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Impact of Urban Waste on the Water Quality of the Ouladine Lagoon (Grand-Bassam, South-East of the Ivory Coast)

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Abstract: The economic explosion accompanied by poorly controlled demographic growth that the city of Grand-Bassam has experienced over the past decade is threatening the preservation of the Ouladine Lagoon due to the direct discharge of large volumes of wastewater. This study aims to evaluate the level of organic pollution in the waters of the Ouladine lagoon. Eight stations spread over the entire lagoon were studied. This study is based on the exploitation of data from the water sampling campaigns carried out. The data were processed using the Organic Pollution Index (OPI) to determine the organic pollution of the water. Principal Component Analysis (PCA) was applied to the data to highlight the phenomena causing water pollution. The results obtained show that the lagoon waters have a high degree of organic pollution overall. This high organic pollution of the lagoon waters is mainly related to the BOD5 load and phosphate ions. The potential causes and threats of pollution in the lagoon are multiple and are closely related to intense human activity. They mainly come from domestic and agricultural wastewater discharges. This assessment highlighted the risk that untreated discharges pose to this aquatic ecosystem and the negative impact on the promotion of ecotourism in the area.

Keywords: Organic Pollution, Wastewater, Physicochemistry, Ouladine Lagoon, Ivory Coast

1. Introduction

Population growth and industrial, tourism and agricultural development are the sources of pollution of the aquatic environment. This is particularly visible in developing countries where people are less aware of health risks [1]. The rapid expansion of industrial activities remains the main cause of direct discharges into water bodies. In addition to this, there are inputs due to bad weather and the effect of local activities such as fishing with chemical products, and the discharge of domestic wastewater, which accelerates the rate of pollution of the aquatic environment [2]. Indeed, this water loaded with pollutants infiltrates directly or indirectly into the surface waters and disturbs their natural balance [3]. This has led to the degradation of the aquatic environment and has caused negative effects on the ecosystem and human life [4]. Coastal lagoons are among the most productive ecosystems in the world. In recent years, human activity around coastal lagoons has increased dramatically, and the impact on these lagoon environments has become a concern in all coastal cities around the world [5]. Given the important role that lagoons play for the surrounding populations, and their highly productive and sensitive nature compared to other natural habitats, society is becoming increasingly concerned about the need to protect and manage coastal lagoons in an integrated and sustainable manner [6]. Located in the town of Grand-Bassam, the Ouladine lagoon is experiencing a worrying deterioration of its waters due to poorly controlled anthropogenic inputs. This lagoon is the receptacle of untreated urban effluents from the town of Grand-Bassam due to the lack of sanitation infrastructures. These inputs are not without danger for the beings living there and the proper functioning of this hydrosystem. The present study aims to assess the degree of organic pollution of the waters of the Ouladine lagoon under the influence of wastewater discharges from Grand-Bassam town. To provide basic information that could be used in the monitoring of the quality of the lagoon environment of this city.

2. Materials and Methods

2.1. Presentation of the Study Area

The Ouladine lagoon is in the southeast of Côte d'Ivoire, at the eastern end of the Ebrié lagoon, with an area of 4.25 km^2 [7]. Oriented west-east, it runs parallel to the barrier beach for a length of 10 km and is influenced by the Comoé River. With its powerful flushing currents, the river opened and passed through the barrier during its long migration between 1845 and 1954 [8]. Traces of this are still visible, such as the hook in the sandy barrier near the village of Azuretti and at the western end of the lagoon [7]. The Ouladine lagoon is limited to the south by the Atlantic Ocean, from which it is separated by a sandy barrier of width varying between 110 and 545 meters. The Ouladine lagoon is in the central zone of the sedimentary basin where one observes, from north to south, the Mio -pliocene to quater y formations. The Mio-pliocene sandy-clay plateaus of the Terminal Continental in the North, dominate the clayey sands of the ante-holocene lowlands which are relayed in the South by the fluvio-lagunar mud and leached sands.

2.2. Sampling Method

The measurement and sampling campaigns were carried out at eight (08) stations spread over the entire lagoon “Figure 1”. The choice of stations was made to obtain good spatial coverage and considered the domestic activities around the water body. The water samples were collected in one-liter polyethylene bottles, which were rinsed three times with the water to be sampled. All the bottles were filled to the brim and sealed, then stored in a cooler to maintain the temperature at 4°C before being sent to the analysis laboratory.

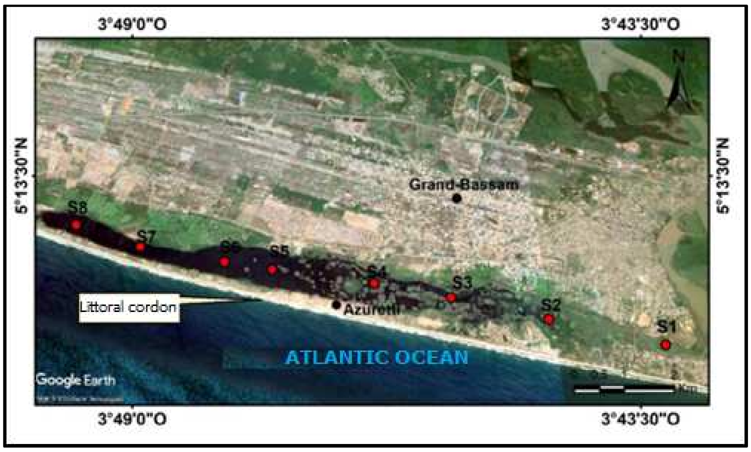

Figure 1. *Location of sampling stations.*

2.3. Analysis Methods

The measurements of some parameters were carried out in situ using a multi-parameter HANNA HI 9828. These are Temperature (T), Hydrogen potential (pH), Electrical conductivity (EC), Redox potential (ORT) and Dissolved oxygen (DO). Other parameters such as BOD5, COD and TSS were measured in the field with a Pastel UV - Secomam portable multiparameter spectrophotometer. In the laboratory, NO_2, NO_3, NH_4, SO_4 and PO_4 were analyzed using a UV-1700 PHARMASPEC spectrometer. The different parameters were analyzed in the laboratory according to the standards [9].

2.4. Data Processing

2.4.1. Statistical Analysis

The physico-chemical parameters were subjected to a simple statistical analysis for better exploitation of the data. Descriptive statistical analysis made by Microsoft Excel software has been used for the calculation of the minimum, maximum, average and standard deviation of each parameter studied. The Principal Component Analysis (PCA) was used to know the typology of the waters of the Ouladine lagoon. The analyses concerned 13 physico-chemical and chemical parameters. The data were processed using XLSTAT Trial software.

2.4.2. Assessment of Organic Pollution

To determine the degree of pollution of the lagoon water, the organic pollution index (OPI) was used. The data processing method based on the organic pollution index was first proposed by Leclercq and Maquet [10]. This index makes it possible to evaluate the chemical quality of the water impacted by organic pollution. Four physico-chemical parameters were used as a basis for this method: BOD5, ammonium, nitrites, and orthophosphates. The principle of the OPI is to divide the values of the pollutants into 5 classes (Table 1) and then determine, from one's measurements, the corresponding class number for each parameter and then take the average [11]. In other words, the SOP is determined by averaging the class numbers for each parameter according to equation (1) [12].

$$IPO = \sum \left(\frac{Ck,.....Ci}{n}\right) i, k \neq 0 \quad (1)$$

With C: the class number of the parameter and n: the number of parameters analyzed.

Table 1. *Organic Pollution Index (OPI) classes [10].*

Parameters Class	BOD5 (mg/L)	Ammonium (mg/L)	Nitrite (µg/L)	Phosphates (µg/L)
Class 5	< 2	< 0,1	5	15
Class 4	2 -5	0.1 -0.9	6 -10	16 -75
Class 3	5.1 -10	1 -2.4	11 -50	76 -250
Class 2	10.1 -15	2.5 -6	51 -150	251 -900
Class 1	> 15	> 6	>150	> 900

BOD: Biological Oxygen Demand.

The values obtained are classified into 5 levels (colors) of pollution corresponding to degrees of organic pollution (Table 2).

Table 2. *Class average and organic pollution characterization [10].*

Classes	Class average	Degree of pollution Organic
Classe 5	5.0 -4.6	Nil
Classe 4	4.5 -4.0	Low
Classe 3	3.9 -3.0	Moderate
Classe 2	2.9 -2.0	Strong
Classe 1	1.9 -1.0	Very high

3. Results

3.1. Physico-chemical Characteristics of the Lagoon Water

The results of the analyses of the physico-chemical parameters of the waters of the Ouladine lagoon compared to the JORF standards [13] are recorded in Table 3.

Table 3. *Descriptive statistics of physico-chemical parameters of the lagoon water.*

Variable	Min.	Max.	Average	Standard Deviation	Standard JORF [13]
T°C	30.90	35.62	32.42	1.46	25
Ph	8.50	9.33	8.82	0.28	6.5 – 8.5
DO (mg/L)	0.77	1.20	0.93	0.12	> 5
EC (µS/cm)	2028.0	5666.0	4162.9	1377.7	1100
ORT (mV)	-513.2	-91.7	-272.6	177.82	-
NO_2 (mg/L)	0.01	0.07	0.04	0.03	-
NO_3 (mg/L)	4.20	25.50	9.91	8.47	50
NH_4 (mg/L)	0.16	0.46	0.30	0.11	4
PO_4 (mg/L)	0.34	1.55	0.91	0.44	0.7
SO_4 (mg/L)	47.21	836.52	248.27	265.42	250
BOD5 (mg/L)	12.60	24.30	16.64	4.01	< 3
COD (mg/L)	27.40	60.20	36.76	10.91	30
TSS (mg/L)	47.20	116.00	68.13	21.81	25

T: Temperature, DO: Dissolved Oxygen, EC: Electrical Conductivity, ORT: Redox potential, BOD: Biological Oxygen Demand, COD: chemical oxygen demand, TSS: Total suspended solids
Min: minimum, Max: maximum.

The results show that the temperature of the lagoon water remains warm and varies between 30.90 and 32.33°C. It does not comply with the standards for raw water used to produce water for human consumption. The pH remains alkaline, does not differ greatly between the sampling stations, and varies between 8.50 and 9.33. These pH values exceed the required standard. The waters of the lagoon are highly mineralized with an electrical conductivity that varies between 2028 and 5666µS/cm. The concentration of dissolved oxygen OD remains low during the sampling period, with a minimum value of 0.77 mg/L and a maximum value of 1.20 mg/L. For Nitrite and Ammonium, the results vary from 0.01 to 0.04 mg/L and from 0.16 to 0.46 mg/L respectively. These nitrite and ammonium levels remain low over the extent of the water body and comply with the required standards. Phosphate levels in the lagoon water are above the standards (0.7 mg/L) at some sampling points. The levels vary between 0.34 and 1.55 mg/L. The organic loads (BOD5 and COD) of the lagoon water are higher than the standards, which are respectively 30 mg/L for COD and 3 mg/L for BOD. The lagoon water is very high in suspended solids with concentrations varying between 47.20 and 116.00 mg/L. These loads of suspended solids are higher than the required standard, which is 25 mg/L.

3.2. Principal Component Analysis (PCA)

The principal component analysis (PCA) shows that the distribution of the parameters in planes F1-F2 “Figure 2” corresponds to a good structuring that allows the discrimination of the lagoon waters. The analysis of the figure shows that the F1 axis represents 35.48% of the variance expressed and is determined in its positive part by the variables: NO_2^- and DO. Its negative part is determined by the variables: NO_3, PO_4, SO_4, T and ORT. These nutrient salts would come from the use of fertilizers, pesticides and the decomposition of organic matter which would have arrived in the lagoon by runoff. As for NO_2 ions, they are very unstable nitrogen compounds and result from the transformation of NO_3. This reaction explains the fact that NO_3 and NO_2 are opposed in the community circle. The F1 factor alone highlights two phenomena, namely anthropogenic inputs of substances of agricultural origin and denitrification.

The F2 axis represents 31.92% of the variance and is determined in its positive part by the variables: BOD5, SS and COD. The TSS would have been loaded with COD and BOD5 which are the elements representative of the household wastewater input. These elements come from the input of wastewater runoff from the city to the Ouladine lagoon. Its negative part is determined by the variables: EC and pH. The mechanism described here is the concentration of water by chloride salts. Indeed, the arrival of lagoon water loaded with ionized salts increases pH and conductivity. The F2 factor expresses two phenomena, namely the inflow of wastewater from the town of Grand-Bassam and saline intrusion.

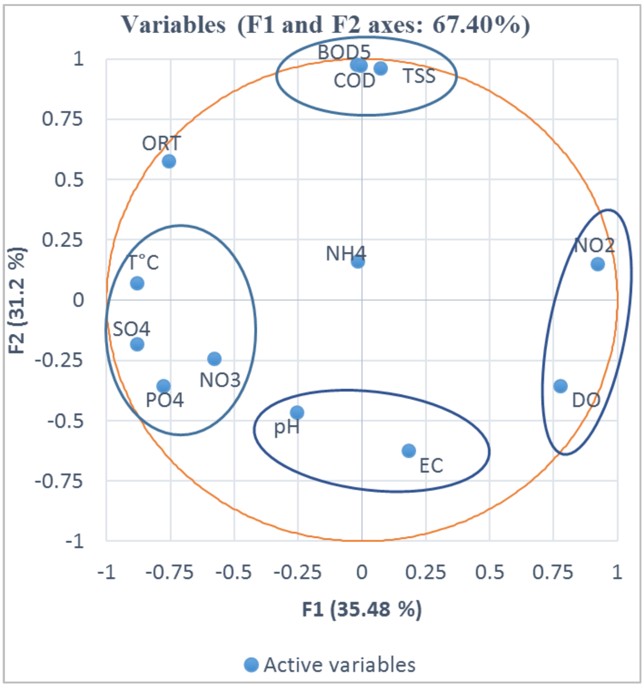

Figure 2. Community circle of the F1-F2 factorial plane.

3.3. Water Quality of the Ouladine Lagoon

The Organic Pollution Index OPI was calculated using the results of the analyses of the pollution indicator parameters (NO_2^-, NH_4^+, BOD5 and PO_4^{3-}). The calculated values of the Organic Pollution Index of the waters obtained for the eight (08) sampling stations are recorded in Table 4.

Table 4. Degree of organic pollution of the waters of the Ouladine lagoon.

Stations	IPO	Degree of organic pollution
S1	2.75	Heavy organic pollution
S2	2.75	Heavy organic pollution
S3	2.75	Heavy organic pollution
S4	2.5	Heavy organic pollution
S5	2.5	Heavy organic pollution
S6	2.5	Heavy organic pollution
S7	2.75	Heavy organic pollution
S8	2.75	Heavy organic pollution

The lagoon waters analysed are characterized by a high degree of organic pollution throughout the water body ($2.5<OPI<2.75$). This high organic pollution is linked to the high BOD5 load in the lagoon waters and the phosphate concentrations exceeding the standards required for raw water intended for drinking water production. It can be noted that this degradation of the lagoon's waters is mainly caused by the city's wastewater, which is discharged directly into the lagoon. This wastewater is the primary cause of pollution of this water resource.

4. Discussion

To study the level of water pollution in different stations of the Ouladine lagoon, eight (08) stations were selected on the whole lagoon water body. The results of this study highlight the significant effect of urban wastewater discharges into the lagoon on the variability of physico-chemical parameters and water quality in the different sampling sites. The temperatures of these waters remain warm (T >30°C) throughout the study period and at all sampling points. The temperatures of the lagoon water are influenced by climatic conditions, but also by the discharge of urban wastewater from the town of Grand-Bassam [14]. These high temperatures favour oxidation reactions of nitrogen derivatives (NH_4^+, NO_2^-) leading to a decrease in the dissolved oxygen rate [15]. The waters of the lagoon are alkaline (pH>8) at all the study stations. This alkalinity can be explained by the intrusion of marine water into the lagoon. However, the origin of the increase in alkalinity is also linked to the discharge of urban wastewater rich in detergents and soap-based alkaline products, to wastewater from recreational activities, hospitals in the city and agricultural runoff (market gardeners) [16]. The conductivity values (>2028 µS/cm) show the high mineralization of the lagoon water. The increase in conductivity could be due to the concentration of mineral salts in the water through evaporation and the increase in alkalinity. The alkalinity itself would be due to saline intrusion during the high tide period. The other probable source of this high mineralization is the discharge of urban wastewater into the lagoon without prior treatment. These discharges of urban wastewater will drain ionic loads which are the cause of the rise in conductivity [17]. The waters of the lagoon are less oxygenated with an average value of 0.93 mg/L. The low dissolved oxygen content of the lagoon water can be attributed to the high temperatures observed. This is because the evolution of water temperature is inversely correlated to that of dissolved oxygen. Thus, cold waters contain a greater quantity of dissolved oxygen than warm waters [18]. This low oxygenation of the lagoon water could be because of high loads of organic matter brought into the lagoon by wastewater discharges with low photosynthetic activity [19]. Thus, the microorganisms will use dissolved oxygen to degrade this organic matter. This will make the environment anoxic, favouring anaerobic fermentation with the release of hydrogen sulfide, which is a source of foul odours [20]. In the absence of dissolved oxygen, the decomposition of the organic matter becomes very slow, and the oxidation-reduction potential (ORT) becomes very low or even negative, leading to a reducing environment characterized by denitrification and transformation of sulfates into hydrogen sulfide [21]. This situation is observed in the present study where negative values of redox potential are recorded with an average of -272.59 mV. These values of the redox potential (ORT) of the lagoon waters correspond to a strongly reducing and anoxic environment. In the water, nitrogen can be present in organic or inorganic form. Inorganic nitrogen, consisting of ammonium (NH_4^+), nitrite (NO_2^-) and nitrate (NO_3^-), constitutes a major part of the total nitrogen [22]. The nitrate content of the lagoon water remains low at all stations and ranges from 0.01 to 0.04 mg/L. These low nitrate levels could be explained by the rapid oxidation of nitrite to nitrate [23]. The presence of nitrate in surface waters is mainly related to either agricultural leaching or oxidative reactions of ammonia nitrogen and nitrite [24]. In the present study, the nitrate concentrations of the water at the various stations remain low with an average of 9.91 mg/L. These low nitrate levels are explained by the phenomenon of denitrification. Heterotrophic bacteria will cover their energy needs from nitrates when dissolved oxygen is lacking. The enrichment of the environment in oxidizable organic matter will lead to a decrease in the concentration of dissolved oxygen due to the use of oxygen for the aerobic decomposition of organic waste by microorganisms [25]. The ammonium content of the lagoon water is low with values between 0.16 and 0.46 mg/L. The low ammonium levels obtained are thought to be related to the basic nature of the lagoon water observed during the study. Under the effect of the alkalinity of the water, the ammonium (NH_4^+) would have volatilized in the form of NH_3 [26]. However, at the various stations, the ammonium content is higher than the nitrite content. This is the result of incomplete degradation of the organic matter, which has led to low nitrification of the water. The average values of phosphates show levels above the standards [13]. The high levels observed reflect a strong anthropization linked to wastewater discharges. Urban domestic waste (loaded with detergents) is discharged directly into the lagoon without treatment by the local population, and runoff from agricultural land (market gardening) leads to large variations in phosphate content [27]. The sulfate concentrations of the waters of the Ouladine lagoon vary between 47.21 and 836.52 mg/L with an average of 248.27 mg/L. These high sulfate levels recorded at certain stations are thought to be linked to the discharge of wastewater from the town of Grand-Bassam and to the leaching of neighbouring agricultural land (market gardening) which receives ammonium sulfate amendments [28]. The analysis of the community circle shows a grouping of nitrates, sulfate, and phosphates, thus expressing the common origin of these elements, which is the leaching of agricultural land (market gardening) close to the lagoon. Loads of suspended matter in the lagoon water are high at all the study stations with a minimum of 47.20 mg/L. These suspended solids loads are a consequence of urban wastewater discharges into the lagoon without prior treatment which brings debris, suspended particles, and disturbance to the bottom [29]. High levels of suspended solids in water can be caused by many environmental factors. These include soil erosion, waste discharge, runoff, or changes in ecological communities [30]. The COD values of the studied lagoon waters are varied with a minimum of 27.40 and a maximum of 60.20 mg/L. This result shows that the lagoon waters are highly loaded with biodegradable and non-biodegradable organic matter (COD). This situation could have negative effects on the water quality (drop in oxygen content) in general and on the aquatic ecosystem. The origins of this increase in COD in the lagoon water are due to the input of organic matter from the city's domestic wastewater discharged without prior treatment [31]. BOD is used to judge the presence of an organic load in a water body. It is a good indicator of whether a water body is in a eutrophic state. Higher BOD levels in a water body are associated with lower dissolved oxygen levels [32]. In the present case, BOD loads remain high at all study stations with a minimum of 12.37 mg/L above the standard [13]. Discharge of liquid wastewater with higher BOD results in water quality impairments such as lower DO and fish kills in receiving water bodies [32]. The BOD loads observed in the present case are due respectively to the presence of domestic sewage and poorly managed household waste from the city that ends up in Ouladine by runoff following storm events. Finally, a domestic source, characterized by water rich in COD and BOD from domestic wastewater sources of pollution has been made by several authors on some lagoon systems under anthropic pressures [33]. In the lagoon. The grouping (TSS, COD and BOD5) on the community circle expresses the community origin of these three elements or the existing links between them. The suspended solids contained in the city's domestic wastewater would have been loaded with COD and BOD5. This is confirmed by the organic pollution index (OPI) used in this study to assess the organic load of the lagoon. The calculated OPI indices showed that the lagoon waters have a high degree of organic pollution overall. This high organic pollution of the lagoon waters is mainly related to the BOD5 load and phosphate concentrations. This result expresses a double origin of the polluting sources of the Ouladine lagoon. An agricultural source characterized by the richness of phosphate ions found mainly in the agricultural fertilizers that are found in the lagoon by runoff following stormy events. Finally, a domestic source, characterized by water rich in COD and BOD from the city's domestic wastewater discharged into the lagoon without prior treatment. These observations on the origins of pollution sources have been made by several authors on certain lagoon systems under anthropic pressure [34].

5. Conclusion

The results obtained in this work made it possible to determine the level of organic pollution in the waters of the Ouladine lagoon. The quality of the water in the Ouladine lagoon has deteriorated significantly, limiting its real water potential, and leading to significant health and ecological impacts. Urban wastewater and the use of agricultural chemicals discharged into the lagoon without appropriate treatment are the main sources of the degradation of its water quality. The monitoring of the organic pollution index (OPI) of the waters during this study shows that the waters of the lagoon are of very poor quality with high organic pollution (OPI). This organic pollution of the lagoon water is due to very high levels of certain physico-chemical parameters (phosphates and BOD5) that exceed the norms and are directly related to the discharge of untreated wastewater from the domestic activities of the town of Grand-Bassam and, to a lesser degree, to the phosphate fertilizers used in agriculture by the market gardeners around the lagoon. The level of organic pollution and the high levels of the parameters studied underline the urgency of reducing the discharge of pollutants into this environment by treating the wastewater from the town of Grand-Bassam, which would avoid problems of public health and the disappearance of fishery resources.

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