International Journal of Innovation and Applied Studies
ISSN 2028-9324 Vol. 37 No. 2 Sep. 2022, pp. 292-304

http://www.ijias.issr-journals.org/

Physico-chemical quality assessment of the waters and sediments of the M'Badon bay in the south of Côte d'Ivoire

Amenan Evelyne Kouassi, Abou Traore, Louan Odile Ble, and J. Biemi

Soil, Water and Geomaterials Sciences Laboratory (LSSEG), UFR STRM, University Felix Houphouët-Boigny of Cocody-Abidjan BP 582 Abidjan 22, Côte d'Ivoire

ABSTRACT: The bay of M'Badon is the receptacle of wastewater of various origins, leaching water from plantations and leachate from the Akouédo landfill. All these inputs are likely to pollute this aquatic environment, which is used by the population for fishing and market gardening. The objective of this study is to determine the quality of the water and surface sediments in the bay. To achieve this, a sampling campaign allowed the collection of a total of sixty-six samples, twelve of leachate, twenty-seven of bay water and twenty-seven of surface sediments. Parameters such as COD, BOD_5, NO_3^-, NO_2^-, NH_4^+, SO_4^-, PO_4^{3-}, Na^+, K^+ and Ca^{2+} were measured by the methods of the French Agency of Standardization and trace metal elements (Zn, Cu, Ni, Cr) were measured by atomic absorption spectrometry. The average values of COD (1306.25 mg O_2L^{-1}), BOD5 (575.85 mgO_2L^{-1}), NO_3^- (92.92 mgL^{-1}) and PO_4^{3-} (128.74 mgL^{-1}) of the Akouédo landfill leachates are well above Ivorian standards. The waters of the bay are turbid, with an average TSS concentration of 65.13 mgL^{-1}. They have a high load of organic and mineral oxidizable matter, with average COD and BOD_5 values of 160.70 mgO_2L^{-1} and 64.04 mgO_2L^{-1} respectively. Their mineralization is due to the combination of two processes, one natural and the other anthropogenic. The average NH_4^+ concentration (0.22 mgL^{-1}) is higher than the French guide value. The sediments of stations B1, B4 and B5 are polluted by Zn and Cu, and the sediments of all stations are polluted by Mo. M'Badon Bay is polluted by anthropogenic activities.

KEYWORDS: Akouédo landfill, M'Badon, pollution, leachate, water, sédiment, trace metal elements, Côte d'Ivoire.

1 INTRODUCTION

Aquatic ecosystems are naturally vulnerable and their ecological balance can be rapidly altered under the influence of natural or anthropogenic factors [1]. They are increasingly affected by agro-industrial runoff, domestic wastewater and industrial effluents. These waters often have a broad spectrum of chemical pollutants [2]. They can not only, pollute water resources but also lead to the reduction and even extinction of certain animal and plant species. Among these pollutants, Trace Metal Elements (TME) are of particular concern due to their resistance to biodegradation, toxicity, and ability to incorporate into the food chain [3], [4]. Once in the aquatic environment, TME partition between the water phase, sediments, and aquatic organisms [4], [5]. Coastal sediments have diverse origins and are often reservoirs for these trace elements [6]. TME trapped in sediments can contaminate the food chain through bioaccumulation and cause risks to living organisms as well as humans [7], [8] et [5].

M'Badon Bay is used by people for crab, shrimp, and fish fishing and for market gardening. Yet, untreated leachate from the Akouédo landfill, leachate from agricultural land, wastewater of all kinds and industrial effluents are discharged into it. The study of the level of contamination of this bay by chemical pollutants is of paramount importance to know the impact of anthropic activities on this aquatic ecosystem. The objective of this work is to evaluate the state of the quality of the water and surface sediments of the bay in order to prevent ecological risks.

2 Material And Methods

2.1 Presentation Of The Study Area

The study area is located in the northeast of the city of Abidjan in the commune of Cocody. Its coordinates in the UTM Clark 1880 reference system, 30 N zone, are between 407,653 and 426,114 meters on the x-axis and 517,090 and 580,323 meters on the y-axis. It includes the Akouedo dump and M'Badon Bay (Figure 1). The Akouedo uncontrolled landfill has an area of about 153 ha and is located halfway along the Abidjan-Bingerville axis. Leachate from the landfill flows into the lagoon bay of M'Badon (Figure 2). The choice of location for this landfill was based on the criteria of the time, which can be summarized as the distance of the site from the city. Nowadays, the landfill has been overtaken by the city due to the galloping urbanization. In operation from 1965 to 2019, it has received several tons of waste including household, industrial, hospital and agricultural waste. In the study area the climate is of the transitional equatorial type, called "Atean climate" which is characterized by 4 seasons [9]:

- a large dry season from December to April;
- a large rainy season from May to July;
- a small dry season from August to September;
- a small rainy season from October to November.

The average annual temperature and rainfall are 26.4°C and 1517 mm respectively. The geology is marked by Quaternary (Holocene) formations, including clayey sands of the "Bas-Plateaux" and Meso-Cenozoic (Mio-Pliocene or Continental Terminal) formations, including sands, clays, and ferruginous sandstones of the "High Plateaux" [10].

2.2 Leachate, Water And Sediment Sampling

A sampling campaign was conducted in the study area. The sampling focused on leachate from the Akouédo landfill, water and surface sediments from M'Badon Bay. Samples of leachate and water from the bay were collected using a telescopic pole with 500 ml bottles attached to the end. These samples were collected in one (1) liter polyethylene bottles, previously washed with nitric acid and distilled water. Before filling, the bottles were washed three times with the water to be collected. The bottles were filled to the brim and then the cap was screwed on to avoid any gas exchange with the atmosphere.

The sampling of the surface sediments of the bay consisted of scraping the bottom of the lagoon with a Van Veen bucket. Samples were packaged in plastic bags.

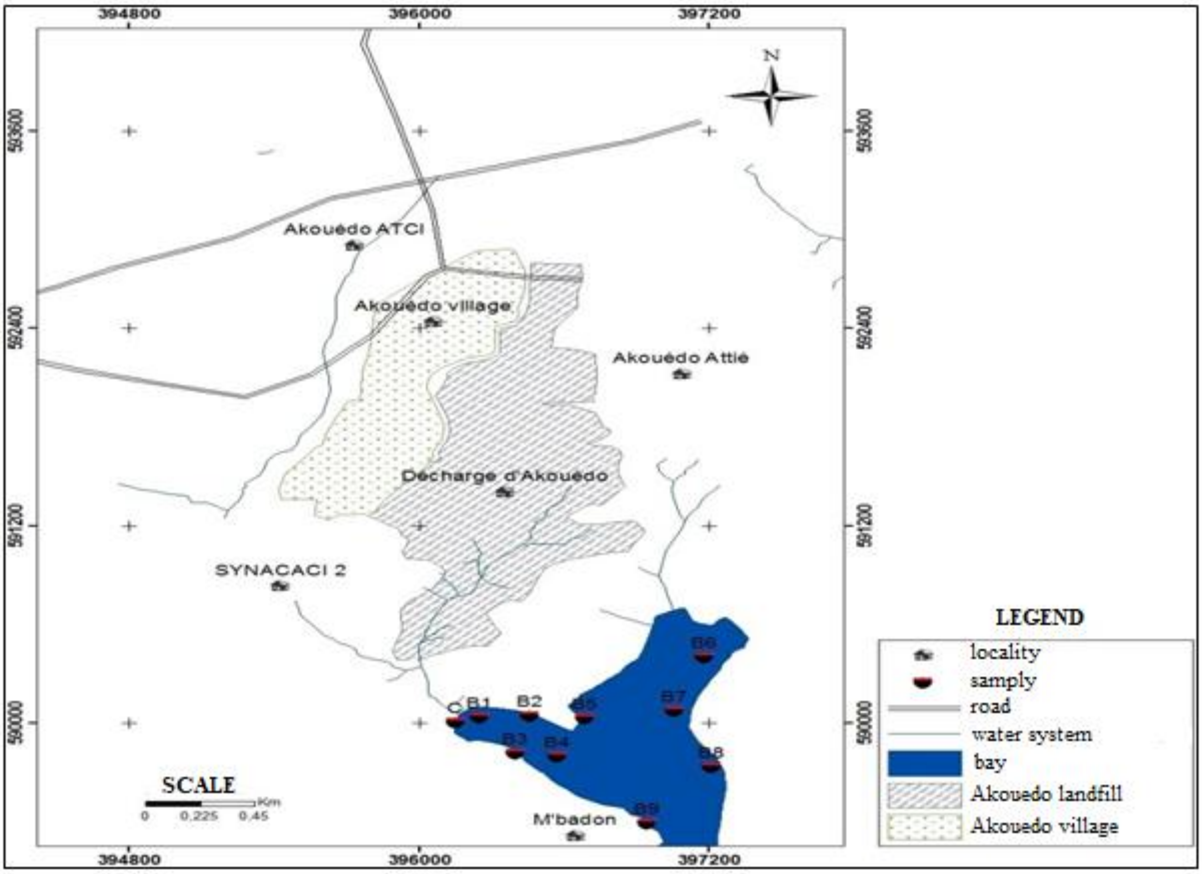

Fig. 1. Location of the study area

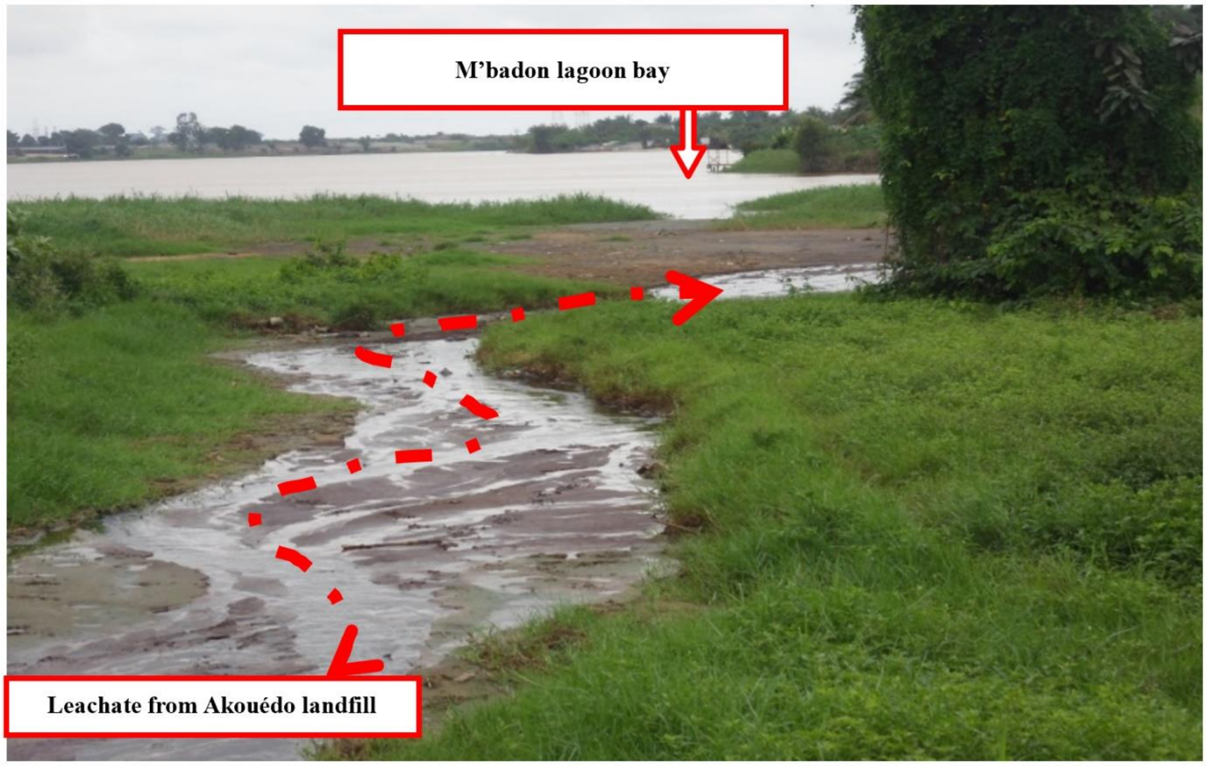

Fig. 2. Leachate runoff into the M'Badon lagoon

Water samples were stored in a cooler containing ice chips and transported to the laboratory where they were analyzed within 24 hours. During water sample collection, physicochemical parameters such as electrical conductivity (EC) and dissolved oxygen (O_2) were measured in situ using a HACH Sension 5 multiparameter instrument. Temperature (T), hydrogen potential (pH) and redox potential (Eh) were measured using a Star 4 multiparameter instrument.

A total of sixty-six samples including twelve leachate, twenty-seven bay water and twenty-seven sediment samples were collected.

2.3 Analytical Methods For Leachate, Water And Sediment Samples

2.3.1 Analytical Methods For Leachate And Water Samples

In the laboratory, determinations were made for nutrients (NO_3^-, NO_2^-, NH_4^+, SO_4^-, PO_4^{3-}), trace metal elements (Zn, Pb, Mn, Cu, Ni, Cr, Fe, Mo), chemical oxygen demand (COD) and biological oxygen demand (BOD_5). The parameters Na^+, K^+, Ca^{2+} were determined by flame atomic absorption spectrometry (FAAS) according to the NF T90-112 (1986) standard [11]. Chlorine (Cl-) was determined by Mohr's volumetric method according to NF T90-014 (1952) [11]. As for the SO_4^{2-} parameter, it was determined by the nephelometric method according to the NF T90-040 (1986) standard [11]. The molecular absorption spectrometric method according to NF T90-045 (1989) [11] allowed the determination of NO_3^- concentrations and the molecular absorption spectrometric method according to NF T90-013 (1993) [11], of NO_2^-. The determinations of PO_4^{3-} and NH_4^+ were done respectively by the spectrometric method according to the NF T90-023 (1982) standard [11] and by the acidimetric method after distillation according to the NF T90-015 (1975) standard [11]. BOD_5 was determined by the permanganate index method according to NF EN ISO 8467 (1995) [12]. For the determination of COD, the open system reflux method according to NF T90-101 (2001) [12] was used.

2.3.2 Methods Of Analysis Of The Sediment Samples

The sediments dried in an oven at 50°C for 24 hours, underwent an initial sieving on 2 mm mesh to remove coarse elements. Then, they were crushed and sieved to obtain a powder with a particle diameter of less than 63 µm. The digestion method that was used was that of [13]. Finally, the concentration of TME (Mn, Cu, Zn, Pb, Ni, Cr, Fe, and Mo) was determined by the flame atomic absorption spectrometric method according to NF T90-112 (1986) [11].

2.4 Estimating The Intensity Of Contamination In Leachate, Water And Sediment Samples From The Bay

The results of the physico-chemical analyses of the leachates from the Akouédo landfill were compared to Ivorian standards. Then, as Côte d'Ivoire does not have guide values for surface water, the results of the physico-chemical analyses of the waters of M'Badon Bay were compared to the French guide values for surface freshwater used for the production of water intended for human consumption from the Journal Officiel de la République Française (JORF) for the year 2017. The Normalized Principal Component Analysis (NPA) was used to highlight the origin of the mineralization of the bay waters.

The results of Trace Metal Element (TME) determination in M'Badon Bay sediments were compared, for the most part, to reference values (Table I) for unpolluted sediments from [14] and [15] and for Molybdenum (Mo) to the concentration in the continental crust [16].

The intensity of sediment contamination is estimated from two indices, the enrichment factor and the geo-accumulation index.

Table 1. Trace element concentrations (mg.kg^{-1}) in unpolluted sediments

ETM (mg.kg^{-1})	Pb	Cu	Zn	Fe	Mo	Ni	Cr	Mn
[14]	19.00	33.00	95.00	41000.00				770
[15]	12.68	24.84	45.13			12.55	51.40	

Enrichment factors (EF)

The EF is calculated to determine the anthropogenic or natural origin of elements in sediments. According to [17], it is defined by the relation: $\mathrm{EF_E} = (\frac{\mathrm{E_{ech}}}{\mathrm{X_{ech}}}) / (\frac{\mathrm{E_{Crust}}}{\mathrm{X_{Crust}}})$ with EF_E: enrichment factor of element E; Eech: mass concentration of the element in the sample; ECrust: mass concentration of the element in the average continental crust; XCrust: content of reference element in the crust; Xech: content of reference element in the sample. Iron (Fe) was chosen as the reference element because of its natural abundance in the study area. The reference [17] divided sediment metal pollution into different categories based on EF values. If EF ≤ 2, he suggest lack of metal enrichment and if the EF value > 2, he is varying degrees of metal enrichment. The classification of the EF calculation results is presented in Table II.

Table 2. Classification of enrichment factor results (Sutherland, 2000)

Enrichment Factor	Classification
EF < 2	No or minimal enrichment
2 ≤ EF < 5	Moderate enrichissement
5 ≤ EF < 20	Significant enrichment
20 ≤ EF < 40	Very high enrichment
EF ≥ 40	Extreme Enrichment

INDEX OF GEO-ACCUMULATION (IGEO)

The intensity of metal pollution can be evaluated from the geo-accumulation index [18]. This index compares a given concentration to a value considered as geochemical background. It is defined by the equation: $\text{Igéo} = \log 2\ [\frac{C_n}{(1{,}5\ X\ B_n)}]$, where Igeo: geo-accumulation index; log2: base 2 logarithm; n: element considered; C: concentration measured in the sample; B: geochemical background; 1.5: exaggeration factor of the geochemical background, the function of which is to take into account natural fluctuations of the geochemical background. [18] retained a scale with six classes of geo-accumulation index (Table III).

Table 3. Classes defined by the geo-accumulation index [18]

Index Value (Igéo)	Pollution intensity
Igeo <0	Pollution free
0 ≤ Igeo < 1	No pollution to moderate pollution
1 ≤ Igeo < 2	Moderate pollution
2 ≤ Igeo < 3	Moderate to heavy pollution
3 ≤ Igeo < 4	High pollution
4 ≤ Igeo < 5	High to extreme pollution
Igeo ≥ 5	Extreme pollution

3 RESULTS

3.1 PHYSICO-CHEMICAL CHARACTERISTICS OF AKOUEDO LEACHATE

The results of the physico-chemical analyses of the Akouedo landfill leachate are presented in Table IV. The mean values of pH (7.68) and EC (8544 µS cm^{-1}) reveal that the leachates studied are alkaline and present a strong mineralization. The mean values of COD (1306.25 mg O_2L^{-1}) and BOD_5 (575.85 mgO_2L^{-1}) are well above the Ivorian standards of 300 mgO_2L^{-1} and 100 mgO_2L^{-1} respectively.

The average concentrations of NO_3^- (92.92 mgL^{-1}), PO_4^{3-} (128.74 mgL^{-1}) and NH_4^+ (388.40 mgL^{-1}) are also well above the Ivorian standards of 10 mgL^{-1}, 2 mgL^{-1} and 10 mgL^{-1} respectively.

Table 4. Physico-chemical characteristics of Akouédo leachates

Chemical parameters	pH	CE (µS cm^{-1})	PO_4^{3+} (mgL^{-1})	NH_4^+ ($mgL^{-1)}$	NO_3^- ($mgL^{-1)}$	DCO (mgL^{-1})	DBO_5 ($mgL^{-1)}$	DBO_5/DCO
Mean values	7.68	8544	128.74	388.40	92.92	1306.25	575.58	0.47
Standard ivorian	5.5-8.5	ND	2	10	10	300	100	ND

3.2 PHYSICO-CHEMICAL QUALITY OF THE WATERS OF THE M'BADON LAGOON

The results of the analyses carried out on the waters of M'Badon Bay are shown in Table V. The pH values vary from neutral to alkaline. They range from 7.01 to 8.31, with an average of 7.58 consistent with the guide values (5.5-9 pH units) [19]. The redox potential (Eh) of the waters ranges from -110.2 to and -0.4 mV, with an average of -40.53 mV. These negative values indicate that the waters are reducing. Recorded temperatures ranged from 25.1 to 32.4°C, with an average of 28.95°C above guide value of 22°C [19]. Dissolved oxygen (O_2) concentrations in the waters range from 3.7 to 13.34 mgL^{-1}, with an average of 6.87 mgL^{-1} or 89.43% consistent with the French guide value that indicates that the percentage of dissolved oxygen saturation should be greater than 30%. The bay waters have an electrical conductivity that ranges from 260 to 1248 μScm^{-1}, with an average of 890 μScm^{-1}, lower guide value of 1100 μScm^{-1} [19]. This value indicates that the lagoon waters show significant mineralization. As for salinity, it ranges from 0.1 to 0.6, with an average of 0.38 indicating that the waters are oligo-haline (salinity between 0.05 and 5). TSS concentrations range from 1.15 to 138.14 mgL^{-1}, with an average of 65.13 mgL^{-1} guide value of 25 mgL^{-1} [19]. COD and BOD_5 in the bay waters range from 87.6 to 230 mgO_2L^{-1} and 34 to 94 mgO_2L^{-1}, respectively. The average COD value (160.70 mgO_2L^{-1}) is well above the French guide value of 30 mgO_2L^{-1}. That of BOD_5 (64.04 mgO_2L^{-1}) is also largely higher than the French guide value which is strictly lower than 7 mgO_2L^{-1}. SO_4^{2-} concentrations range from 24 to 35 mgL^{-1}, with an average of 29.93 mgL^{-1} which is below the guide value of 150 mgL^{-1} [19]. Na^+, Ca^{2+}, K^+ concentrations range from 12.1 to 20.93 mgL^{-1}, 20.5 to 33.27 mgL^{-1}, and 17.7 to 26.3 mgL^{-1}, respectively, with respective means of 17.03 mgL^{-1}, 26.30 mgL^{-1}, and 21.33 mgL^{-1}. Chlorine (Cl^-) has concentrations that range from 38.3 to 54 mgL^{-1}, with an average of 45.15 mgL^{-1}, well below the guide value of 200 mgL^{-1} [19]. The average NH_4^+ concentration (0.22 mgL^{-1}) is higher than the French guide value of 0.05 mgL^{-1}. On the other hand, that of NO_3^- (0.05 mgL^{-1}) is in accordance with the French guide value which is 25 mgL^{-1}. The concentrations of PO_4^{3-} and NO_2^- are respectively between 0.08 and 0.29 mgL^{-1} and 0 and 0.03 mgL^{-1}, with respective averages of 0.15 mgL^{-1} and 0.01 mgL^{-1}.

Table 5. Physico-chemical characteristics of the waters of the lagoon bay of M'Badon

Variables	Minimum	Maximum	Mean	Standard deviation
MES (mgL^{-1})	1.15	138.14	65.13	42.39
SAL (mgL^{-1})	0.10	0.60	0.38	0.19
T° (°C)	25.10	32.40	28.95	2.23
pH	7.01	8.31	7.58	0.29
Eh (mV)	-110.20	-0.4	-40.53	29.94
O_2 (mgL^{-1})	3.70	13.34	6.87	1.70
CE (μScm^{-1})	260	1248	890	373
DCO (mg O_2L^{-1})	87.60	230.00	160.70	31.40
DBO_5 (mg O_2L^{-1})	34.00	94.00	64.04	13.23
HCO_3^- (mgL^{-1})	80.60	135.00	104.87	12.94
NH_4^+ (mgL^{-1})	0.06	0.41	0.22	0.06
SO_4^{2-} (mgL^{-1})	24.00	35.00	29.93	2.08
PO_4^{3-} (mgL^{-1})	0.08	0.29	0.15	0.02
Cl^- (mgL^{-1})	38.30	54.00	45.15	2.88
Ca^{2+} (mgL^{-1})	20.50	33.27	26.30	2.51
Na^+ (mgL^{-1})	12.10	20.93	17.03	2.21
K^+ (mgL^{-1})	17.70	26.30	21.33	1.82
NO_3^- (mgL^{-1})	0	0.17	0.05	0.03
NO_2^- (mgL^{-1})	0	0.03	0.01	0.01

3.3 ORIGINS OF MINERALIZATION IN THE WATERS OF M'BADON BAY

The correlations that exist between the variables taken in pairs and indicated by the correlation coefficients are presented in the correlation matrix (Table VI). Some pairs of variables show statistically significant correlations ($r > 0.7$; $p < 0.05$).

The most significant correlations are those realized between: Eh and pH (r = -0.90), TSS and T° (r = 0.89), O2 and Eh (r = -0.88), Na+ and HCO_3^- (r = 0.86), BOD_5 and COD (r = 0.85), $Ca^{2+}$and HCO_3^- (r = 0.84), pH and T° (r = 0.83), Eh and T° (r = -0.83), and Ca^{2+} and EC (r = 0.81). To a lesser degree, there is a good correlation between: TSS and pH (r = 0.78), O_2 and pH (r = 0.75), HCO_3^- and EC (r = 0.75), K^+ and HCO_3^- (r = 0.73), K^+ and Ca^{2+} (r = 0.73).

The different percentages expressed by the first three factors are respectively F1 (36.25%), F2 (26.45%) and F3 (10.5%) of the variance. These three factors alone account for 73.2% of the variance expressed and contain the maximum amount of information to allow for the interpretation of the results. The representation using these factors (Figures 3 and 4) gives a satisfactory account of the structure of the scatterplots.

In the community circle (Figure 3), factor 1 is determined in its negative part by variables such as: Ca^{2+}, HCO_3^-, EC, K^+, BOD_5, COD, Na^+ and SO_4^{2-} and to a lesser degree by Cl^-. Some elements, including Ca^{2+}, Cl^-, HCO_3^-, SO_4^{2-}, Na^+, K^+ are derived from precipitation, hydrolysis of minerals from underlying sediments, and leaching from watershed rocks. BOD_5 and COD are indicator parameters for the proportion of biodegradable organic matter and total oxidizable matter (mineral salts and organic compounds) respectively. Therefore, F1 reflects the natural mineralization of the water. Factor 2 is defined by pH, Eh, T°, O_2 and TSS. These parameters are important in the hydrolysis of silicates and in the degradation of organic matter. They give an account of the environmental conditions in the acquisition of mineralization. The factor 2 expresses the phenomenon of oxidation-reduction.

In the factorial plane F1-F3 (figure 4), factor 1 is determined by the variables Ca^{2+}, HCO_3^-, O_2, CE, K^+, Eh, Na^+ and SO_4^{2-}. It always expresses the phenomenon of natural mineralization of water. The factor 3 is defined by BOD_5, COD, Cl^- and NH_4^+. These variables are indicators of the degree of water pollution. F2 thus expresses the phenomenon of anthropic mineralization.

Table 6. Correlation matrix between physico-chemical parameters

Variables	T°	pH	Eh	O_2	MES	CE	DCO	DBO_5	HCO_3^-	NH_4^+	SO_4^{2-}	Cl^-	PO_4^{3-}	Ca^{2+}	Na^+	K^+
T°	1															
pH	**0.83**	1														
Eh	**-0.83**	**-0.90**	1													
O_2	0.60	**0.75**	**-0.88**	1												
MES	**0.89**	**0.78**	-0.67	0.42	1											
CE	-0.24	-0.17	-0.20	0.38	-0.46	1										
DCO	0.05	0.16	-0.30	0.30	0.08	0.55	1									
DBO_5	0.21	0.34	-0.40	0.36	0.26	0.38	**0.85**	1								
HCO_3^-	-0.01	-0.004	-0.28	0.31	-0.13	**0.75**	0.54	0.38	1							
NH_4^+	-0.45	-0.31	0.54	-0.51	-0.19	-0.19	-0.30	-0.05	-0.01	1						
SO_4^{2-}	-0.22	-0.11	-0.06	0.10	-0.23	0.63	0.43	0.30	0.69	0.16	1					
Cl^-	-0.14	-0.04	-0.07	0.28	-0.12	0.45	0.40	0.39	0.26	0.15	0.61	1				
PO_4^{3-}	0.20	0.23	-0.23	0.03	0.23	-0.12	0.12	0.18	-0.06	-0.05	-0.09	-0.12	1			
Ca^{2+}	0.23	0.24	-0.52	0.50	0.04	**0.81**	0.40	0.24	**0.84**	0.34	-0.68	0.25	-0.03	1		
Na^+	0.01	-0.06	-0.19	0.25	-0.08	0.64	0.63	0.53	**0.86**	-0.25	0.53	0.29	-0.17	0.68	1	
K^+	0.05	-0.02	-0.18	0.17	-0.15	0.45	0.24	0.09	**0.73**	-0.22	0.54	0.17	0.04	**0.73**	0.63	1

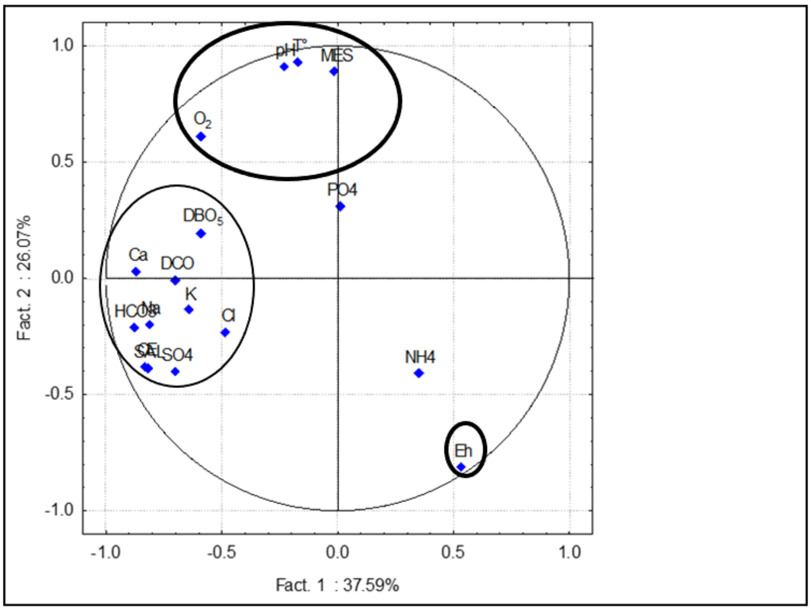

Fig. 3. Community circle of the F1-F2 factorial design

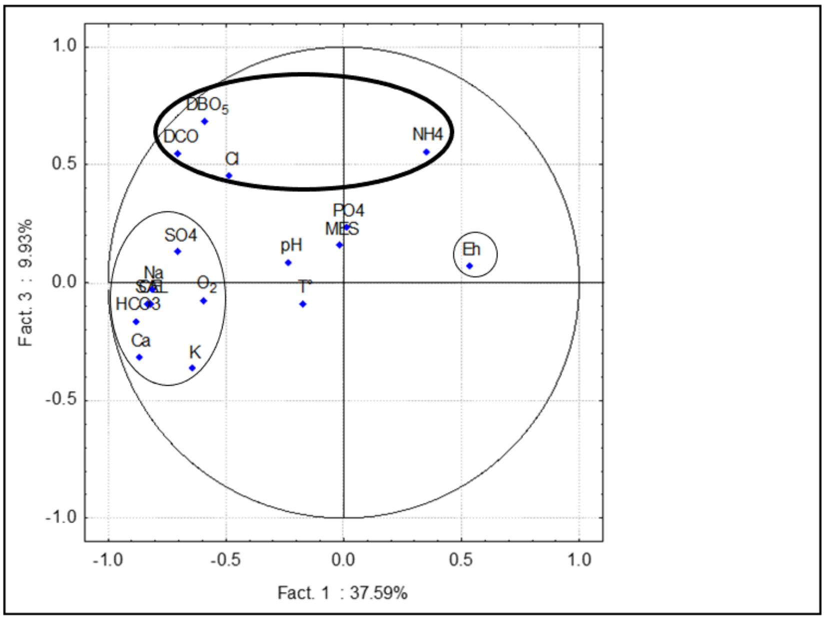

Fig. 4. Community circle of the F1-F3 factorial design

3.4 Estimation Of The Intensity Of TME Contamination In Sediments

Sediment quality status

The TME concentrations of the sediments in M'Badon Bay are presented in Table VII. Analysis of this table shows that manganese concentrations range from 17.55 to 49.17 mg.kg^{-1}, with an average of 34.13 mg.kg^{-1} below the 770 mg.kg^{-1} concentration recommended for unpolluted sediments by [15]. For iron, the average concentration of 16490.37 mg.kg^{-1} is lower than the concentration of 41000 mg.kg^{-1} recommended by [15]. For zinc, copper, lead, nickel and chromium, the concentrations are between 11.4 and 76.7 mg.kg^{-1}, 5.95 and 26.73 mg.kg^{-1}, 0.23 and 0.61 mg.kg^{-1}, 5.07 and 10.86 mg.kg^{-1} and between 5.03 and 12.93 mg.kg^{-1}, respectively. The respective mean concentrations of 38.36 mg.kg^{-1}, 18.03 mg.kg^{-1}, 0.42 mg.kg^{-1}, 7.86 mg.kg^{-1}, and 7.72 mg.kg^{-1} are lower than the values of 45.13 mg.kg^{-1}, 24.84 mg.kg^{-1}, 12.68 mg.kg^{-1}, 12.55 mg.kg^{-1}, and 51.40 mg.kg^{-1} recommended for unpolluted sediments by [14]. However, zinc concentrations at stations B1 (76.7 mg.kg^{-1}), B4

(55.64 mg.kg^{-1}) and B5 (46.72 mg.kg^{-1}) are higher than the recommended value. For copper, the concentrations at stations B1 (24.87 mg.kg^{-1}) and B4 (26.73 mg.kg^{-1}) are also above the recommended concentration. Molybdenum concentration ranged from 1.93 to 11.67 mg.kg^{-1}, with an average of 5.72 mg.kg^{-1} upper continental crust (UCC) value of 1.4 mg.kg^{-1} [16], reflecting contamination of surficial sediments by this element. Its concentration at all stations, is higher than the recommended value.

Table 7. Concentrations (mg.kg^{-1}) of M'Badon Bay sediments

	Mn	Zn	Cu	Pb	Ni	Cr	Fe	Mo
B1	45.1	76.7	24.87	0.4	10.8	12.93	13726.67	5.77
B2	32.93	35.18	17	0.37	6.53	5.54	15014.33	11.67
B3	29.38	23.4	14.97	0.3	6	5.87	16452.67	8.87
B4	31.7	55.64	26.73	0.5	10.9	8.93	20257.67	7.7
B5	34.78	46.72	18.63	0.31	8.33	6.96	20964.33	2.17
B6	49.17	31.97	17.7	0.48	7.17	7.65	17381	5.8
B7	17.55	11.4	5.95	0.23	5.07	5.03	11206.33	1.93
B8	33.91	34.47	17.33	0.6	7.97	8.8	14082.67	4.83
B9	32.68	29.8	19.05	0.61	8.01	7.75	19327.67	2.73
Moy	34.13	38.36	18.03	0.42	7.86	7.72	16490.37	5.72
Max	49.17	76.7	26.73	0.61	10.86	12.93	20964.33	11.67
Min	17.55	11.4	5.95	0.23	5.07	5.03	11206.33	1.93

B=station; Moy=mean; Max=maximum; Min=minimum

ENRICHMENT FACTOR (EF)

Enrichment factor (EF) values are presented in Table VIII. In the sediments of M'Badon Bay, manganese EFs range from 0.09 to 0.19, with an average of 0.12. All stations have EFs less than 2, suggesting that the manganese is of terrigenous origin. Zinc EFs range from 0.6 to 3.32, with an average of 1.39. With the exception of station B1, which has the highest enrichment (3.32), all other stations have EFs below 2. Zinc is therefore mainly of terrigenous origin, except at station B1 where, in addition to the terrigenous source, there is an anthropogenic source. At this station, zinc is moderately enriched. As for copper, its average EF is 2.34 and the minimum and maximum are respectively 1.17 and 4. For this TME, except for stations B5 and B7, which are enriched from terrigenous sources, all other stations are enriched from anthropogenic sources in addition to the natural source. They all experience moderate copper enrichment. Lead EFs range from 0.03 to 0.08, with an average of 0.05. All stations have EFs below 2. The lead enrichment is therefore of terrigenous origin. For nickel, EFs range from 0.59 to 1.28, with an average value of 0.79. The source of its enrichment is therefore natural. The same is true for chromium, whose EFs range from 0.29 to 0.83, with an average of 0.43. For molybdenum, the average EF is 7.83, with values ranging from 2.28 to 17.15. All the stations have a EF greater than 2 for this element, which suggests that in addition to the terrigenous source, it is enriched by anthropogenic means. It represents the most enriched element. At stations B5, B7 and B9 it is moderately enriched and at stations B1, B2, B3, B4, B6 and B8 it is significantly enriched. Overall, the origin of the enrichment of M'Badon Bay sediments in manganese, zinc, lead, nickel and chromium is natural. On the other hand, copper and molybdenum are enriched from anthropogenic sources in addition to natural sources.

Table 8. Enrichment factor (EF) values for trace metal elements at different stations in M'Badon Bay

	Mn	Zn	Cu	Pb	Ni	Cr	Mo
B1	0.19	3.32	4	0.05	1.28	0.83	9.27
B2	0.13	1.3	2.5	0.04	0.71	0.33	17.15
B3	0.1	0.84	2.01	0.03	0.59	0.31	11.9
B4	0.09	1.63	2.91	0.04	0.87	0.39	8.03
B5	0.1	1.32	1.96	0.03	0.65	0.29	2.28
B6	0.17	1.09	2.25	0.05	0.67	0.39	7.36
B7	0.09	0.6	1.17	0.04	0.74	0.4	3.8
B8	0.14	1.45	2.09	0.08	0.92	0.55	7.57
B9	0.1	0.92	2.17	0.06	0.67	0.35	3.12
Moy	0.12	1.39	2.34	0.05	0.79	0.43	7.83
Max	0.19	3.32	4	0.08	1.28	0.83	17.15
Min	0.09	0.6	1.17	0.03	0.59	0.29	2.28

B=station; Moy=mean; Max=maximum; Min=minimum

INDEX OF GEO-ACCUMULATION (IGEO)

The geo-accumulation indices for TME in the sediments of M'Badon Bay are recorded in Table IX. For manganese, there is an absence of pollution at all stations. Indeed, the Igeo varies between -1.66 and -0.39, with an average of -1.27. For zinc, the Igeo is between -0.83 and 0, with an average value of -0.36. Except for station B1 where there is moderate pollution, all other stations are without pollution. As far as copper is concerned, only station B7 is free of pollution. The other stations are moderately polluted, with Igeo values varying between -0.55 and 0.10. For lead, nickel, chromium and iron, there is an absence of pollution at all stations, which is indicated by Igeo between -2.04 and -1.62, -0.74 and -0.42, -1 and -0.1 and between -0.61 and -0.34 respectively. As for molybdenum, with the exception of station B7, which has no pollution, all the other stations have moderate pollution, with Igeo values ranging from -0.04 to 0.70.

Table 9. Values of the geo-accumulation index of metallic trace elements at different stations in M'Badon Bay

	Mn	Zn	Cu	Pb	Ni	Cr	Fe	Mo
B1	-1.24	0	0.07	-1.8	-0.42	-0.61	-0.53	0.4
B2	-1.38	-0.37	0	-1.86	-0.64	-0.1	-0.49	0.7
B3	-1.43	-0.52	0	-1.92	-0.68	-0.95	-0.45	0.6
B4	-0.39	-0.15	0.1	-1.7	-0.42	-0.77	-0.36	0.5
B5	-1.36	-0.22	0	-1.91	-0.53	-0.89	-0.34	0.01
B6	-1.21	-0.39	0	-1.72	-0.59	-0.82	-0.42	0.4
B7	-1.66	-0.83	-0.55	-2.04	-0.74	-1	-0.61	-0.04
B8	-1.36	-0.35	0	-1.63	-0.55	-0.78	-0.52	0.36
B9	-1.39	-0.41	0	-1.62	-0.55	-0.83	-0.38	0.11
Moy	-1.27	-0.36	-0.04	-1.80	-0.57	-0.75	-0.46	0.34
Max	-0.39	0	0.1	-1.62	-0.42	-0.1	-0,34	0.7
Min	-1.66	-0.83	-0.55	-2.04	-0.74	-1	-0.61	-0.04

B=station; Moy=mean; Max=maximum; Min=minimum

4 DISCUSSION

The leachates from the Akouédo landfill are highly mineralized, with an electrical conductivity of 8544 µScm^{-1}. They present a high pollution load in biodegradable organic matter and inorganic salts and oxidizable organic compounds. The average values of COD (1306.25 mg O_2L^{-1}) and BOD_5 (575.58 mg O_2L^{-1}) are well above Ivorian standards. The COD and BOD_5 of these leachates are in the same orders of magnitude as those reported by other autor [20] on the Akouédo landfill, which are respectively 1837.33 mg O_2L^{-1} and 853.44 mg O_2L^{-1}. On the other hand, they are significantly lower than the COD (85511 mg O_2L^{-1}) and BOD_5

(66330.44 mg O_2L^{-1}) values obtained at the Oujda landfill in Morocco [21]. This difference could be related to the age, nature and quantity of the waste as well as the different climatic factors such as rainfall, air humidity and temperature. Indeed, according to [22], these different factors are at the base of the variability of the pollutant loads [22]. According to [23], the BOD5/COD ratio is between 0.1 and 0.5 for intermediate leachates. With a BOD5/COD ratio of 0.47, the leachate from the Akouédo landfill is therefore an intermediate leachate. This means that the organic molecules contained in these leachates have not yet reached the final stage of their degradation. At this stage, they are characterized by an unstable phase of methane fermentation, which favors the phenomenon of anaerobiosis and the maintenance of the landfill in an active degradation phase [24]. Leachate from the Akouédo landfill flows into the waters of M'Badon Bay, which it contributes to pollute. The temperatures recorded in these waters range from 25.1 to 32.4°C, with an average of 28.95°C above the guide value of 22°C [19] for surface fresh waters used for the production of water for human consumption. They are acceptable because they are consistent with those of the climate in the Abidjan region. The average of 28.95°C is close to those obtained by [25] for other bays of the Ebriée Lagoon. These are the bays of Banco (29.72 °C), Cocody (28.97 °C), Marcory (29.11 °C), Milliardaires (29.13 °C) and Biétri (29.74 °C). TSS concentrations ranged from 1.15 to 138.14 mgL^{-1}, with an average of 65.13 mgL^{-1} guide value of 25 mgL^{-1} [19]. Most chemical pollutants are adsorbed onto TSS which is a pollution factor [26], [27]. This adsorption of chemical pollutants on TSS drained in lagoon environment, limits the penetration of light into the water and results in a decrease in photosynthesis of phytoplankton underwater, with the consequent reduction of dissolved oxygen in the aquatic environment [2]. The average electrical conductivity of 890 μScm^{-1} is lower than the guide value of 1100 μScm^{-1} [19]. However, it indicates significant mineralization of the waters. The mean values of COD (160.70 mgO_2L^{-1}), BOD_5 (64.04 mgO_2L^{-1}) and NH_4^+ (0.22 mgL^{-1}) are higher than the French guide values. COD and BOD_5 are in the same orders of magnitude as those obtained on the Baie des Milliardaires [25] which are 175.50 mgO_2L^{-1} and 51.7 mgO_2L^{-1} respectively. However, they remain lower than those obtained by these authors in the bays of Banco (286.3 mg O_2L^{-1} and 111.7 mg O_2L^{-1}), Cocody (273.7 mg O_2L^{-1} and 112 mg O_2L^{-1}, Marcory (309.7 mgO_2L^{-1} and 101.4 mgO_2L^{-1}) and Biétri (381.8 mg O_2L^{-1} and 125.6 mgO_2L^{-1}). These bays are subject to direct discharges, which are greater than those from M'badon Bay. These discharges would come from industrial, agricultural, port, domestic and artisanal activities [28]. The Principal Component Analysis (PCA) shows that the mineralization of the waters of M'Badon Bay has a natural and an anthropogenic origin. Indeed, the bay is under the influence of rainfall that falls directly on the water body, leaching water from the rocks of the watershed, decomposition of organic matter, hydrolysis of minerals from the underlying sediments and leachate inputs from the Akouédo landfill. According to [29] and [30], hydrolysis of minerals from underlying sediments is a source of ions for surface waters even though its contribution seems relatively small. This is because of the relatively short residence time of water in the bedrock. On the other hand, leachates from the Akouédo landfill are a considerable source of organic and mineral elements and nutrients as evidenced by the average values of NO_3^- (92.92 mgL-1), PO_4^{3+} (128.74 mgL^{-1}) and NH_4^+ (388.40 mgL^{-1}) in these leachates. According to [30], various domestic and industrial wastes are generally rich in monovalent and divalent ions that contribute to elevated water conductivity. M'Badon Bay is also polluted by untreated industrial effluents that are discharged into it. Indeed, industrial effluents are mainly composed of pollutants in solid or dissolved state, minerals, metals, hydrocarbons, solvents and organic matter, at various levels of toxicity [2]. Riparian populations also contribute to the pollution of the bay, with open defecation on the shoreline, illegal dumping of household garbage around the bay, agricultural runoff, and uncontrolled discharge of domestic wastewater.

In the surficial sediments of M'Badon Bay, average concentrations of Mn, Zn, Cu, Fe, Pb, Ni and Cr are lower than those recommended for unpolluted sediments by [15] and [14]. However, zinc at stations B1, B4 and B5 and copper at stations B1 and B4 have concentrations above the recommended values. This could be explained by the fact that these stations are located in the area where Akouédo leachate enters the bay. As for Mo, it has concentrations higher than that recommended by [16] at all stations.

The study of enrichment factors for Zn, Cu, Mn, Pb, Ni and Cr reveals no or minimal enrichment at some stations and moderate enrichment at others. The moderate enrichment of Zn at station B1, of Cu at stations B1, B2, B3, B4, B6, B8 and B9 and of Mo at stations B5, B7 and B9 as well as the significant enrichment of the latter at stations B1, B2, B3, B4, B6 and B8, reflect the direct influences of anthropogenic inputs. These inputs are conveyed by leachates from the Akouédo landfill [32] and the network of domestic wastewater, stormwater and industrial effluents that discharge into the bay. Regarding the geo-accumulation index, it indicates that station B1 is moderately polluted by Zn. It also shows that stations B1, B2, B3, B4, B5, B6, B8 and B9 are moderately polluted by Cu and Mo. According to [33], the TME pollution load of the sediments comes from different discharges from agricultural, domestic and artisanal activities.

5 CONCLUSION

In this study, the quality of water and sediment in M'Badon Bay was assessed. The methodology used showed that the waters of the bay are polluted by organic and mineral oxidizable matter. It highlighted the pollution of surface sediments by Zn, Cu and Mo. All of these organic and chemical pollutants come from anthropogenic activities. The State should take measures to ensure that domestic wastewater, landfill leachate, and industrial effluents undergo adequate treatment before discharge into the aquatic environment to avoid environmental problems.

ACKNOWLEDGEMENTS

We express our gratitude to the direction of orientation and scholarships of the Ministry of Higher Education and Scientific Research as well as to the steering committee of PASRES of the Swiss Center for Scientific Research (CSRS) for their financial support.

Our thanks also go to the Laboratory of the Ivorian Anti-pollution Center (CIAPOL) for its technical support

REFERENCES

[1] Issola Y., Kouassi A. M., Dongui B. K., Adingra A. A. et Biemi J. (2009). Concentration en métaux lourds des sédiments d'une lagune côtière tropicale: lagune de Fresco (Côte d'Ivoire). Journal of Applied Biosciences, 18, pp.1009-1018.

[2] Dongo K. R., Niamke B. F., Adje A. F., Britton B. G. H., Nama L. A., Anoh K. P., Adima A. A. et Atta K. (2013). Impacts des effluents liquides industriels sur l'environnement urbain d'Abidjan - Côte D'Ivoire. Int. J. Biol. Chem. Sci., Vol 7, N°1, pp. 404-420.

[3] Kinimo K. C., Yao K. M., Marcotte S., Kouassi N. L. B., Trokourey A. (2018). Distribution trends and ecological risks of arsenic and trace metals in wetland sediments around gold mining activities in central-southern and southeastern Côte d'Ivoire. Journal of Geochemical Exploration, Vol. 190, pp. 265-280.

[4] Ouattara A. A., Sangare N., N'goran K. P. D. A., Yao K. M., Albert Trokourey A. et Diaco T. (2021). Evaluation de la contamination des éléments traces métalliques dans les sédiments de la rivière N'zi, Côte d'Ivoire. Int. J. Biol. Chem. Sci., Vol 15, N°5, pp. 2199-2208.

[5] Togbe A. M. O., Kouame K. V, Yao K. M., Ouattara A. A., Tidou A. S., Atsé B. C. (2019). Évaluation de la contamination des eaux de la lagune Ebrié (Zones IV et V), Côte d'Ivoire en arsenic, plomb et cadmium: variations spatio-temporelles et risques sanitaires. Int. J. Biol. Chem. Sci., Vol. 13, N°2, pp. 1162-1179.

[6] Cisse D., Ndiaye B., Ndiaye M., Diagne I., Dione C. T., Hane M. & Diop A. (2021). Assessment of Contamination Marine Sediments From Dakar Coast (Senegal) By Chlorine And Metallic Elements (Cu, Zn and Cr). European Journal of Applied Sciences, Vol.9, N°2, pp. 107-114.

[7] Wei X., Han L., Gao B., Zhou H., Lu J., Wan X. (2016). Distribution, bioavailability, and potential risk assessment of the metals in tributary sediments of Three Gorges Reservoir: The impact of water impoundment. Ecol. Indicat., Vol. 61, part 2, pp. 667-675.

[8] Ouattara A. A., Yao K. M., Soro M. P., Diaco T., Trokourey A. (2018). Arsenic and Trace Metals in Three West African rivers: Concentrations, Partitioning, and Distribution in Particle-Size Fractions. Archives of Environmental Contamination and Toxicology, Vol. 75, N°3, pp. 449-463.

[9] Traoré A. (2016). Impacts des changements climatiques et du changement de l'occupation et de l'utilisation du sol sur les ressources en eau de l'environnement lagunaire d'Aghien et de Potou (Sud-est de la Côte d'Ivoire). Thèse de Doctorat Unique, Université Félix Houphouët-Boigny de Cocody, Abidjan-Côte d'Ivoire, 220 p.

[10] Delor C., Diaby I., Simeon Y., Adou M., Zamble B. Z., Tastet J-P., Yao B., Konan G., Chiron J-C. et Dommanget A. (1992). Carte géologique de la Côte d'Ivoire à 1/200 000, 1ère Edition, Feuille GRAND-BASSAM, Direction de la Géologie, Abidjan, Côte d'Ivoire.

[11] Association Française de Normalisation (AFNOR) (1994). Qualité de l'eau. Recueil de normes françaises, Environnement. Première édition, Paris, France, 862 p.

[12] Rodier J. (2009). L'Analyse de l'eau 9ème édition, Dunod, Paris, France, 1579 p.

[13] Tessier A., Campbel P.G.C. and Bisson M. (1979). Sequential extraction procedure for the speciation of particulate traces metals. Analytical Chemistry, Vol.51, N°7, pp. 844-851.

[14] Kikouama O. J. R., Konan K. L., Katty A., BonneT J. P., Balde L. and Yagoubi N. (2009). Physicochemical characterization of edible clays and release of trace elements. Appl. Clay Sci., Vol.43, N°1, pp. 135-141.

[15] Calamari D. et Naeve H. (1994). Revue de la pollution dans l'environnement aquatique africain. Document Technique du CPCA, No25. Rome, FAO, 129 p.

[16] Wedepohl K.H. (1995). The composition of continental crust. Goechimica and Cocmochimica Acta, Vol.59, N°7, pp. 1217-1232.

[17] Sutherland R. A. (2000). Bed sediment associated trace metals in an urban stream, Oahu, Hawaii. Environmental Geology, Vol.39, pp. 611-637.

[18] Müller, G. (1969). Index of geoaccumulation in sediments of the Rhine River. Geojournal, Vol.2, pp. 109-118.

[19] Journal Officiel De La République Française (2007). Limites et références de qualité des eaux destinées à la consommation humaine, à l'exclusion des eaux conditionnées. Ministère de la Santé et des Solidarités. Arrêté du 11 janvier 2007 relatif aux limites et références de qualité des eaux brutes et des eaux destinées à la consommation humaine mentionnées aux articles R. 1321-2, R. 1321-3, R. 1321-7 et R. 1321-38 du code de la santé publique, 9 p.
[20] Kouame K. I. (2007): Pollution physico-chimique des eaux dans la zone de la décharge d'Akouedo et analyse du risque de contamination de la nappe d'Abidjan par un modèle de simulation des écoulements et du transport des polluants. Thèse de Doctorat, Université d'Abobo Adjamé, Côte d'Ivoire, 212 p.
[21] Saadi S., Sbaa M. et El Kharmouz M. (2013): Caractérisation physico-chimique de lixiviats du centre d'enfouissement technique de la ville d'Oujda (Maroc oriental). Science Lib Editions Mersenne, vol. 5, n° 130517, pp. 1-12.
[22] Christensen T. H., Kjeldsen P., Bjerg P. L., Jensen D.L., Christensen J. B., Baun A., Albrechten H-J. et Heron G. (2001). Biogeochemistry of landfill leachate plumes. Applied Geochemistry, vol. 16, N° 7-8, pp. 659-718.
[23] Amokrane A., Comel C. and Veron J. (1997): Landfill leachate pretreatment by coagulation-floculation. Water Research, vol 31, n°11, pp. 2775-2782.
[24] Ahel M., Mikac N., Cosovic B., Prohic E. et Soukup V. (1998): The impact of contaminant from a municipal solid waste landfill (Zagreb, Croatie) on underlying soil, Water Science and Technology, vol 37, n°8, pp. 203-210.
[25] Yao K. M., Soro M. B., Trokourey A. and Bokra Y. (2009). Assessment of Sediments Contamination by Heavy Metals in a Tropical Lagoon Urban Area (Ebrié Lagoon, Côte d'Ivoire). European Journal of Scientific Research, ISSN 1450-216X, Vol.34, No.2, pp. 280 -289.
[26] Marchand M. et Martin J.L. (1985): Détermination de la pollution chimique (hydrocarbures, organochlorés, métaux) dans la lagune d'Abidjan (Côte d'Ivoire) par l'étude des sédiments. Océanogr. Trop., Vol. 20, N°1, pp. 26- 39.
[27] Affian K, Kadio B, Djagoua E. V, Digbehi Z. B, Monde S, Wognin A. V, Adonis K. D. et Mobio A. (2008): Flux de la matière en suspension du fleuve Comoé de la zone littorale ivoirienne. Revue CAMES, serie A, vol 6, pp. 88-93.
[28] Soro G., Metongo B. S., Soro N., Ahoussi E K, Kouamé F. K., Zadé S. G. P. et Soro T. (2009): Métaux lourds (Cu, Cr, Mn et Zn) dans les sédiments de surface d'une lagune tropicale africaine: cas de la lagune Ebrie (Côte d'Ivoire). International. Journal of Biological Chemical Science vol 3, n°6, pp. 1408-1427.
[29] Yidana S. M. (2008). The hydrochemical framework of surface water basins in southern Ghana. Journal of Environmental Hydrology, vol.16, p.1-11.
[30] Traoré A., Soro G., Keumean K. N., Aka N., Ahoussi K. E., Soro N. et Biémi J. (2017). Etude de la qualité physique et chimique des eaux d'une lagune tropicale anthropisée: cas de la lagune Aghien (Sud-Est de la Côte d'Ivoire). EWASH & TI Journal, 1 (2), 13-24.
[31] Ben Bouih H, Nassali H, Leblans M. et Srhiri A. (2005): Contamination en métaux traces des sédiments du lac Fouarat (Maroc). Afrique Science, vol 1, n°1, pp 109-125.
[32] Sangaré N., Yao K. M., Kwa-Koffi E. K., Kouassi N. L. B., Soro M. B. et Kouassi A. M. (2016). Évaluation de la qualité des ressources en eau près de la décharge urbaine non contrôlée d'Akouédo par le calcul des risques cancérigènes et des indices de pollution, Côte d'Ivoire. Afrique SCIENCE, Vol. 12, N°5, pp. 279-290.
[33] Keumean, K.N., Bamba, S.B., Soro, G., Soro, N., Metongo, B.S. & Biemi, J. (2013). Concentration en métaux lourds des sédiments de l'estuaire du fleuve Comoé à GrandBassam (Sud-Est de la Côte d'Ivoire). J. Appl. Biosci., Vol. 61, pp 4530 – 4539.