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(Research Article)

Spatio-temporal characterization of the ecological state of the Bandama River in the Marahoué region using diatomic indices

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Abstract

This study aims to know the ecological quality and the level of organic pollution of the waters of the Bandama River under high anthropogenic pressure. Benthic diatoms were collected from six stations from October 2019 to August 2020 due to one campaign per month in the Bandama River portion covering the Marahoué region. After analysis of the samples the specific pollution sensitivity index (SPI) and the diatom trophic index (TDI) were determined according to the spatiotemporal scale. The results of the IPS and TDI indices indicate average water quality. TDI results indicated that river trophic level varied from oligo-mesotrophic to mesotrophic at both spatial and temporal scales. Concerning the IPS index, the results reveal a moderate organic pollution to raise both on the spatial and temporal scale. This result challenges us on the need to put in place sustainable water resources management strategies that will take into account the physico-chemical quality of water and the preservation of biodiversity in order to guarantee health security, and food to populations directly and indirectly dependent on the Bandama.

Keyword: Organic pollution; Bandama river; Diatomic index; Gold panning; Eutrophication

1. Introduction

Access to water being a vital need, hydro-systems, particularly continental ones, are increasingly being attacked by the effects of human activities [1]. The Bandama River with its watershed entirely on ivorian territory occupies a special place in the socio-economic development of Côte d'Ivoire. On this river, numerous hydro-agricultural dams and two large hydro-electric dams (Kossou and Taabo) are built there, thus contributing to the development of agriculture and energy autonomy. Fishing is also practiced, particularly on Lake Kossou and Lake Taabo, contributing to food self-sufficiency in Côte d'Ivoire [2,3]. However, in addition to being the receptacle of various types of waste generated by human activities carried out in its watershed, this river faces intense gold panning activity [4,5]. From there, the ecological health assessment of this environment is necessary. Indeed, the impact of anthropogenic activities on hydrosystems has direct repercussions on the quality of the structure and the degree of organization of the species that live there [6]. This scenario therefore gives bioindication a prominent place in determining the quality of functioning of ecosystems. Benthic diatoms are commonly used in bioindication because they react differently to environmental conditions [7]. On the Bandama, studies on limnology, taxonomic knowledge of Bacillariophyceae (diatoms) were carried out by Lévêque *et al.* [8]. Furthermore, the determination of water quality using diatomic indices was made in the hydro-biological study in the zone of influence of the Yaouré gold project by Konan *et al.* [4]. However, the determination of the ecological state of the two arms of the Bandama River covering the Marahouré region, an area

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strongly impacted by gold panning activity and a receptacle for domestic and industrial waste, has not yet been carried out. The objective of this study is to evaluate the ecological quality of the waters of the Bandama river, subject to strong anthropogenic pressure, in order to ensure rational management of this watercourse.

2. Materials and methods

2.1. Sampling stations

Sampling was carried out monthly from October 2019 to August 2020. Six (6) stations were sampled on two tributaries of the Bandama River (Bandama Blanc and Bandama Rouge) covering the Marahoué region and at their melting zone. The sampling stations were chosen taking into account the accessibility, the anthropization level of the riverbanks, and human activities in the vicinity of the river, such as gold panning and presence of industrial or domestic waste. Sampling station S1 is located on Lake Kossou, close to the Kossou hydroelectric dam. This station is bordered by fishing camps and is subject to domestic activities. Station S2 is located on the riverine section just after the dam of Kossou hydroelectric dam. This station is overgrown with more or less well-preserved vegetation. There are also plantations and gold panning activities on the left bank downstream of this station. Station S3 is located near the village of Bambakro. In addition to the domestic activities that take place there (washing, doing the dishes) and bathing, this station is also the site of intense gold panning activity. These three stations (S1, S2 and S3) are located on the Bandama Blanc tributary. Stations S4 and S5 are located on the Bandama Rouge tributary. Station S4 is located near Zuénoula beneath the bridge settled on the Bandama river. Plantations and sparse forest can be seen all along this station. This station has received industrial discharges further in upstream. Station S5 is located between Zuenoula and Bouaflé. The banks of this station are occupied by stretches of forest and plantations. No gold-panning activity was noted at this station, station S6 is located at the confluence of the two tributaries (Bandama Blanc and Bandama Rouge). This site is bordered by an open forest and an area developed for leisure activities. However, on the opposite bank to this recreation area, gold-panning activities have been carried out on the riverbank. The study area and stations are shown in Figure 1.

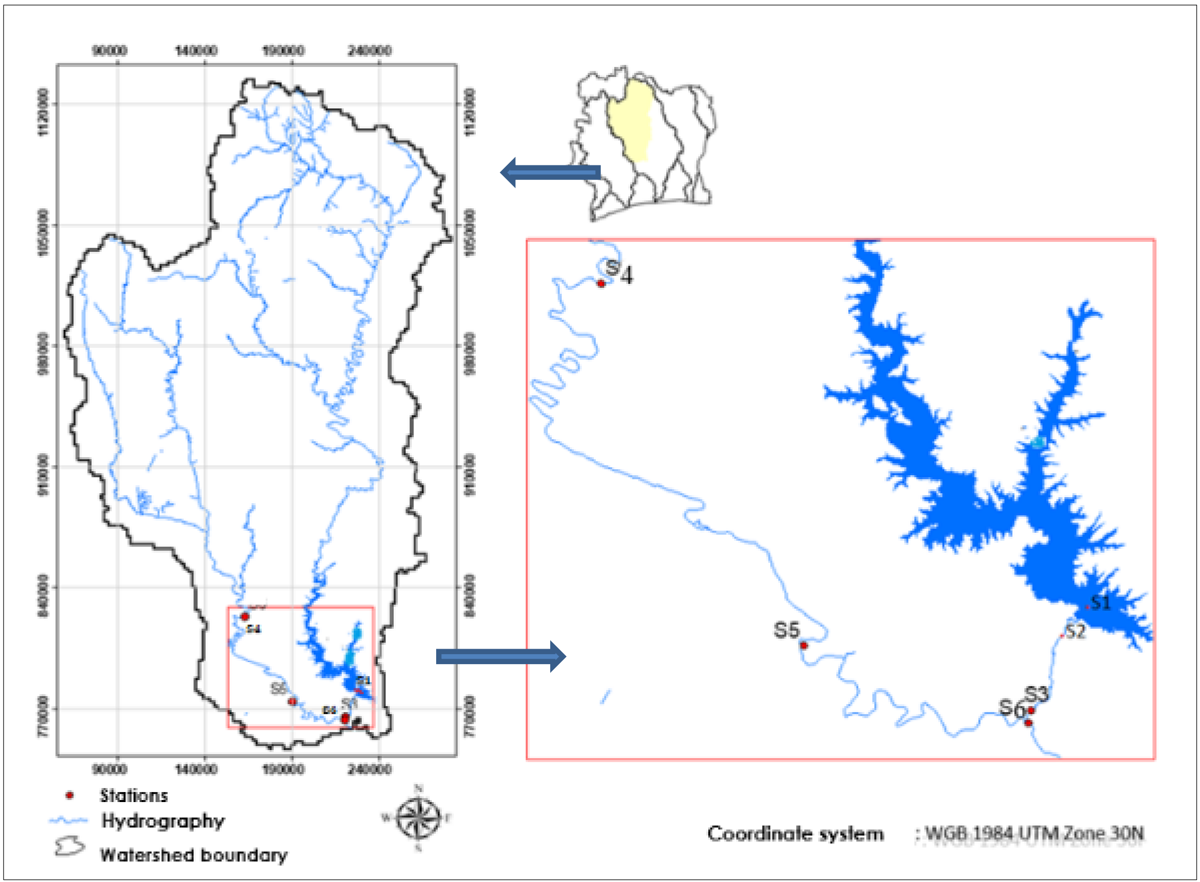

Figure 1 Map showing sampling stations

2.2. Diatoms sampling

Benthic diatoms were obtained from periphyton sampling carried out on submerged and fixed tree trunks from the Bandama River. It consisted of brushing a surface area equivalent to 20 cm^2, rinsed with distilled water then collected in a 120 ml pill bottle. These collected periphytic samples were identified and fixed with formalin at the final concentration of 5% [10].

2.3. Identification and enumeration of diatoms

In the laboratory, the identification and enumeration of taxa were carried out using an inverted microscope according to the [11] method by the combination of identification works by [12, 13, 14], on the IBD guide by [10]. For easy identification of diatoms, a 25 ml subsample and the same quantity of 65% nitric acid was added. After homogenization, the mixture obtained is put in a heat-resistant bottle then brought to the boil on the hot plate until the observed brown vapor disappears. This step aims to destroy any organic matter present in the sample in order to better reveal the details of the ornamentation of the siliceous shell of the diatom [15, 16]. After cooling, the solution obtained was centrifuged three times at a minimum speed of 2,000 rpm for 15 min interspersed with rinsing with distilled water. A few drops of the final suspension were placed on a coverslip and heated. The blade and the coverslip are brought together by applying a drop of highly refractive resin (Naphrax™IR = 1.74) then observed under an upright AFNOR NF T 90-354 microscope (December 2007).

2.4. Determination of diatomic indices

The specific pollution sensitivity index (IPS) defined by [17], which makes it possible to integrate the effects of organic pollution, was calculated using the formula updated by [18].

$$IPS = \frac{\sum A_j V_j S_j}{\sum A_i V_i} * 4.75 - 3.75$$

Aj: the density of species j in the sample; Vj indicator value (1-3); S: sensitivity to pollution (1-5) of species i.

Table 1 Classes of the specific pollution sensitivity index

Index value (IPS)	Ecological status
17-20	Very good
16,9-15	Good
14,9-12	Moderate
11,9-8	Poor
<7,9	Bad

The diatom trophic index (TDI) defined by [19] makes it possible to evaluate the sensitivity of taxa in relation to nutrient salt concentrations (soluble phosphate, total phosphorus, nitrate and ammonia) and therefore eutrophication. It uses indicator taxa and is calculated using the formula:

$$TDI = \frac{\sum A_j V_j S_j}{\sum A_i V_i} * 25 - 25$$

With Aj: the density of species j in the sample; Vj value of the index indicator (1-3); S: sensitivity to pollution (1-5) of species j. The interpretation scale for this index is presented in Table 2

The spatiotemporal variations of the results of these indices were presented in the form of a contour curve using the Surfer 20 software.

Table 2 Diatom Trophic Index (TDI) Classes

Index value (TDI)	Pollution degree TDI
TDI<35	Oligotrophic state
35-50	Oligo-mesotrophic
50-60	Mesotrophic state
60-75	Eutrophic state
75-100	Hypertrophic state

3. Results

The ecological and trophic quality of the waters was determined through a spatio-temporal analysis of the IPS and TDI indices. The smallest value of SPI (5.87) was obtained at station S2 in the month of August and the highest (14.88) at station S6 in May. The TDI values varied from 10.48 (S3-April) to 100 (S2-March). Spatially, stations S2, S3, S4 and S5 with respective SPIs of 9.50, 11.18, 11.59 and 11.73 falling between 8 and 11.9 are classified as poor quality. The SPI of stations S1 (13.06) and S6 (12.77), in the range of 12 to 14.9, undergo moderate organic pollution. For the TDI index the stations S1, S2, S3, S5 and S6 with respective values of 38.39, 47.44, 34.41, 47, 96 and 47.87 all in the range of 35-50 are oligo-mesotrophic state. Station S4 with a TDI value of 58.25, values within the margin of 50-60, is qualified as a mesotrophic state. Based on the IPS and TDI indices, stations S1 and S6 characterized by a moderate pollution and oligo-mesotrophic ecological status appear to be the best preserved compared to the others. The station S4 with a poor quality and mesotrophic ecological state is the most disturbed table 3.

At the monthly level, the values of IPS for the months October (10.66), November (8.15), December (10.58), February (10.44) March (10.34) June (11.6) and July (10.81) were all within the range of 8 to 11.9, qualifying them as poor ecological status. For the months of January, April December May and August with respective SPIs of 12.11, 15.23, 14.07 and 13.77 have moderate pollution. For the TDI, the months of October (37.74), December (48.50), February (49.01), April (30.97) May (37.04), June (42.73), July (46 .76) August (38.65) this classifies in the oligo-mesotrophic category. As for the months of November (57.50), January (52.77) and March (58.59) their TDI values lying between 50 and 60 are qualified as mesotrophic state. Figure 2 presents the spatio-temporal variation of the two classes obtained from the two diatomic indices, that is to say poor and moderate (orange and yellow) for the IPS (figure 2-A) and oligo-mesotrophic and mesotrophic (green and yellow) for TDI (Figure 2-B).

Table 3 IPS and TDI index results

Stations	IPS	TDI
S1	Moderate	Oligo-mesotrophic
S2	Poor	Oligo-mesotrophic
S3	Poor	Oligo-mesotrophic
S4	Poor	Mesotrophic state
S5	Poor	Oligo-mesotrophic
S6	Moderate	Oligo-mesotrophic

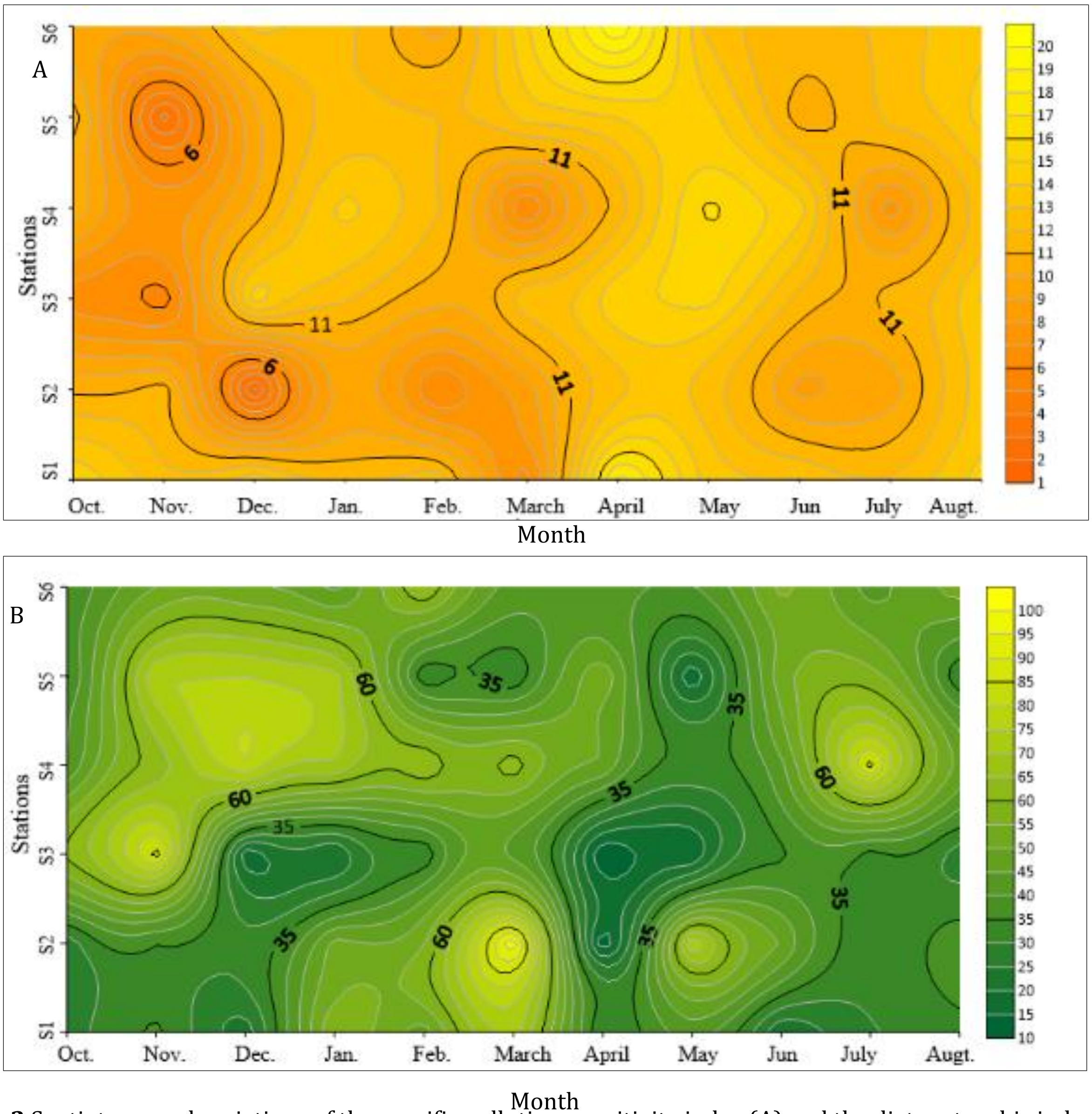

Figure 2 Spatiotemporal variations of the specific pollution-sensitivity index (A) and the diatom trophic index (B) of the waters of the Bandama River.

4. Discussion

The understanding of the ecological health of the waters of the Bandama River through the calculation of the IPS and TDI indices reveals a water quality below the average. The TDI results indicated that river trophic level varied from oligo-mesotrophic to mesotrophic, both spatially and temporally based on classes defined by Kelly [19]. Concerning the IPS index, the results indicate a moderate pollution to raise both on the spatial and temporal scale according to the classes defined by Descy [18]. The moderate organic pollution determined at station S1 would be due to factors such as external inputs and water mass of the lake. Indeed, this station located on the lake of the hydroelectric dam of Kossou is subject to the effects of domestic activities of the camps of fishermen. Thus, due to the large area of this lake, the concentration of organic pollution would tend to dilute. The dilution effect of organic pollution on the Great Lakes was also observed by Gao [20] in Dragon Lake in China and by Minor [21] in Baikal, Tanganyika, Superior, Malawi and Michigan highlighted this dilution effect of large lakes in organic pollution.

At the S6 station constituting the confluence of the Bandama rouge and the Bandama blanc, moderate organic pollution is explained by the mixing of the waters of these two branches of the river. According to Wang *et al*. [22], the mixing of water at the confluence leads to dilution or concentration of organic matter. Starting from the fact that the stations S2, S3, S4 and S4, upstream of the confluence presented a high organic pollution (poor water quality), we can deduct from the dilution effect of the organic pollution by the action of water mixing at the confluence. This result corroborates that of Yuan [23] .

Eutrophication of rivers results from the accumulation of nutrients in the environment. This phenomenon is the result of the effects of nutrients from intensive agriculture, discharges of domestic and industrial wastewater without prior treatment in the environment [24]. The mesotrophic state determined at station S4, seems to result from these accumulations. Indeed, although the other stations are subject to anthropogenic activities as mentioned above, the S4 station would also suffer the impact of an agro-food industry of its upstream plantations [25]. At the monthly level, the peaks in the IPS and TDI indices did not systematically coincide with the seasons. However, out of the eleven months of sampling, seven showed high organic pollution, which shows a constant aggression of the river at all times of the year. However, the trophic state oligo-mesotrophic determined in all months of sampling would attest to a remarkable resilience of the river waters which would be linked to the self-purifying power of microalgae when assimilating nutrients for their physiological functions inducing their decrease in the environment [26].

5. Conclusion

The study of the water quality of the Bandama River reveals a worrying situation that requires special attention. Diatomic indices, although varying in space and time, indicate below average water quality. Although the resilient capacity of the waters allowed to maintain an acceptable ecological level. It is imperative to put in place strategies for the sustainable management of water resources that will take into account the physico-chemical quality of water and the preservation of biodiversity in order to guarantee health security, and food to populations directly and indirectly dependent on the Bandama. This study highlights the importance of aquatic ecosystem monitoring and calls for cross-sectoral collaboration to implement effective solutions.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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