 0.20 mg/L at station Ba2. These concentrations did not vary significantly (Anova, p = 0.08) in space (Figure 5B1). Temporally, orthophosphate concentrations varied from 0.33 ± 0.11 mg/L in the long dry season to 0.52 ± 0.10 mg/L in the long rainy season. These concentrations did not vary significantly (Anova, p = 0.06) over time (Figure 5B2). The average total phosphorus concentration is 135 ± 60.50 mg/L. Concentrations range in space between 136 ± 3.53 mg/L at station Ba3 and 165.03 ± 43.30 mg/L at station Ba2. These concentrations do not vary significantly (Anova, p = 0.07) in space (Figure 5C1). At the seasonal level, total phosphorus concentrations range between 159.5 ± 17.34 mg/L, in the short rainy season and 136.5 ± 13.02 mg/L in the short dry season. Total phosphorus concentrations do not vary significantly (Anova, p = 0.01) over time (Figure 5C2). The mean alkalinity is 9.79 ± 3.78 mg/L.

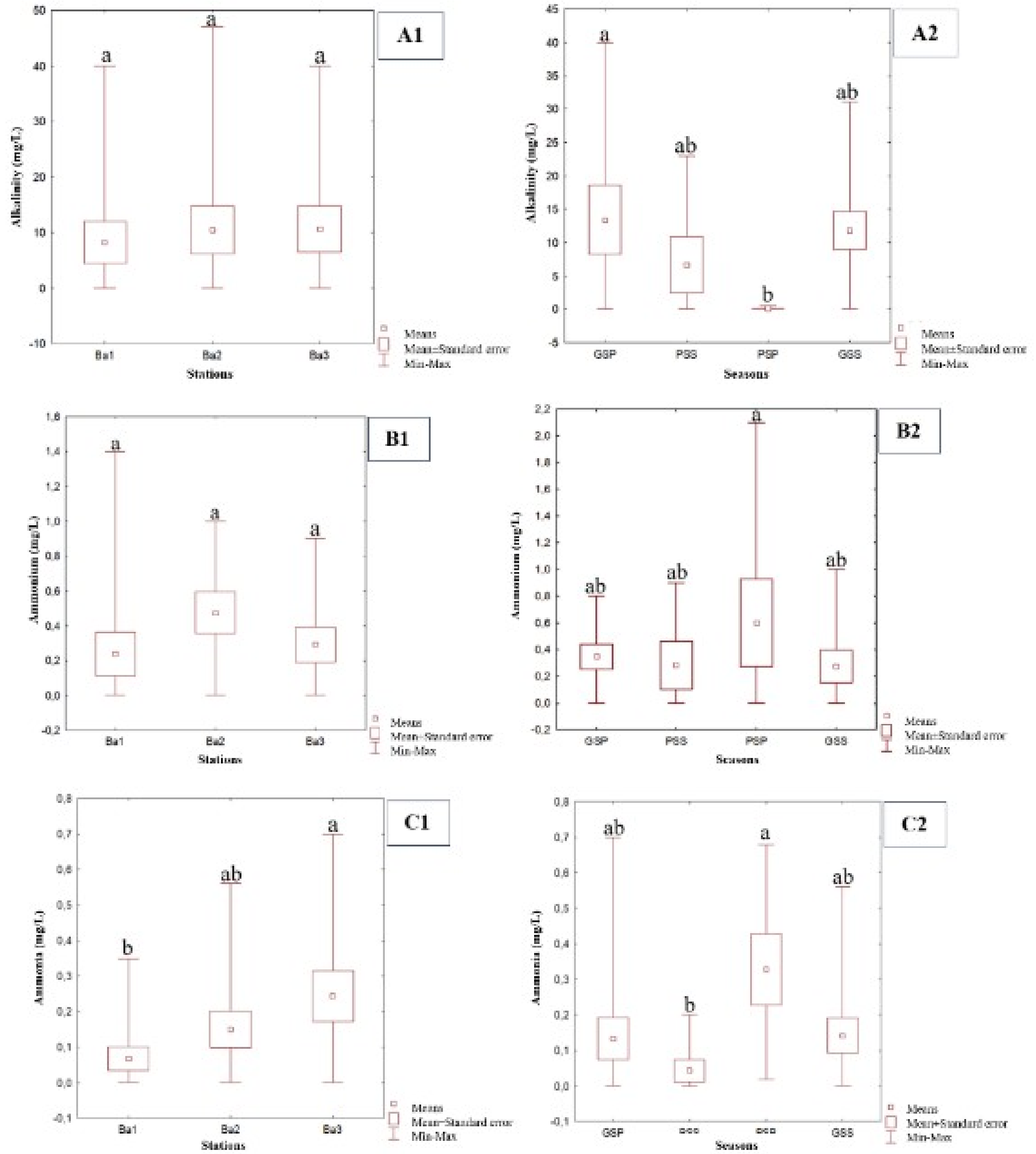

Fig. 6. Spatial and temporal variations of alkalinity (A), ammonium (B) and ammonia (C) in the hydrosystems of the Bandama River estuary from March 2019 to February 2020; (Ba1 = Point O ; Ba2 = Avickam lodge ; Ba3 = Ségui ; GSP = long rainy season ; PSP = short rainy season; GSS = long dry season ; PSS = short dry season ; the mean values of parameters having a letter (a, b or c) in common do not differ significantly (ANOVA, p > 0.05))

Alkalinity varies spatially between 8.25 ± 3.66 mg/L at station Ba1 and 10.5 ± 1.78 mg/L at station Ba2. These concentrations do not vary significantly (ANOVA, p = 0.07) spatially (Figure 6A1). Seasonally, alkalinity ranges from 0.09 ± 0.002 mg/L in the short rainy season to 14.17 ± 8.15 mg/L in the long rainy season. Alkalinity is significantly higher (ANOVA, p = 0.04) in the long rainy season and lower in the short rainy season (Figure 6A2).

The mean ammonium concentration is 0.44 ± 0.22 mg/L. Ammonium concentrations ranged from 0.55 ± 0.18 mg/L at station Ba1 to 0.48 ± 0.18 mg/L at station Ba2. These concentrations did not vary significantly (Anova, p = 0.08) in space (Figure 6B1). Temporally, ammonium varied from 0.28 ± 0.001 mg/L in the short dry season to 1.10 ± 0.78 mg/L in the short rainy season. Ammonium concentrations were significantly higher (Anova, p = 0.006) in the short dry season (Figure 6B2). The average ammonia concentration is 0.16 ± 0.08 mg/L. These concentrations vary in space from 0.074 ± 0.001 mg/L at station Ba1 to 0.24 ± 0.02 mg/L at station Ba3. These concentrations are significantly higher (Anova, p = 0.02) at station Ba3 (Figure 6C1). At the seasonal level, the ammonia concentration is minimum (0.044 ± 0.32 mg/L) in the short dry season and maximum (0.33 ± 0.001 mg/L) in the short rainy season. Ammonia concentrations are significantly higher (Anova, p = 0.001) in the short rainy season (Figure 6C2). The average manganese concentration is 1.28 ± 0.4 mg/L. Spatially, manganese concentrations range from 0.25 ± 0.13 mg/L at station Ba2 to 1.31 ± 0.53 mg/L at station Ba2. These concentrations are significantly higher (ANOVA, p = 0.04) at station Ba2 (Figure 7A1). Temporally, manganese concentrations range from 0.15 ± 0.23 mg/L in the short dry season to 2.93 ± 2.36 mg/L in the long dry season. Seasonal manganese concentrations are significantly higher (ANOVA, p

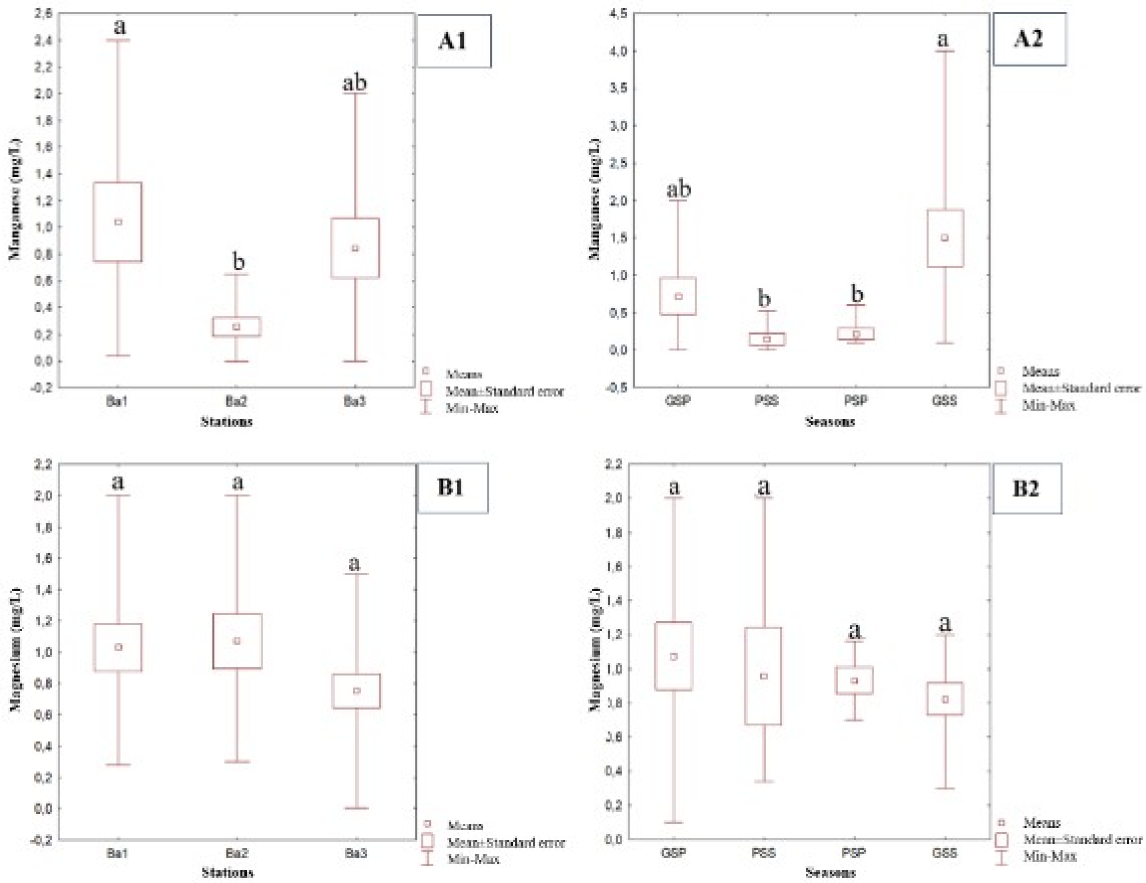

Fig. 7. Spatial and temporal variations of magnesium (A) and magnesium (B) in the hydrosystems of the Bandama River estuary from March 2019 to February 2020; (Ba1 = Point O ; Ba2 = Avickam lodge ; Ba3 = Ségui ; GSP = long rainy season ; PSP = short rainy season; GSS = long dry season ; PSS = short dry season ; the mean values of parameters having a letter (a, b or c) in common do not differ significantly (ANOVA, p > 0.05))

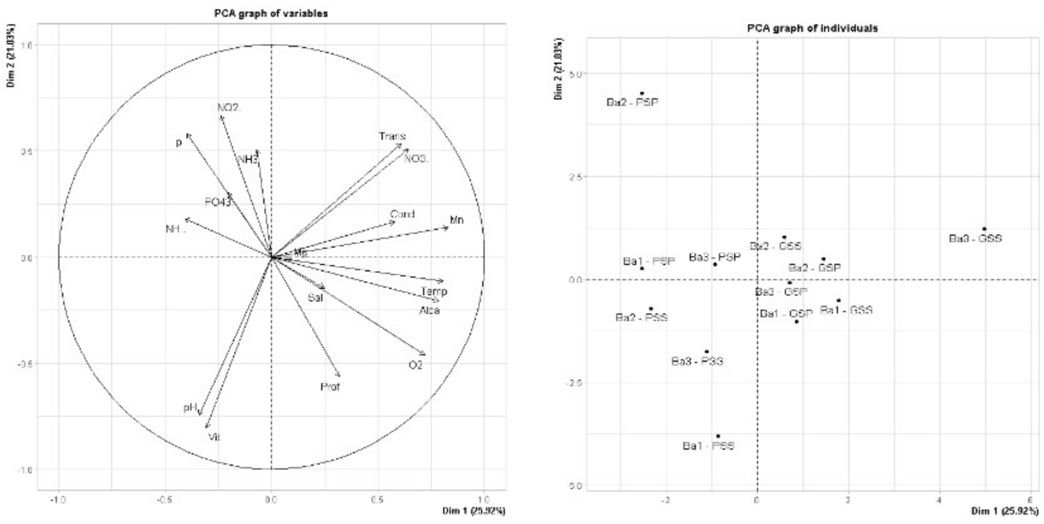

Fig 8. Representation of the results of the Principal Component Analysis (PCA) based on the physicochemical parameters measured in the hydrosystems of the Bandama River estuary from March 2019 to February 2020

= 0.01) in the long dry season (Figure 7A2). The average magnesium concentration is 6.81 ± 1.84 mg/L. At the spatial level, magnesium concentrations ranged from 1.07 ± 0.31 mg/L at station Ba2 to 18.87 ± 5.30 mg/L at station Ba3. Magnesium concentrations do not vary significantly (Anova, p = 0.06) spatially (Figure 7B1). At the seasonal level, magnesium concentrations vary from 21.05 ± 13.29 mg/L in the main rainy season to 0.83 ± 0.01 mg/L in the main dry season. Magnesium concentrations do not vary significantly (Anova, p = 0.86) over time (Figure 7B2).

Station Typology and Grouping: Principal Component Analysis shows that axis 1 (25.92%) and axis 2 (21.03%) account for a total variance of 46.95%, associated with physicochemical variables. The correlation circle of the variables indicates that 10 physicochemical variables (salinity, dissolved oxygen, manganese, alkalinity, temperature, magnesium, conductivity, nitrate, transparency, and ammonia) are positively correlated with axis 1 (Figure 8A). The variables that are positively correlated with axis 2 are: velocity, pH, orthophosphate, total phosphorus, nitrite, ammonium, and water depth. Among the physicochemical parameters, only pH and velocity have a negative correlation with both axes. During the Long Dry Season (GSS) and the Long Rainy Season (GSP), all stations are positively correlated with axis 1 of the PCA (Figure 8B). At these times of the year, stations are mainly characterized by temperature, alkalinity, dissolved oxygen, salinity, manganese, nitrates, transparency and conductivity. During the Short Dry Season (PSS), stations Ba1 and Ba3 are negatively correlated with axis 2, while station Ba2 is negatively correlated with axis 1. During this period, stations Ba3 and Ba1 are characterized by water velocity and pH, while station Ba2 is characterized by ammonia. In the Short Rainy Season (PSP), stations Ba1 and Ba3 are negatively correlated with axis 1, unlike station Ba2 which is positively correlated with axis 2.

DISCUSSION

The temperatures recorded in the waters of the Bandama River estuary show high values during the dry seasons. These high temperatures are thought to be related to the absence of plant cover along the water body, which allows solar radiation to penetrate, leading to an increase in the temperature of the hydrosystem. These observed temperatures are similar to those obtained by Aboua (2012) and Soro *et al.* (2021) in the Bandama River, which are 21.3°C and 32.5°C, respectively. Indeed, the increase in temperature during the long dry season is thought to result from a cumulative effect of the global warming of the atmosphere observed during this period, coupled with a loss of plant cover. Similar results were obtained by Kouyaté (2022) in the Bagoué River in Côte d'Ivoire. However, the recorded temperatures remain ideal for aquatic life, primarily the growth and conservation of ichthyofauna (Yoboué *et al.*, 2018). In addition, the hydrosystems of the Bandama River estuary have an acidic pH and high conductivity. This state is explained by a significant input of organic matter from human activities carried out in the watershed. According to Rodier *et al.* (2009), the acidity of watercourses is of natural or anthropogenic origin. In fact, the drainage of domestic waste into the watercourse by runoff water increases the level of organic matter in the water, thus promoting an increase in the concentration of carbonic acid (H2CO3), which causes the decrease in pH. This same concentration of organic matter in the hydrosystems induces an increase in the activity of microorganisms (anaerobic bacteria) responsible for the mineralization of the organic matter present in the watercourses. This strong mineralization of the environment also induces a drop in hydrogen potential (Konan *et al.*, 2008) and an increase in conductivity (Adon *et al.*, 2017). Salinity values in the hydrosystems of the Bandama River estuary are high on average. These high salinity levels result from its connection with the ocean. As a matter of fact, tidal fluctuations cause ocean waters to penetrate the lower reaches of the Bandama River, thus promoting an increase in salinity. According to Albaret and Diouf (1994) and Kamelan *et al.* (2022), upwelling of marine waters in river estuaries and lagoons increases their salinity and influences their conductivity. The hydrosystems of the Bandama River estuary observe good oxygenation on average (6.3 mg/L). However, the oxygenation rate drops considerably during the short rainy season (5.4 mg/L). The oxygen depletion observed during the short rainy seasons is thought to be linked to low flow velocities and the activity of mineralizing microorganisms. Reduced flow prevents atmospheric oxygen from mixing into the water, resulting in a low dissolved oxygen turnover rate. The increased activity of mineralizing anaerobic bacteria that are very oxygen, also induces an overconsumption of dissolved oxygen, which depletes the environment in oxygen. Konan *et al.* (2013) and Koné *et al.* (2021), indicate that oxygen concentrations in aquatic ecosystems are closely linked to biological phenomena (photosynthesis, respiration, mineralization) that occur in hydrosystems. The concentrations of nitrite (4.53 mg/L), nitrate (0.059 mg/L), orthophosphate (0.43 mg/L), total phosphorus (135 mg/L), ammonium (0.44 mg/L), ammonia (0.16 mg/L), manganese (1.28 mg/L) and magnesium (6.81 mg/L) in the Bandama River estuary are heterogeneous both in space and time. The contamination of the hydrosystems of the Bandama River estuary could be explained by organic inputs from agricultural areas, residential areas and the upstream part of the Bandama River. Indeed, the use of agricultural fertilizers in plantations, as well as domestic and agri-food industry waste, situated near the Azagny National Park and along the Bandama River, provide hydrosystems with nitrogen and phosphate bases in the form of organic matter. They decompose there and release the bases they contain. According to Derwich *et al.* (2010), the presence of nitrogen and phosphate compounds in hydrosystems results from the degradation of organic matter contained in industrial, domestic and agricultural waste. The increased use of fertilizers in agricultural activities is an important factor that would influence nutrient concentrations in peripheral hydrosystems (Diomandé *et al.*, 2019 ; Koné *et al.*, 2024). Principal Component Analysis made it possible to determine a seasonal fluctuation in environmental characteristics. The stations during the long dry and rainy seasons have high concentrations of chemical elements and are more degraded. In fact, during the long rainy seasons, under the influence of drainage, they receive chemicals used in the surrounding plantations and chemical inputs from the Bandama River during the long rainy season. In addition to these, there are chemical compounds from chemical fishing practiced in the lagoon section. During the long dry season, under high temperatures, the hydrosystems, also undergo evaporation which induces a high concentration of ionic compounds. All of these inputs of chemical elements and their concentrations in the environment would be the basis of the degradation of the stations during the long dry and rainy seasons. According to Soro *et al.* (2021), the inputs of chemical elements during the rainy seasons are the basis of the physicochemical degradation of the hydrosystems. Koné *et al.* (2024), also indicate that the increase in evaporation from hydrosystems in the dry season induces a high concentration of chemical elements leading to a degradation of the aquatic environment.

CONCLUSION

The results of this study allowed us to characterize the physicochemical environment of the Bandama River estuary, located in Azagny National Park (PNA), highlighting seasonal and spatial variability in the measured parameters. The hydrosystem of the Bandama River estuary has an ideal temperature (28.29°C) and good oxygenation (6.3 mg/L). Salty (9.53‰), this hydrosystem has high conductivity values (201.94 µS/cm). Magnesium and manganese concentrations are higher upstream in the Bandama River estuary. However, nitrate, nitrite, orthophosphate, total phosphorus, ammonium, and ammonia are highly concentrated downstream during the short rainy season and the long dry season. Furthermore, the

PCA indicates chemical degradation of the stations during the long dry and rainy seasons. In order to fully and sustainably benefit from the ecosystem services of the Bandama River estuary, it is imperative that managers and decision-makers pay particular attention to this strategically important area. The results of this work will serve as a basis for PNA managers to take appropriate measures for better conservation of aquatic fauna whose survival depends on the hydrosystems that host it. They will also allow targeted awareness campaigns to be launched among the surrounding populations on the risks associated with the misuse of agricultural inputs, poisoning fishing and uncontrolled mineral extraction.

Conflict of interests: The authors have not declared any conflict of interests.

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