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ASSESSING THE ENVIRONMENTAL QUALITY OF THE WATERS OF AN ESTUARINE BAY : THE CASE OF BINGERVILLE BAY (COTE D'IVOIRE)

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Abstract : Bays are sediment deposition environments in which the depth of the water column tends to decrease due to the numerous deposits of sediment from wastewater and run-off. Anthropogenic activity has a negative impact through pollution and changes to the hydrology of this environment. This pollution is linked to a number of anthropogenic factors, such as domestic wastewater discharges, industrial discharges from ships, human waste and run-off, etc. These various forms of pollution have a negative impact on the waters of the bays of the Ebrié Lagoon, often leading to the disappearance and death of several aquatic species. Studying this pollution using the various physico-chemical parameters will make a beneficial contribution to solving the pollution problem encountered in this aquatic ecosystem. This research work has therefore made it possible to assess the environmental quality of the aquatic system in Bingerville Bay. Hydrochemistry was used to determine the level of pollution by producing several diagrams of temporal variations in hydrochemical parameters at depth (water column). These different variations in the water column will make it possible to determine the degree of pollution linked to the various physico-chemical parameters.

Indexterms- physico-chemical parameters, quality, pollution, Bingerville Bay, Côte d'Ivoire

1. INTRODUCTION

Located in West Africa, Côte d'Ivoire has a lagoon system that runs parallel to the shore of the Gulf of Guinea between 2°50' and 5°25' west longitude over almost 300 km, with a total surface area of 1.200 km^2 (Tastet, 1994). It is made up of three main lagoons running from west to east : the Grand-Lahou lagoon, the Ebrié lagoon and the Aby lagoon (Ettien, 2010). They are linked by artificial canals (Varlet, 1978). A bay is an indentation in the coastline that extends into the mainland. It is a receiving environment (deposition environment) for dissolved, solid and suspended matter. The Ebrié lagoon contains numerous bays located in the estuarine environment. It is bounded to the west by the bay of Adiopo-Doumé and to the east by that of Bingerville. Given these economic activities, the Ebrié lagoon is subject to numerous anthropogenic pressures. These human activities (fishing, sand extraction, discharge of domestic and industrial wastewater) are the subject of a number of forms of pollution (pollution linked to domestic waste, pollution linked to industrial chemical waste, pollution linked to wastewater from ships and run-off water, etc.) which tend to alter the quality of the water in the various bays. These bays are the main outlet for wastewater and solid waste drained by the city of Abidjan's drainage system (Coulibaly et al., 2010 ; Diangoné et al., 2014). All this pollution is deteriorating the quality of the water resources in this aquatic system. Managing and protecting this environment is of particular interest in this study. In order to solve this pollution problem, the main objective will be to assess the environmental quality of water resources in Bingerville Bay using hydrochemical parameters. In view of the significant deterioration of the lagoons, we will determine the level of pollution of the physico-chemical parameters by means of time variation diagrams at depth (water column). The data recorded in the water column will then be statistically analysed. The levels of the parameters will be compared with WHO standards in order to determine the potability status of the water resources in Bingerville Bay and to protect the lagoon environment from any form of contamination. Finally, to analyse the various hydrological changes linked to the pollution of physico-chemical parameters in the bays as a result of various human activities.

2. RESEARCH METHODOLOGY

2.1. Study area

Bingerville Bay lies to the west of Bingerville and to the east of Abatta and Akouedo. It lies between longitudes 398912 m and 401216 m and latitudes 589482 m and 591790 m (UTM coordinates). It is located in the Ebrié lagoon on the north bank and covers an area of 2.59 km^2 (Figure 1).

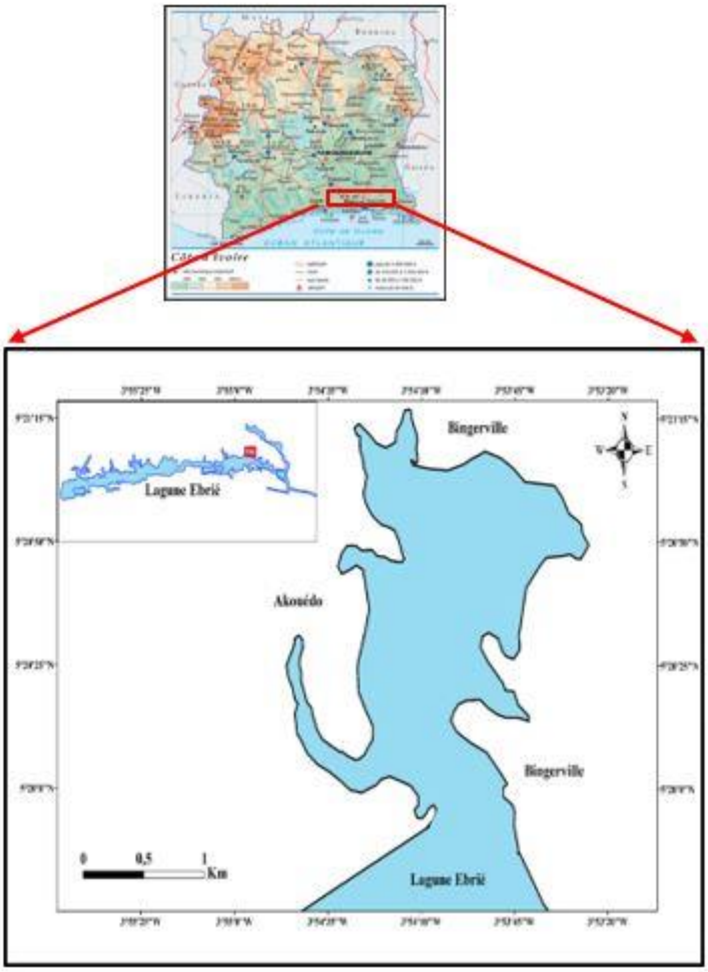

Figure 1 : Location of Bingerville Bay

2.2 Materials and methods

A sampling campaign organised in May 2018 made it possible to take several surface and bottom water samples in Bingerville Bay using a Niskin bottle. The geographical coordinates of the five (5) water sampling stations were determined by a Gamin model GPS. The coordinates of the various water sampling stations and the outline of the bay will be integrated into Arcgis software and used to produce the spatial distribution map of the sampling stations (Figure 2). These water samples are sent to the CRO (Oceanological Research Centre) for analysis to determine the levels of suspended solids. The PCA (principal component analysis) study was carried out on the five (5) sampling stations, bringing together a total of ten (10) water samples, including five (5) from depth and surface. The concentrations of physico-chemical parameters, also known as hydrochemical parameters, were measured using a HACH HQ40D multiparameter and a Secchi disk. These included pH, conductivity, temperature, total dissolved solids, suspended solids, transparency, oxidation-reduction potential and dissolved oxygen. The results of the PCA are represented by the table of eigenvalues, the matrix and the correlation circle using STATISTICA software. All these concentrations will be compared with the WHO (2011) in order to assess water quality.

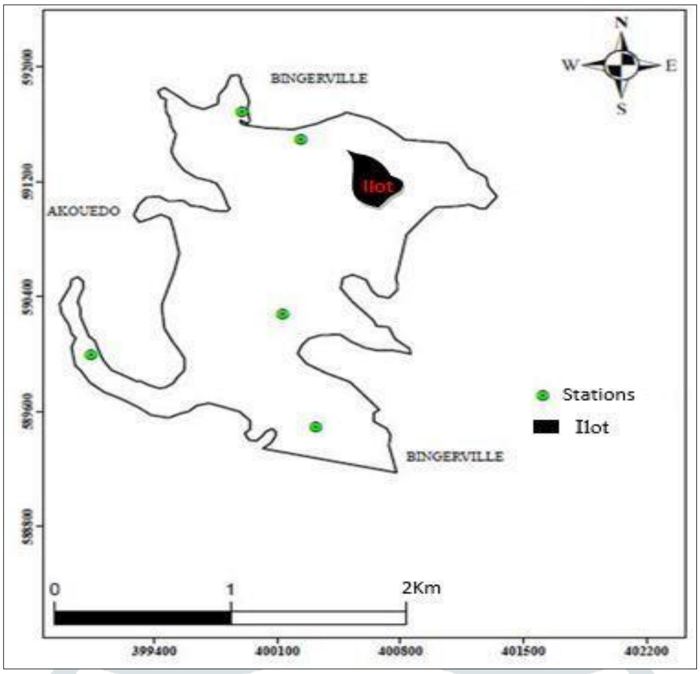

Figure 2 : Hydrological network stations in Bingerville Bay

3. RESULTS AND DISCUSSION

3.1 Evolution of hydrochemical parameters in Bingerville Bay.

This chapter will characterise the physico-chemical parameters at the surface and in the water column. This study will be carried out at three (3) stations, given that the depth did not exceed 2 (two) metres out of the five (5) water sampling stations.

3.1.1. Variation in pH

The various pH measurements are presented in Table I. The pH varies between 6.8 and 7.3. The surface waters of Bingerville Bay have an average pH of 7.2. This water is not acidic but basic. However, the pH value of deep waters varies between 7.2 and 7.3.

Table I : pH measurements at various stations in Bingerville Bay

Stations		**Station1**	**Station2**	**Station3**	**Station4**	**Station5**
Longitude		400318	399041	399897	400130	400234
Latitude		589495	589995	591684	590281	591493
pH	**Surface water (*)**	7.2	6.8	7.2	7.3	6.9
	Ground water(**)	7.2	-	-	7.3	7.2

Depth : (*) =0,5m ; (**) =2m

The pH does not vary ; it is the same at station 1 and 4 deep in the water column. There is no current . The environment is relatively calm and not agitated. At station 5, on the other hand, there is a variation in pH in the water column, precisely at depth, reflecting the presence of currents and an agitated environment. This variation in pH is linked to human activity (sewage run-off, etc.) and the various marine currents. Surface pH and pH at depth are regulated by anthropogenic marine activity. Anthropogenic activity plays a harmful role and disturbs the lagoon environment.

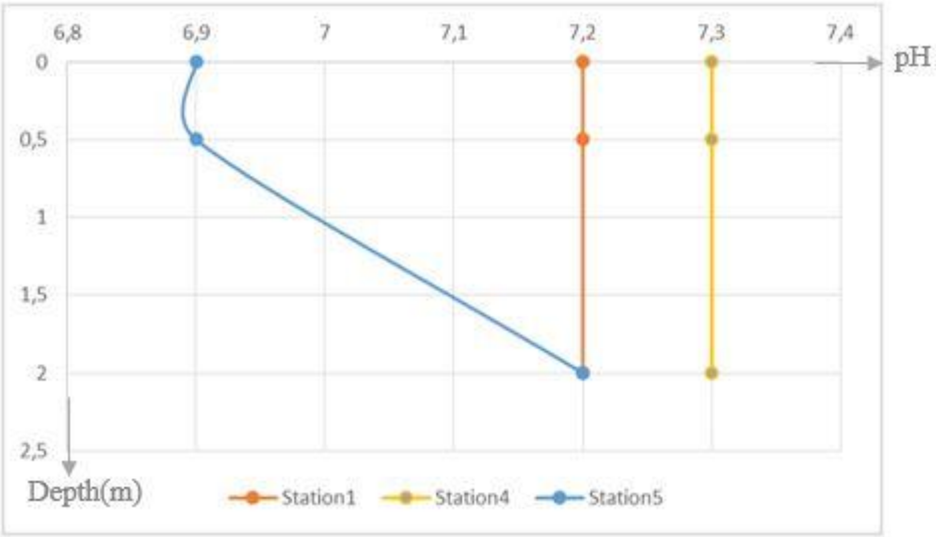

Figure 3 : Variation in pH at depth in Bingerville Bay

3.1.2. Temperature variation (T °c)

The temperatures measured are recorded in Table II. Temperatures vary between 26°C and 27.5°C with an average of 26.7°C. The thermal difference is 1.5°C. The maximum value was recorded at station 2. Station 5 has the lowest value.

Table II : Temperature values for the various stations in Bingerville Bay.

Stations		**Station1**	**Station2**	**Station3**	**Station4**	**Station5**
Longitude		400318	399041	399897	400130	400234
Latitude		589495	589995	591684	590281	591493
T° c	**Surface water (*)**	26.7	27.5	26.9	26.9	26
	Ground water (**)	26.7	-	-	26.6	26.7

Depth : (*) =0,5m ; (**) =2m

At station 1, the surface and deep water temperatures do not vary. It is the same throughout the water column, reflecting the absence of currents and a calm environment. The temperature remains constant at the surface at stations 4 and 5. In the bottom waters, this parameter varies, indicating the presence of a current in a relatively turbulent environment. The currents at this level are very strong and meet in places. The current at station 4 meets the other currents and that at station 5 meets that at station 1. The variation in this parameter is very significant at station 5 and station 4.

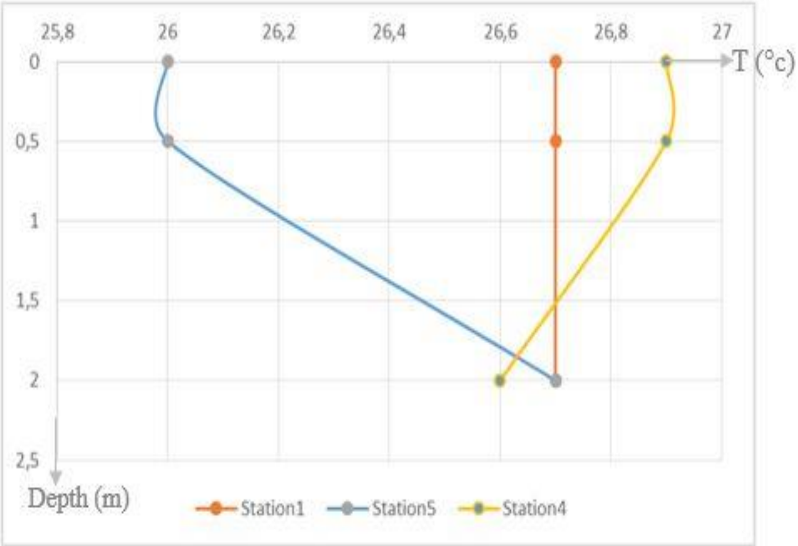

Figure 4 : Variation in temperature at depth in Bingerville Bay

3.1.3. Conductivity of Bingerville Bay

Table III shows the conductivity concentrations measured in Bingerville Bay. The average conductivity of surface water is 3730 us/cm. However, for deep waters, it is 2662 us/cm. The maximum and minimum conductivities are 5990 and 2360 us/cm respectively. The standard deviation is 950 us/cm.

Table III : Conductivity concentrations at stations in Bingerville Bay

Stations		Station1	Station2	Station3	Station4	Station5
Longitude		400318	399041	399897	400130	400234
Latitude		589495	589995	591684	590281	591493
Conductivity	Surface water (*)	4540	3730	2360	3790	2380
	Ground water (**)	4430	-	-	5990	2890

Depth : (*) =0,5m ; (**) =2m

The variation in surface conductivity was the same at all three (3) stations in the water column. At depth, there was a slight variation in conductivity at stations 1 and 5. However, this variation is very strong at station 4, reflecting a strong current. The currents at stations 1 and 4 are in the same direction and are weak. The current at station 4 meets the current at station 1. This is a very turbulent environment and the currents are the same. The variation in conductivity is very high at station 4.

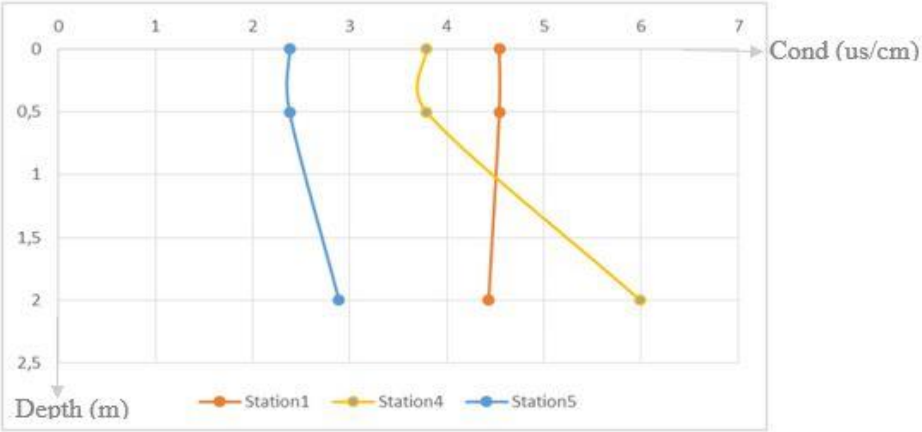

Figure 5 : Variation in conductivity at depth in Bingerville Bay

3.1.4. Variation in dissolved oxygen (DO)

The minimum value of dissolved oxygen measured was 5.61 mg/l. On the other hand, it has a maximum value of 7.16 mg/l and an average of 6.37 mg/l. The standard deviation is 0.55mg/l at the surface. All these levels are recorded in Table IV.

Table IV : Dissolved oxygen (DO) values in Bingerville Bay

Stations		**Station1**	**Station2**	**Station3**	**Station4**	**Station5**
Longitude		400318	399041	399897	400130	400234
Latitude		589495	589995	591684	590281	591493
OD	**Surface water (*)**	5.97	5.61	6.77	6.87	6.63
	Ground water (**)	6.74	-	-	6.12	7.16

Depth : (*) =0,5m ; (**) =2m

At the surface, dissolved oxygen is stable at all three stations. At depth, a variation in the parameter was observed at all three stations, resulting in a current. These currents flow in opposite directions. The current at stations 1 and 5 opposes that at station 5. The place where the currents from station 4, station 1 and station 5 meet is a very agitated place where the current is gyratory. This is a very turbulent environment with strong currents. The variation in oxygen in Bingerville Bay reflects heterogeneity.

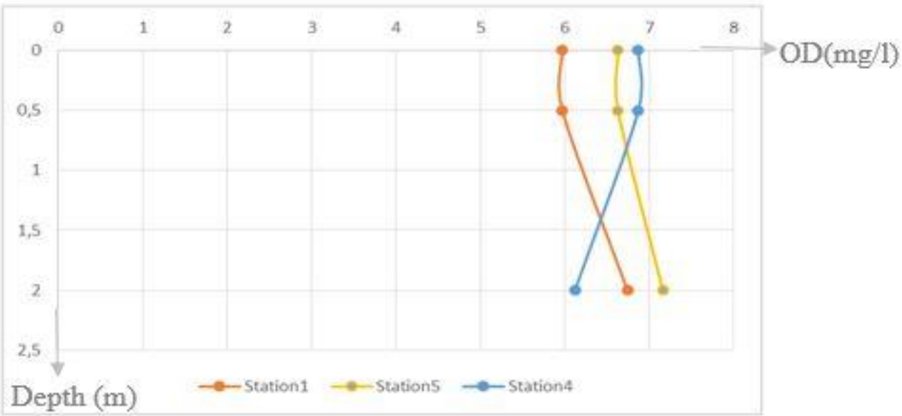

Figure 6 : Variation in dissolved oxygen at depth in Bingerville Bay

3.1.5. Variation in redox potential (ORP)

Table V shows the minimum and maximum ORP values. They are -48.6 and -19.3 mV respectively. The mean value for surface water is 34.04 mV. The standard deviation is 12.19 mV.

Table V : ORP values for the various stations in Bingerville Bay.

Stations		Station1	Station2	Station3	Station4	Station5
Longitude		400318	399041	399897	400130	400234
Latitude		589495	589995	591684	590281	591493
ORP	Surface water (*)	-39.5	-19.3	-39.2	-48.6	-23.6
	Ground water (**)	-43.7	-	-	-47.2	-41.4

Depth : (*) =0,5m ; (**) =2m

At the surface and at depth, the ORP value is not the same. The variation in ORP at the surface is constant (stable). At depth, however, there is a slight variation in this parameter at stations 1 and 4, indicating a weak current. At station 4 this variation is strong, indicating that the current at this level is strong. The environment is therefore agitated.

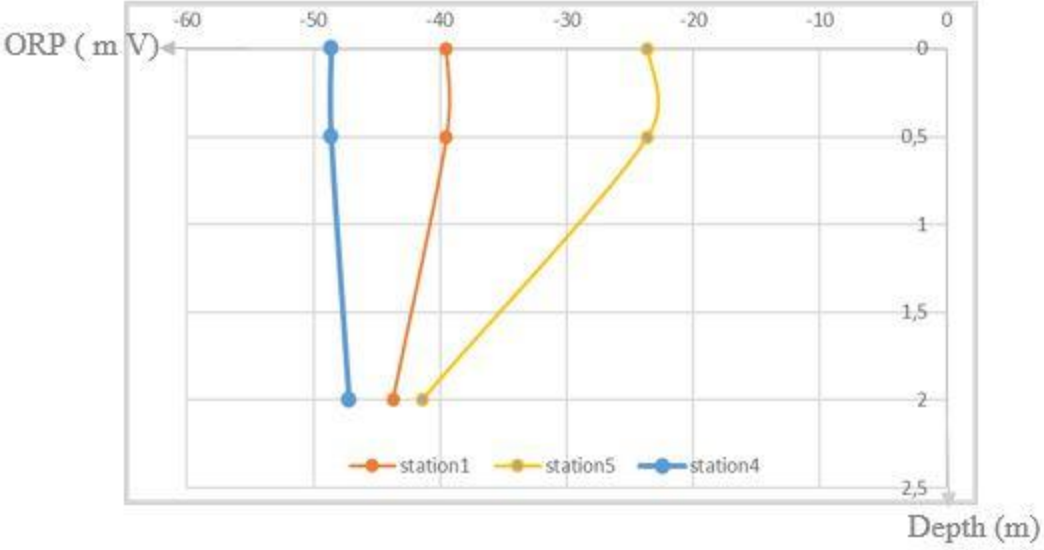

Figure 7 : Variation in ORP at depth in Bingerville Bay

3.1.6. Total dissolved solids (TDS) in Bingerville Bay

The dissolved solids content (TDS) shows minimum and maximum levels of 1.18 and 2.99g/l respectively in Table VI. The average content of surface water is 1.67g/l. The standard deviation is 0.47g/l.

Table VI : TDS values for the various stations in Bingerville Bay.

Stations		Station1	Station2	Station3	Station4	Station5
Longitude		400318	399041	399897	400130	400234
Latitude		589495	589995	591684	590281	591493
TDS	Surface water (*)	2.27	1.86	1.18	1.89	1.19
	Ground water (**)	2.22	-	-	2.99	1.45

Depth : (*) =0,5m ; (**) =2m

The variation in the TDS parameter at the surface is constant. It is the same at all three (3) stations. When we are in the bottom waters of Bingerville Bay, this parameter tends to vary. This variation is due to the current. The current is weak at stations 5 and 1, but strong at station 4. The currents at stations 4 and 1 meet at a very specific point, which indicates that the current is the same at that point. This is a turbulent and very agitated environment in which the variation in the hydrological parameter is very significant in Bingerville Bay.

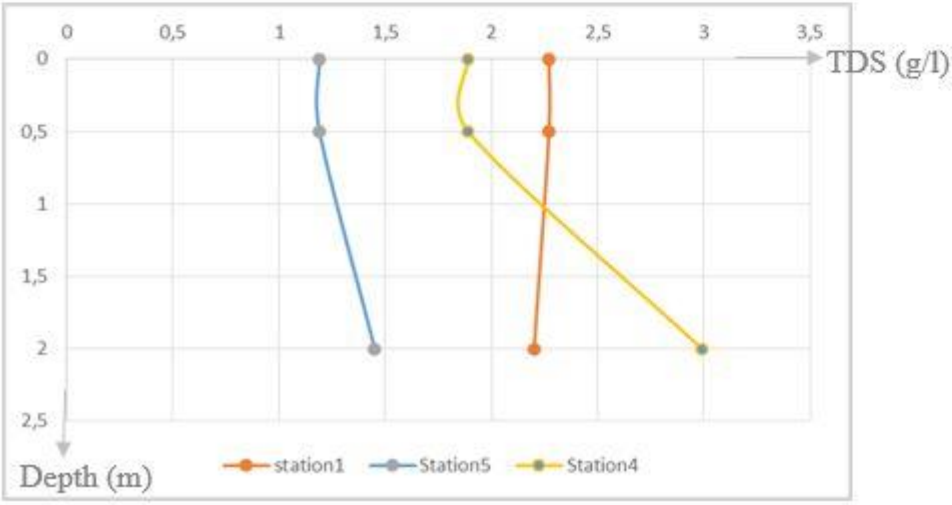

Figure 8 : Variation in TDS at depth in Bingerville Bay

3.1.7 Suspended solids (SS) in Bingerville Bay.

Table VII shows the TSS values. The levels vary between 8 and 16 mg/l. The average concentration in surface water is 8.8 mg/l. The standard deviation is 1.78 mg/l.

Table VII : TSS values for the various stations in Bingerville Bay.

Stations		Station1	Station2	Station3	Station4	Station5
Longitude		400318	399041	399897	400130	400234
Latitude		589495	589995	591684	590281	591493
MES	Surface water (*)	8	8	8	8	12
	Ground water(**)	8	-	-	12	16

Depth : (*) =0,5m ; (**) =2m

At station 1 in the water column the variation in suspended matter is the same, it is constant both at the surface and at depth. There is no current in the water column to influence the variation of this parameter at this level. The environment is calm. At stations 4 and 5, there is a large variation in suspended matter, which is reflected in a strong current in the same direction (from left to right). This is a very agitated environment in which the suspended solids move with the current in the waters of Bingerville Bay.

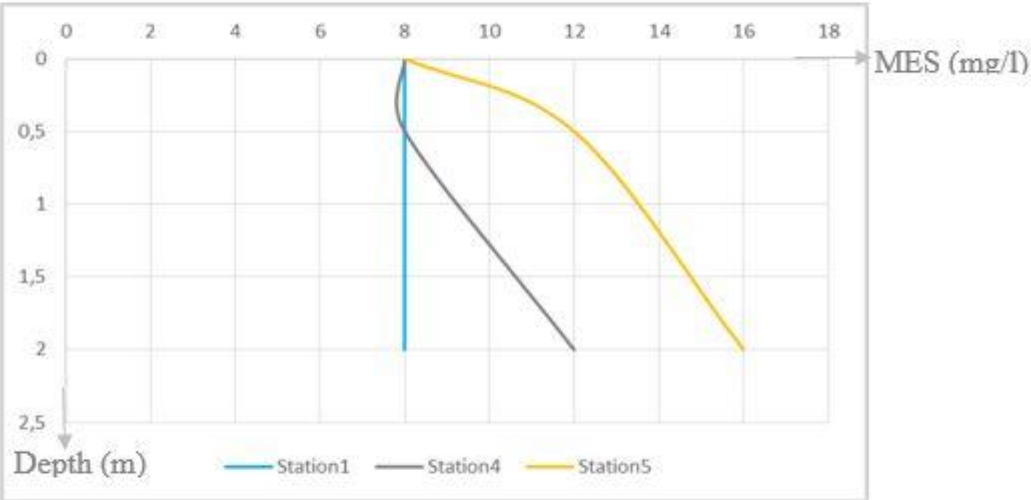

Figure 9 : Variation in TSS at depth in Bingerville Bay

3.2. Statistical analysis of hydrochemical parameters

3.2.1. Correlation between variables

The correlation between two variables shows the relationship that exists between the variables observed in Table II, known as the correlation matrix. After analysis, this table shows a good correlation between transparency and dissolved oxygen (0.92), conductivity and TDS (0.99), transparency and pH (0.63), which are interactions between these variables. This interdependence can be explained by origin or a similar process that regulates the development of hydrochemical parameters in the aquatic ecosystem. The negative values observed between transparency and T (-0.71), between transparency and ORP (-0.61), between pH and ORP (-0.99), between T and TSS (-0.83) reflect inverse interactions called good anti-correlation. These hydrochemical variables have a different factorial design. They do not also have the same mechanism that determines their development in the aquatic environment (Table VIII).

Table VIII : Variable correlation matrix

	Transparence	TDS	PH	T	Conductivity	OD	ORP	MES
Transparence	1.00							
TDS	-0.43	1.00						
pH	0.63	0.22	1.00					
T	-0.71	0.41	-0.06	1.00				
Conductivity	-0.43	0.99	0.22	0.42	1.00			
OD	0.92	-0.56	0.57	-0.51	-0.56	1.00		
ORP	-0.61	-0.26	-0.99	0.02	-0.26	-0.58	1.00	
MES	0.33	-0.57	-0.46	-0.83	-0.57	0.26	0.41	1.00

3.2.2. Proportions of factorials

Table IX shows precisely the maximum statistical information through the observed eigenvalues based on the estimation of the quantity of the factorials. Observation of this table highlights the factorials F1 and F2 expressing 74.52% and 19.24% of the variance expressed. However, in terms of cumulative variance, they account for 93.77%. Based on these data, the statistical information generated by these two factorials is estimated at 93.77%. The analysis of the different factorial designs of our principal component analysis (PCA) will therefore focus on these two factorials.

Table IX : Proportion (%) of factorials

	F1	F2	F3	F4	F5	F6
Eigenvalues	5.96	1.53	0.30	0.18	0.01	0.00
%Variance expressed	74.52	19.24	3.75	2.31	0.15	0.00
%Cumulative variance	74.52	93.77	97.52	99.84	99.99	100.00

3.2.3. F1-F2 factorial design

The F1 factorial, which has a proportion of more than 74.52%, is made up of two (2) poles. A maximum number of variables are projected onto axis 1 (horizontal axis). It is determined by conductivity, TDS, transparency, pH, dissolved oxygen, temperature and TSS. The concentrations of conductivity, TDS, pH, transparency, TSS and temperature appear on the positive pole. However, the oxidation-reduction potential (ORP) appears on the negative pole. These different physico-chemical parameters are characterised by the same origin and a similar phenomenon (Figure 10).

Factorial F2, which consists of a single pole, expresses a proportion of 19.24%. On axis 2 (vertical axis), on the positive side, the ORP appears, with variations of various origins. These include variations in pH and dissolved oxygen. The variation in the oxidation-reduction potential can be explained by the influence of the pH on the oxygen present in the water. When the oxygen content is low, the pH is high, which means that the environment is basic. Factor 2 could therefore reflect an environment favourable to the growth of aquatic organisms and plants.

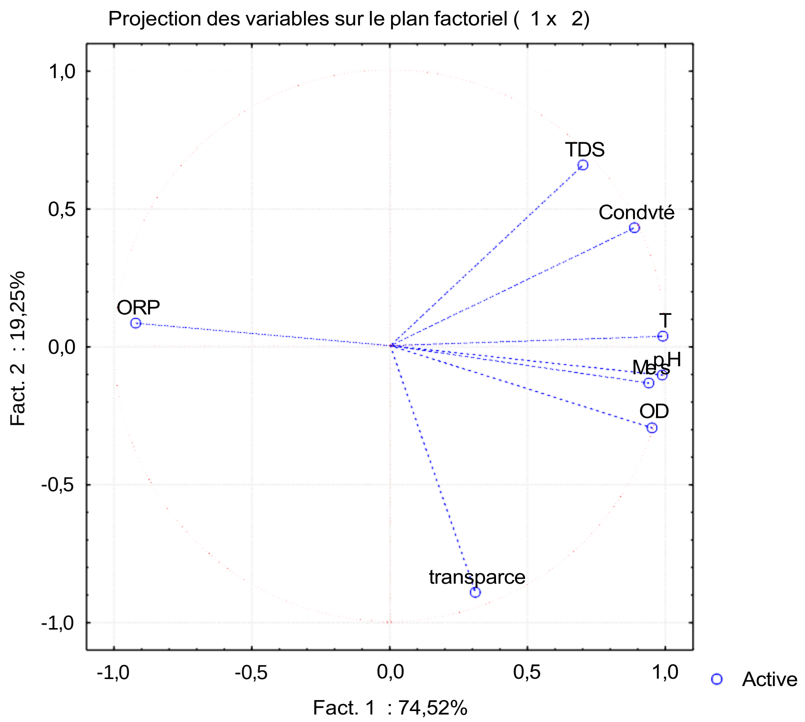

Figure10 : Representation of the variables in the F1-F2 factorial design

According to WHO guidelines (2011), which is a reference for drinking water safety, the pH measured in Bingerville Bay at depths of 0.5 and 2m varies between 6.8 and 7.3. This water has a relatively neutral pH and tends towards basicity. This could be due to the presence of bicarbonate, which buffers the flowing water (Diangoné et al., 2019). The basicity of the water in the bay is also thought to be of continental origin, with run-off water being added. This basicity of bay water is linked to contamination of the environment by bacteria or chlorophyll pigments (Houma, 2004). Compared with the standards (WHO, 2011), it can be seen that they comply with and are within the recommended standards (6.5 and 9.5). This could confirm that the water in Bingerville Bay is basic. The lowest temperature is 26°C (minimum) measured in the northern part and the highest is 27.5°C (maximum) measured in the western and southern parts at a depth of 0.5m. The high temperature values could be explained by the fact that these parts are not very deep and receive direct sunlight. The sun's rays heat the water faster at a depth of 0.5 m than at 2 m (Diangoné et al., 2019) in the south and west than in the north. These values do not comply with the WHO standard (2011) for drinking water to have a temperature of 25°C or less (22 to 25°C). So this water is poor. TDS measurements taken in Bingerville Bay vary between 1.18 (minimum) and 2.99 g/l (maximum) at 0.5 and 2 m. The high TDS concentrations observed in certain areas of the bay could be due to the decomposition of organic matter brought in by run-off water (Diangoné et al., 2019). Compared with WHO standards (2011), which do not have a guide value but an optimum that is below 1000mg/l or 1.0g/l. This could mean that the water in Bingerville Bay is polluted and contains dissolved solids. The high conductivity values measured in Bingerville Bay are 4540 and 5990 us/cm respectively. These values are much higher than the results obtained by (Soro et al, 2009) which is 4793.75 µS/cm and would indicate mineralisation of the water (Soro, 2003). The concentrations are higher than 3000µS/cm, and therefore higher than those of (WHO, 2011). Given the values obtained, this water is highly mineralised and is close to seawater. The variations in conductivity could be explained by the input of lagoon and continental water. It could also be due to dissolved minerals in the bay (Diangoné et al., 2019). The dissolved oxygen (DO) content measured at 0.5m (5.61mg/l) and 2m (7.16mg/l) has a saturation percentage that varies between 71.6% and 90%. Water quality is good when dissolved oxygen varies between 5 and 7 mg/l according to (WHO, 2011). This indicates an oxygenated environment, which could be explained by the plant cover bordering the bay (Diangoné et al., 2019). The minimum and maximum transparency measurements vary between 0.60 m and 0.70 m. Transparency is low. According to (Durand, 1994), the maximum values observed in the lagoon are 3 m. The lowest values indicate a low level of transparency. The low levels observed to the south and west could reflect the high turbidity of the water during the various measurements. This turbidity could be due to run-off. The interaction between the hydrochemical parameters shows that there is a correlation between some of the physico-chemical parameters studied (TDS and conductivity, transparency and dissolved oxygen, transparency and ph evolve synchronously). Conductivity is significantly dependent on TDS. Transparency depends on dissolved oxygen. However, in the Baie du Banco, conductivity is significantly dependent on salinity (Amani *et al.*, 2020). According to Durand and Guiral (1994), the relatively high salinity in the bay (24.38 ppm) is due to the constant renewal of water in this area via the Vridi canal. The parameters (ORP and pH ; transparency and temperature) move in opposite directions. Also, there is an inverse correlation between ORP and pH, transparency and temperature. Compared with the study carried out on Banco Bay, the correlations are proportionally inverse between transparency and temperature, TDS and temperature, and salinity and temperature. Transparency and dissolved oxygen reflect the oxygenation of the environment. Transparency and pH reflect the basicity of the environment. The influence of the external environment on the chemistry of the water causes the pH to vary and suspended solids act under the effect of the dynamics of the water in the bay.

4. CONCLUSION

The hydrochemical study of Bingerville Bay was possible thanks to the physico-chemical parameters (transparency, TDS, pH, temperature, conductivity, dissolved oxygen, oxidation-reduction potential and TSS). By interpreting the diagrams of these parameters, we were able to determine the variation in current at the various stations in the water column. Examination of the hydrochemical data revealed variations in the concentration or content of the various hydrochemical parameters at the surface of Bingerville Bay. The average hydrochemical values in Bingerville Bay are given by the physico-chemical parameters during surface and deep water sampling. The temperature is 26°C. The surface water has a hydrogen potential (pH) of 7.08. It has an average conductivity of 3360 us/Cm. Dissolved oxygen in the bay is 6.37mg/l. Surface concentrations of suspended matter vary between 8 mg/l and 12 mg/l, with an average of 8.8 mg/l. They are under the control of wastewater and run-off. These results confirm the degree of pollution observed in the bay. All the hydrochemical parameter values recorded do not comply with the drinking water guidelines set by the WHO. The results of the PCA (principal component analysis) showed that 80% of the cumulative variance gave a good representation of the variables on the factorial axes. However, for this study, the first two (02) factorial axes F1 and F2 express 93.77% of the cumulative variance, which is therefore an acceptable and satisfactory percentage for statistical analysis. The variables in the correlation matrix are positively correlated (proportional variables) and negatively correlated (inversely proportional variables). Transparency and the variables TDS, conductivity, pH, TSS, temperature and dissolved oxygen form an acute angle with the correlation circle. These variables are said to be a good criterion for estimating transparency. As for transparency and ORP or pH and ORP, these two (02) variables are almost opposite each other on the community circle, forming an obtuse angle. These variables are said to be dependent on each other.

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