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Assessment and Impact of Leachate Generated by the Landfill City in Abidjan on the Quality of Ground Water and Surface Water (M'Badon Bay, Côte d'Ivoire)

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Abstract

The municipal Akouedo landfill of the city of Abidjan (Cote d'Ivoire) is composed of more than 60% of household waste. It lacks a leachate collecting and treatment device. To highlight the impact of the leachate on the receiving environments, some sampling campaigns of leachate, groundwater and surface waters were conducted from June 2013 to January 2014. Analyses of leachate samples revealed relatively high concentrations of trace metals: Fe (6450 ± 8690 µg/L), Cu (400 ± 272 µg/L), Zn (520 ± 240 µg/L), Cd (113 ± 105 µg/L), Pb (550 ± 237 µg/L), Ni (312 ± 97 µg/L) and Co (77 ± 56 µg/L). Fe is the most abundant chemical element. The analysis of groundwater and surface indicates that the levels of trace metals in these waters are higher than WHO standards except Zn.

Keywords

Leachate, Coastal Lagoon, Groundwater, Trace Metals, Pollution

1. Introduction

The disposal of municipal solid waste is a major concern, especially in developing countries where poverty, population growth and high urbanization rates, lack of financial and technical resources can hamper the efficient and sustainable management of waste [1]. Landfill and/or open dumpsite are the common and inexpensive practice for municipal solid waste disposal in developing and developed countries [2]. Unfortunately, the implementation of these "wild" landfills is generally not preceded by an environmental and social impact assessment. As a consequence, they present potential risks to the environment and populations through the emission of biogas and especially the production of leachates.

Leachates composition varies according to several factors such as the nature and the age of the landfill, the type of waste, the method of landfill, the nature of the site and the climatic conditions [3] [4] [5]. Leachates contain dissolved organic and inorganic compounds, trace metals (cadmium, copper, zinc, lead, nickel, cobalt, iron etc.) and xenobiotic organic substances (phthalates, benzene, phenols) [6]-[13]. The mineral fraction of landfill leachates essentially consists of chlorides, sulphates, bicarbonates, potassium, sodium and ammonium, while the organic part is closely related to the age of the waste. If young discharges are characterized by the dominance of volatile fatty acids (especially acetic, propionic and butyric acids), they are predominantly fulvic and humic acids in older leachates [6].

Leachate accumulates at the bottom of the landfill and percolates through the soil leading to the receiving environments (groundwater and surface water) pollution. The impact of leachate on the surface and groundwater has given rise to a number of studies in recent years. The study of the physicochemical quality of groundwater near the Casablanca urban landfill revealed high levels not only of heavy metals but also of trace metals emanating from the leachates [14]. The work of Ikem *et al.* [10] showed that the sediments of the Ibadan and Lagos (Nigeria) landfills were heavily contaminated by metals such as Zn and Pb (Ibadan), and by Zn, Pb, Cu and Cd (Lagos). Similarly, Kanmani and Gandhimathi [15] reported a case of lead contamination of groundwater near the Aryamangalam landfill in Tamil Nadu (India). Low levels of metal contamination have been reported in the sediments of the landfills Oblogo, Ghana [16] and in the soils of the Enyimba landfill in Nigeria [17].

The metals contained in the leachate can either migrate to the water table and make it unfit for consumption, or accumulate in soils and bioaccumulate in agricultural products [18] [19] [20] [21] [22]. The release of leachate into natural waters can have serious consequences for aquatic species [23]. Sediments are generally considered as a sink for metals and play an important role in the regime of groundwater pollution and aquatic systems [24] [25] [26] [27]. The assessment of metal concentrations in sediment in landfills is essential in understanding the impact of landfill on metal pollution in the environment.

In Côte d'Ivoire, the municipal Akouedo landfill of the city of Abidjan covers an area of over 153 ha. The literature only revealed the work undertaken by Adjiri *et al.* [28] on the chemical and microbial contamination of the soil of the Akouedo landfill and that of Kouassi *et al.* [29] on the chemical characterization (NO_3^-, PO_4^{3-}, NH_4^+, DBO_5, DCO) of the leachate. The influence of the season on the production of methane released by the landfill Akouédo was also studied by Adjiri *et al.* [30]. Few other studies have been devoted to the impact of the landfill on the environment in the vicinity of the landfill. The aim of this work is to study the impact of the Akouédo landfill leachate on groundwater and the Ebrié lagoon ecosystem.

2. Materials and Methods

2.1. The Study Area

The study area is the Akouédo landfill, which is the only landfill in the Abidjan district. It is located in the northeast of the district, in the commune of Cocody (residential district high standing), between 396,000 m and 397,000 m on the abscissa and between 590,000 m and 591,000 m as ordinates in the reference frame UTM 30N. This landfill, established since 1965, covers an area of 153 ha. It is located halfway between the Abidjan-Bingerville axis and 18 km from the city center. It occupies a talweg with a natural drainage to the Ebrié lagoon (M'Badon Bay), to the south, within 2.1 km [31]. To the north, it is limited by the high-class residential areas Genie 2000 and Les Lauriers, to the west by the village of Akouédo, and to the east by the village of Akouédo Attié and the commune of Bingerville (**Figure 1**). In its current functioning, it is classified as a wild dump [32] approximately receiving 550,000 tons of waste per year, of which two thirds are composed of domestic waste and the third remaining of industrial and some dangerous waste [31]. The leachate generated from the landfill is drained in an anarchistic way under the heaps of garbage towards the Bay of M'Badon.

The M'badon bay, one of the Ebrié lagoon ecosystem bays, (**Figure 1**) is localized between longitude 3˚89'E - 3˚90'E, latitude 5˚34'N and altitude 73 m above the sea level. This bay covers a surface area of 3.91 Km^2 and has a perimeter of 8 Km. It is characterized by depths generally less than 3 m, with a length and average width, respectively of 2.3 km and 1.70 km. This bay has an estimated water volume 9.8×10^6 m^3. Its watershed is estimated to be 78,000 Km^2. The M'Badon bay is under the influence of continental (the Comoe River and rainfall), oceanic and anthropogenic inputs.

2.2. Water Sampling and Analysis

Sampling of groundwater, surface waters and leachate was conducted from the leachate flow to the lagoon between 2013 and 2014 during the dry (December and January) and rain seasons (June and July) (**Figure 1**). Stations L1 and L2 were selected in the valley, 0.3 km and 0.7 km respectively from the landfill. The wells located not far from the lagoon and the leachate flow were also sampled (P1 and P2). Eight sampling stations (S1 to S8) were also selected in the M'Badon bay, a receptacle of the leachate water. The stations S1, S2, S3 and S6 are near the weir of the leachate. Station S4 is located in a confined area of the bay. Station S5 receives discharges from the population of M'Badon. The S7 and S8 stations are located at the entrance of the bay and receive the waters of the Comoé River during the flood season and the marine waters mainly during the dry season.

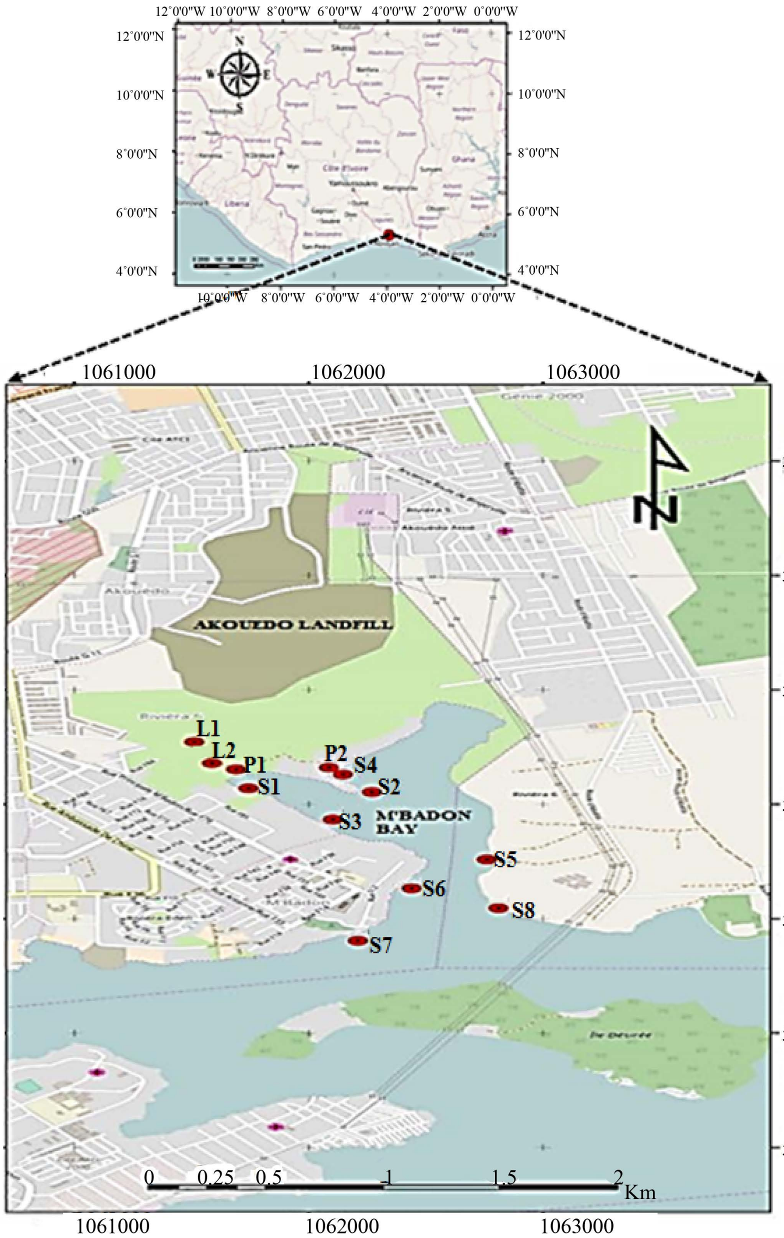

Figure 1. Location of Akouedo landfill and sampling stations.

The water samples were taken using a Niskin bottle at the depth of 0.5 m and collected in one liter polyethylene bottles. The bottles were stored immediately in cool (4˚C) and protected from light in order to avoid any possible photo-chemical or biological reaction. In the laboratory, all water samples were directly stored in freezers at temperatures below 4˚C. Temperature, conductivity, salinity and pH were measured in situ using the HI 9828 pH /ORP/EC/DO multiparameter brand HANNA. Trace metals (Cd, Pb, Cu, Ni, Zn, Fe et Co) concentrations were determined using an atomic absorption spectrophotometer to air-acetylene flame like Varian AA20 (SpectrAA100 Varian spectrophotometer, Japan). All water samples for metal analysis were acidified with nitric acid (2%). For statistical analysis parametric test of ANOVA (Software Statistica 7.1) and test of WILCOXON were used to compare the mean values of the tested parameters for all the different sampling sites.

3. Result and Discussion

3.1. Leachate Physico-Chemical and Chemical Characterization

3.1.1. Leachate Physico-Chemical Characterization

1) pH

The results of the physico-chemical analyses of leachate samples are presented in **Table 1**. The pH in the leachate range from 8.33 to 8.78 (**Table 1**), with an average of 8.51 ± 0.14, showing its basic character. Studies carried out on the same landfill have obtained similar pH [31] [33]. These data are also of the same order of magnitude as those obtained by El Khamlichi *et al.* [34] on the landfill in Rabat (Morocco) and Tränkler *et al.* [35].

The basic character of the leachate seems to indicate that the Akouédo landfill is an old and stabilized landfill, with an anaerobic fermentation (methanogenesis) stage [30]. Leachate waters presenting an acid character are those from the young landfill [36]. The pH obtained in the leachate from the Akouedo landfill could also be related to the low concentration of volatile organic compounds. Indeed, during acid fermentation, the first phase of anaerobic waste decomposition, young percolates are rich in volatile organic compounds. During this phase, the recorded pH is generally less than 4 [37]. As leachate ages, it becomes depleted of volatile organic compounds and is enriched with carbonates ($CaCO_3$) and ammonium (NH_3^-) [5]. This will lead to the increase of the pH to 7 or higher [38]. The seasonal pH variation in the leachate (**Figure 2**) shows that it remains basic in all seasons. It is also important to note that pH is significantly higher (Wilcoxon test, $p < 0.05$) during the rainy season than during the dry season. Our results are corroborated by Er-Raioui *et al.* [39] who observed a basic leachate with a pH of 7.87 during the rainy season and acid leachate (pH = 4.78) during the dry season.

2) Temperature

The temperature of the leachate varies between 23.90˚C and 35.19˚C with an average of 29.52˚C ± 3.12˚C (**Table 1**). The temperature recorded during the dry season are the highest (ANOVA, $p < 0.05$) (**Figure 3**) and are due to the high ambient temperature. According to Kouamé [31], these temperatures are susceptible to favor the maintenance of colonies of "mesophilic" microorganisms

Table 1. Leachate physical parameters.

Parameters	pH	Temperature (˚C)	Conductivity (mS/Cm)	Salinity (‰)
L1	8.53	29.25	25931	14.97
	8.33 - 8.78	23.92 - 32.2	10060 - 37990	0.04 - 23.93
L2	8.50	29.79	24619	13.85
	8.35 - 8.71	23.90 - 35.19	10220 - 37320	0 - 23.48

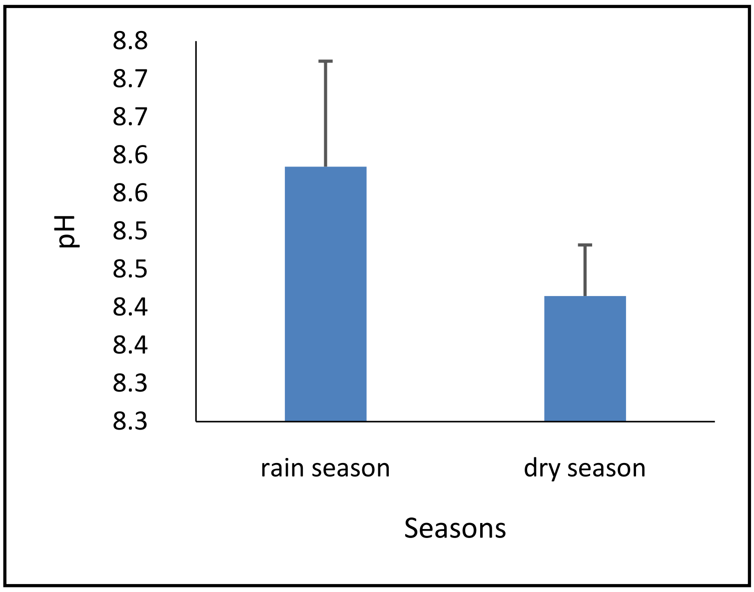

Figure 2. Seasonal variations of pH in leachate.

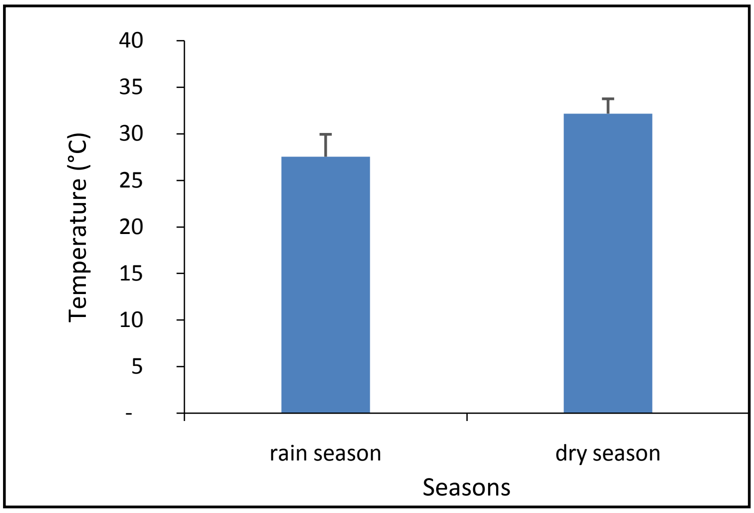

Figure 3. Seasonal variations of temperature in the leachate.

which develop at a temperature between 20˚C and 40˚C. The increase in temperature can also stimulate the oxidation, the hydrolysis and the remineralization of waste by bacteria (stimulation of bacterial enzymatic activity) and make the leachate rich in mineral elements [31]. Temperatures recorded during the dry season are the highest (ANOVA, $p < 0.05$) (**Figure 3**) and are due to the high ambient temperature.

3) Conductivity

The electrical conductivities recorded in leachate fluctuate between 10,060 and 37990 $\mu S \cdot cm^{-1}$ (**Table 1**). The mean conductivity is 25,275 ± 8340.99 $\mu S.cm^{-1}$. Kouassi *et al.* [29] studied the physico-chemical characteristics of the Akouedo landfill and obtained conductivities ranging from 2390 μS/cm to 17,150 μS/cm; the mean value being 7805.42 μS/cm. These results are lower than those obtained in this study, but of the same order of magnitude as the conductivity measured in the leachates of the landfills in Colombia [40] and Morocco [41]. The high conductivities are related to a strong accumulation of ions in the Akouedo leachate. High conductivities are recorded during the dry season (**Figure 4**). The low conductivities obtained during the rainy season could be explained by the dilution phenomenon. Indeed, during this season, the leachates receive a large quantity of water resulting in a considerable dilution of the chemical elements [31].

3.1.2. Chemical Characterization of Leachate

1) Total metallic trace elements concentration in the leachate

Trace metals from the Akouédo landfill leachate have average concentrations of 6450 ± 8690 µg/L for Fe, 400 ± 272 µg/L for Cu, 520 ± 240 µg/L for Zn, 113 ± 105 µg/L for Cd, 550 ± 237 µg/L for Pb, 312 ± 97 µg/L for Ni and 77 ± 56 µg/L for Co (**Table 2**). All these concentrations are much lower than the limit

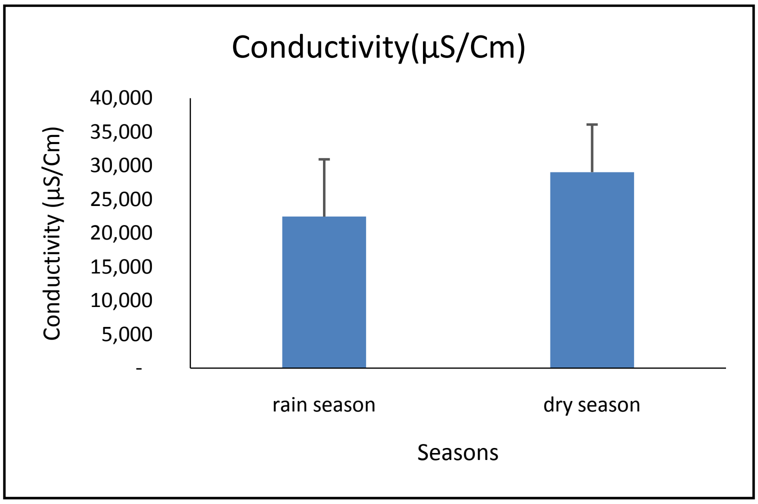

Figure 4. Seasonal variations of conductivity in the leachate.

Table 2. Metallic trace elements concentrations in the leachate.

Parameters	L1	L2	variation (mg/L)
Fe (µg/L)	4570 70 - 10,540	8330 70 - 34,100	3 - 5500
Cu (µg/L)	400 210 - 1120	400 80 - 800	0.005 - 10
Zn (µg/L)	510 197 - 840	520 204 - 1020	0.03 - 1000
Cd (µg/L)	90 50 - 250	130 30 - 360	0.0001 - 0.4
Pb (µg/L)	540 Nd - 820	560 Nd - 950	1 - 5
Ni (µg/L)	310 210 - 430	320 250 - 410	0.015 - 13
Co (µg/L)	90 Nd - 180	70 40 - 130	0.015 - 14

concentrations set by WHO [42] except for Cd, which has a concentration close to the limit value.

Of all these trace metals, Fe exhibited the highest concentrations in the two study stations; this could, be explained by the predominance of Fe among the metal scrap of the landfill. The dark brown color of the leachate was mainly attribute to the oxidation of ferrous to ferric form and the formation of ferric hydroxide colloids and complexes with fulvic/humic substance [43]. According to Legret [44], nickel and zinc are the most leachable elements in fresh waste. They may both come from special wastes such as batteries, paint pigments, stabilizers or rubbers [45] [46]. The presence of Pb in the leachate indicates the discharge of batteries, Pb-based paint, chemicals from photographic treatments. Copper, for its part, could originate from several types of waste, such as printing inks or paints, cardboard, rubber and textiles [47].

The concentrations of the trace metals of the Akouedo landfill leachate are globally identical to those of the leachates generated by other garbage dumps and are of the same order of magnitude as the results obtained by other landfills (**Table 3**). The concentrations of trace metals in the leachate from the Akouédo landfill are low and do not reflect the actual metal concentrations of the of old landfills. The majority of trace metals, mainly copper, nickel, lead, iron, zinc and cadmium could be trapped within the Akouedo landfill [48] [49]; that is the reason trace elements concentrations are low. Baccini *et al.* [48] estimate that more than 99.9% of heavy metals remain trapped in the landfill after 30 years. For François [50], 95% of the metals remained trapped within the mass of waste at the end of 4 years.

It should be noted that the concentrations of the various metals obtained are in the range of those from the so-called old leachate [16] [41] [42] [27] [54] (**Table 3**). Studies have shown that the older the waste, the more stable the metals within the waste [50]. François [50] has also shown through fractionation protocols applied to wastes of different ages that metals are more easily remobilizable in a young waste than in an old waste. The concentrations of trace elements obtained in the leachate from the Akouédo landfill might be due to the composition of the waste, the basic character and the age of the landfill. The metal charge, however, poses an enormous risk to groundwater because there is direct contact of the leachate with the underlying aquifer in the landfill area and also for the surrounding surface waters.

The seasonal variations of trace metals in the leachate are shown in **Table 4**. High concentrations of Ni, Fe and Zn metals are observed during the rainy season; Pb, Cu, Co and Cd have high concentrations during the dry season. The ANOVA statistical analysis ($p < 0.05$) indicates that there is a significant difference between the rainy season and the dry season for trace metals such as Pb, Cd, Zn and Cu. This result can be explained by a dilution of the leachate by precipitation water. On the other hand, no significant difference was observed between the two seasons for Fe, Co and Ni. High concentrations of Zn during the

Table 3. Comparison of trace metals concentrations of leachate from the Akouedo landfill with leachate from other landfills.

Stations	Fe (µg/L)	Zn (µg/L)	Pb (µg/L)	Cd (µg/L)	Cu (µg/L)	Ni (µg/L)	Co (µg/L)	References
Akouedo landfill	72 - 34100	197 - 1015	233 - 947	29 - 362	83 - 1117	95 - 412	8 - 176	Present study
Mashhad landfill (Iran)			200 - 450	7	30 - 400	200 - 450		[27]
Effurun landfill. (Nigeria)	17490	197	88		4030			[51]
Oblogo landfill (Ghana)	3830 - 5960	7420 -		140 - 200	8970 - 13780			[16]
Ibb City landfill. Yemen	46000 - 47700	56000 - 85500	2600 - 2850	250 - 300	21500	1700 - 1800		[52]
Henchir ElYahoudia landfill	26 - 76	30 - 800	10 - 180	10 - 30	40 - 90	130 - 670		[53]
Etueffont landfill (France)	2630	300 - 1850	100	10	0 - 1770	170 - 8640	60	[54]
El Jadida landfill (Maroc)	24000	0 - 747.2		0 - 34	0 - 159	0 - 133.8		[41]
WHO	3 - 5500	0.03 - 1000	1 - 5	0.0001 - 0.4	0.005 - 10	0.015 - 13	0.015 - 14	[42]

Table 4. Seasonal variations in metal concentrations in leachate.

Seasons	Fe (µg/L)	Cu (µg/L)	Zn (µg/L)	Cd (µg/L)	Pb (µg/L)	Ni (µg/L)	Co (µg/L)
Rain Seasons	8.92 ± 9.70	0.28 ± 0.12	0.63 ± 0.21	0.05 ± 0.02	0.42 ± 0.15	0.32 ± 0.11	0.09 ± 0.04
Dry Seasons	0.09 ± 0.03	0.70 ± 0.33	0.27 ± 0.10	0.25 ± 0.10	0.82 ± 0.10	0.28 ± 0.08	0.11 ± 0.05

rainy season show that other factors such as chemical and physical biological processes within the landfill can influence the seasonal variation of metals in the leachate. Further studies are needed to better explain the seasonal variation of Zn in leachate from the Akouedo landfill.

3.2. Evaluation of the Impact of Leachate on the Quality of Groundwater near the Akouedo Landfill

3.2.1. Physico-Chemical Characterization of Groundwater

1) pH and Temperature

The physical and chemical parameters of the groundwater are displayed in Table 5. The M'badon groundwater pH is between 4.72 and 6.46, showing its acidic character compared to the leachate which is more basic. The average M'badon groundwater temperature is between 24.49˚C and 30.23˚C (Table 5). The M'badon groundwater temperature is well above 25˚C, a tolerated value for water intended for human consumption in France (French Standards, 1999) and in Morocco (Moroccan Standards, 2002). In accordance with international standards (Table 6), the M'badon groundwater is not suitable for domestic use especially for drinking water.

The M'badon groundwater pH and temperature seasonal variation are shown in Figure 5. The temperature and pH are relatively lower during the rainy season than during the dry season, due to dilution and ambient temperature, respectively.

Table 5. Physical parameters of groundwater.

Parameters	pH	Temperature (˚C)	Conductivity (µs/Cm)	Salinity (‰)
P1	5.36 4.78 - 6.46	27.05 24.02 - 30.23	72.29 43 - 86	0.03 0.02 - 007
P2	5.31 4.72 - 6.42	26.97 24.49 - 28.97	51.71 5 - 39	0.02 0 - 0.1

Table 6. Recommended standard for WHO, US EPA and EU for drinking water.

Parameters	BIS standards (IS 10500: 1991) [55]		WHO (2002) [56]	WHO (2008) [56]	WHO (2011) [57]	US EPA (2009) [58]	UE [59]
	Limite desirable	Limite permitted					
pH	6.5 - 8.5	6.5 - 8.5	6.5 - 9.2				
Fe (mg/L)	0.3	1	0.3	0.3	0.3	0.3	-
Cd (mg/L)	0.01	-	0.005	0.003	0.003	0.005	0.003
Cu (mg/L)	0.05	1.5	1	2	2	1.3	2
Zn (mg/L)	5	15	5	3	3	5	3
Pb (mg/L)	0.05	-	0.05	0.01	0.01	0.015	0.01
Ni (mg/L)	-	-		0.15 - 13	0.07	-	0.02
Co (mg/L)	-	-		0.04	-	-	-

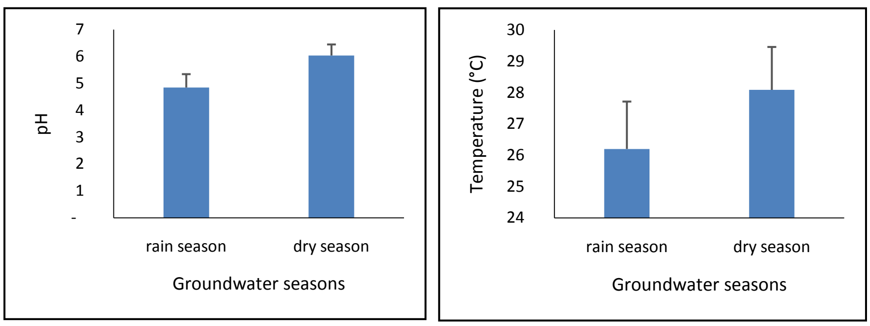

Figure 5. Seasonal variation of pH and Temperature in groundwater.

2) Conductivity

Table 5 presents the M'badon groundwater conductivity. The conductivity is generally below 86 µS/cm, showing a low mineralization of the groundwater. The M'badon conductivity is lower than that found in groundwater located near a landfill in France (32 - 245 µS/cm) [54] and in Morocco in the El Jadida public dump (Morocco) (1510 - 8400 µS/cm) [41].

3.2.2. Total Concentration of Groundwater in Traces of Metal

The M'Badon groundwater trace metals concentrations are shown in Table 7. Trace metal concentrations are lower than those of the Akouédo landfill leachate but above the WHO standards, except for Zn, which has a lower concentration (30 µg/L) than the standard (3000 µg/L). Cu is the most recovered element in

Table 7. Concentrations of trace metal in groundwater.

Parameters	P1	P2
Fe (µg/L)	321 87 - 598	Nd
Cu (µg/L)	1041 16 - 3932	194.2 7 - 864
Zn (µg/L)	30.83 3 - 56	28.83 17 - 39
Cd (µg/L)	60 7 - 158	31 4 - 132
Pb (µg/L)	764 nd - 764	502 nd - 502
Ni (µg/L)	51.33 3 - 103	64 nd - 64
Co (µg/L)	48.5 44 - 53	44 nd - 44

high amount (3932 µg/L) followed by Pb (764 µg/L). The results obtained from this study are similar to those obtained by Kanmani *et al.* [15]. The ANOVA analysis ($p < 0.05$) shows that there is no significant difference between the stations P1 and P2. Of all these observations, it is difficult to conclude that the Mbadon groundwater is affected by the metal contamination of the Akouedo landfill leachate. According to several authors [1] [16] [51] [57] [60] (**Table 8**)., the migration of metals into a permeable medium is complex from the reaction point of view (physicochemical reactions involved). Similarly, the presence of clay lenses and shales can constitute a retention factor for these trace elements, which contribute to their entrapment in the surface layer. Some metallic pollutants illustrate a "hunting phenomenon" of the input signal either instantaneously or with a certain lag. The latter is variable because it depends on the rains intensity, the nature of the chemical element, the distance from the water source of the discharge and the position of the trace metal with respect to the direction of the flow [47].

3.3. Evaluation of the Impact of Leachate on the Quality of Lagoon Water (M'Badon Bay) near the Akouédo Landfill

3.3.1. Physico-Chemical Characterization of Lagoon Water

1) pH

The pH of the M'badon bay varies from 5.94 to 7.58 (**Table 9**). Mean pH varied significantly (ANOVA, $P < 0.05$) according to the hydroclimatic season. Mean pH is 7.79 during the dry season while those of the rainy and flood season are respectively 6.86 and 6.64 (**Table 10**). Data collected in other sectors of the lagoon show the same trend. The pH is higher during the period of oceanic influence (dry season) and lower during the period of continental influence [62] [63]. Therefore, the pH variations observed in the M'badon bay of the Ebrie lagoon do not appear to be due to the influence of the Akouedo landfill on the coastal ecosystem.

2) Temperature

Table 8. Comparison of the concentration of metals of groundwater in the vicinity of the Akouédo landfill to those reported in groundwater in some areas and to WHO quality standards.

	Akouedo landfill (Cote d'Ivoire)	Alimosho landfill Lagos (Nigeria)	Oujda landfill (Maroc)	Oblogo landfill (Ghana)	Effurn Delta State landfill (Nigeria)	Kapuluppada MSW landfill (Visakhapatnam Inde)	Guidelines WHO* (mg/L)
Fe (mg/L)	0.087 - 0.598	2.45	0 - 0.91	1.67 - 5.1	1.45	4.55	0.3
Cu (mg/L)	0.007 - 3.932	2.26	nd	1.47 - 3.36	0.25	88 ± 36	2
Zn (mg/L)	0.003 - 0.056	23.71	0 - 0 42	2.1 - 3.91	1.2	0.25 - 5.711	3
Pb (mg/L)	0.502 - 0.764	0.06	nd	nd	<0.001	0.045 - 4.287	0.01
Cd (mg/L)	0.004 - 0.158	0.03	0.01 - 0.32	0.04 - 0.14	nd	0.002 - 2.482	0.003
Co (mg/L)	0.044 - 0.053	nd	nd	nd	nd	0.001 - 0.007	0.04
Ni (mg/L)	0.003 - 0.103	15.1 - 43.9	0 - 0.14	nd	nd	0.8	0.07
References	Present study	[1]	[61]	[16]	[51]	[61]	[57]

*Water consumption. nd: non detected.

The temperature varied from 23.43˚C to 31.27˚C in the M'Badon bay (**Table 9**). Maximum temperatures are observed during the dry season and minimum temperatures during the rainy and flood season of the Comoe River (**Table 10**). Those results were identical to those observed by Kouassi [63]. According to this author, the high temperature in the dry season was due to the insolation and the low temperature to the upwelling of cold water during the month of August. Moreover, the spatial variability across the lagoon is relatively low in the order of 1˚C. This spatial variability of waters was due to the backgrounds areas, to the inputs of continental and oceanic waters at different period [64]. The temperature of ocean water are constantly colder than the lagoon waters, this showed a few positif horizontal gradient from Vridi channel to upstream. Variations of temperature and pH did provide of the influence of Akouedo landfill to the lagoon ecosystem.

The average temperature of the M'badon bay is 28.09˚C ± 2.04˚C (**Table 9**). Maximum temperatures are observed during the dry season and the minimum temperatures during the rainy and flood season of the Comoe River (**Table 10**). The temperatures are identical to those observed by Kouassi [63]. According to this author, the high temperatures in the dry season are due to insolation and low temperatures during the upwelling period, occurring in August of the year. Moreover, the spatial variability over the whole lagoon is relatively low in the order of 1˚C. This spatial variability of the lagoon is due to the inputs of continental and oceanic waters at different period [64] [65]. The temperature of the oceanic waters being constantly colder than that of the lagoon waters, there is a small positive horizontal gradient of the Vridi channel upstream. Temperature variations do not therefore appear to be due to the influence of the Akouedo landfill on the lagoon ecosystem.

Table 9. Physical parameters of lagoon waters.

STATIONS	pH	T (˚C)	Conductivity (µs/Cm)	Salinity (‰)
S1	6.97	28.02	6841	3.74
S2	6.88	27.65	7393.71	4.05
S3	6.77	27.68	7154.86	4.12
S4	6.94	28.00	7045.43	3.89
S5	6.85	28.00	6946.71	4.35
S6	6.88	27.97	7645.14	4.21
S7	6.92	29.27	7545.40	4.40
S8	6.93	28.63	6894.00	4.01
M'Badon	6.90 ± 0.36	28.09 ± 2.04	7181 ± 8675	

Table 10. Seasonal variation of physical parameters in lagoon waters.

PARAMETERS	SEASONS		
	Rain	Floods	Dry
pH	6.86	6.64	7.29
Temperature (˚C)	25.65	28.48	29.38
Conductivity (µS/Cm)	6160.50	781.50	17543.94

3) **Conductivity**

Mean conductivity of the M'badon bay is 7181 ± 8675 µS/cm (**Table 9**). Seasonal variations of the surface water conductivity are very marked, rising from 782 µS/cm during the flood and rainfall seasons (6161 µS/cm) to more than 17,544 µS/cm during the dry period (**Table 10**). According to Dufour [64], as the circulation is of the estuarine type in the eastern part of the Ebrié lagoon, seawater flows in depth towards the upstream forming a wedge of salt water which undergoes twice-daily pulsations The amplitude of the tides and the regime of rivers. Its extension is maximum in the high dry season at high tide [65]. On the surface, there is an inverse current of less salty water becoming intense during periods of rains and flood of the Comoé and limiting then the extension of the salt water to a few meters of thickness [63]. All the above shows that the conductivities observed in the Bay of M'Badon and in the lagoon of Anna are related to the hydrology of the lagoon.

3.3.2. Concentration of Metals in Lagoon Waters (M'Badon Bay)

Mean concentrations and seasonal variations of trace metals in the Mbadon bay waters of the Ebrié lagoon are presented in **Table 11** and **Table 12**.

Iron

Mean Fe concentrations are between 220 and 1120 µg/L. The statistical analysis (ANOVA) shows that there is no significant difference between the stations. However, a significant difference ($p < 0.05$) was observed between seasons in

Table 11. Concentrations of metal trace elements in lagoon waters (M'Badon).

Station	Fe (mg/L)	Cu (mg/L)	Zn (mg/L)	Cd (mg/L)	Pb (mg/L)	Ni (mg/L)	Co (mg/L)
S1	0.59	0.37	0.04	0.07	0.63	0.03	0.04
S2	1.10	0.15	0.04	0.08	0.75	0.07	0.14
S3	1.12	0.16	0.05	0.09	0.83	0.07	0.09
S4	0.60	0.45	0.06	0.10	0.65	0.08	0.10
S5	0.76	0.14	0.03	0.09	0.26	0.08	0.09
S6	0.56	0.23	0.04	0.10	0.26	0.11	0.11
S7	1.03	0.10	0.03	0.10	0.86	0.12	0.10
S8	0.91	0.06	0.04	0.09	0.43	0.14	0.09

Table 12. Seasonal variations in heavy metal content in lagoon waters.

PARAMETERS	M'Badon		
	Rain	Floods	Dry
Fe (mg/L)	0.23	1.49	0.25
Cu (mg/L)	0.04	0.03	0.50
Zn (mg/L)	0.04	0.04	0.04
Cd (mg/L)	0.02	0.01	0.24
Pb (mg/L)	0.08	0.30	0.70
Ni (mg/L)	0.03	0.04	0.13
Co (mg/L)	-	-	0.09

MBadon Bay. The highest Fe concentrations are observed during the flood season (1490 µg/L) and the lowest during the wet season (230 µg/L).

Copper

Mean Cu concentrations in the MBadon Bay range from 60 µg/L to 1440 µg/L. They significantly ($p < 0.05$) vary between seasons. The highest concentrations are obtained during the dry season (500 µg/L). No significant difference was observed between stations.

Zinc

The average Zn concentrations obtained in each station are in the range of 30 µg/L to 50 µg/L. This metal does not exhibit significant inter-station variations ($p < 0.05$). Maximum concentrations were obtained during the dry season in the M'Badon Bay waters with a significant difference ($p < 0.05$) between seasons.

Cadmium

Cadmium concentrations are high in the dry season and low in the rainy season. Statistical analysis (ANOVA) showed a significant difference ($p < 0.05$) between seasons and no difference between stations.

Lead

Mean lead concentrations range from 260 µg/L (S6) to 860 µg/L (S7) in the

Mbadon bay lagoon waters. There is no statistical difference ($p < 0.05$) between the stations in the in the bay. The seasonal variation in M'Badon Bay showed that the maximum level (700 µg/L) was obtained during the dry season with a significant difference ($p < 0.05$) between the seasons.

Nickel

Mean nickel concentrations are between 30 and 140 µg/L (Table 11). There is no significant difference between the stations in the M'Badon bay. However, the ANOVA analysis ($p < 0.05$) shows a significant difference between the seasons at M'Badon Bay. Maximum concentrations were recorded during the dry season.

Cobalt

Co concentrations were only obtained during the dry season. There are no significant differences ($p < 0.05$) between inter-seasons and inter-stations in the M'Badon bay. The variation of the concentrations between the stations is of the order of 40 µg/L to 110 µg/L. The high concentrations observed during the dry season are probably due to lack of algae, water evaporation and lack of dilution.

Except Zinc, trace element concentrations in the M'Badon Bay are above WHO water consumption standards (Table 13 and Table 14). This may be due to the proximity of the landfill and to anthropogenic activities in the M'Badon area (agriculture, fishing, urbanization, etc.).

The M'Badon bay waters are more contaminated in lead and cadmium than other sectors of the Ebrié lagoon [57] [66] [70]. This may be attributed to the nature of the wastes (industrial waste, electronic and household) of the Akouédo landfill. However, trace metals concentrations of the M'Badaon bay surface water are lower than those of the Akouedo landfill leachate. These low concentrations are probably due to the process of sedimentation, adsorption, dilution and flocculation of metals during their transport.

4. Conclusion

The results obtained from this study show that the Akouedo landfill leachate has no impact on the groundwater and the Mbadon bay surface waters. The leachate

Table 13. Comparison of metal concentrations in the waters of M'Badon Bay with those of certain bays in the Ebrié lagoon.

Parameters	Cocody [66]	Bingerville [66]	Biétri (SIR) [66]	Marcory (Biafra) [66]	This study
Temperature	28.46	29.15	29.73	28.74	28.13
pH	7.51	7.28	8.10	7.34	6.89
Conductivity (Ms/Cm)	18.16	21.76	25.44	19.42	7.18
Salinity	1.03	1.13	1.44	1.18	4.1
Pb(µg/L)	590	75.2	625	535	514.18
Cd (µg/L)	12.5	3	32.5	40	90
Ni (µg/L)	157.5	21.5	230	135	83
Zn (µg/L)	14662.5	1415	23187.5	39315	40

Table 14. Comparison of concentrations of trace metallic elements of surface waters near landfills in other regions to those of M'Badon Bay.

	M'Badon bay (Cote d'Ivoire)	Sakumo lagoon. (Ghana)	Ikpoba in Benin City (Nigeria)	Lac (Kenya)	Ebrié lagoon (Côte d'Ivoire)	Cocody bay (Cote d'Ivoire)	guidelines WHO
Zn (µg/L)	6 - 166	77 - 160	24	40 - 235	-	36 - 376	3000
Pb (µg/L)	12 - 1371	57	70	25 - 563	75.2 - 670	Nd - 96	10
Cd (µg/L)	1 - 322	49	-	2 - 43	3 - 47.5	30 - 47	3
Ni (µg/L)	3 - 257		141	nd - 288	21.5 - 262.5	6	70
Cu (µg/L)	60 - 450	112 - 158				79 - 91	
References	Present study	[67]	[68]	[69]	[66]	[70]	[57]

is characterized by a basic pH, and a conductivity fluctuating between 10,060 and 37,990 µS·cm^{-1}. The groundwater in the vicinity of the Akouedo landfill shows an acidic character and a conductivity generally below 86 µS/cm. The pH of the M'badon bay varies from 5.94 to 7.58 and the mean conductivity between 7181 ± 8675 µS/cm. The high conductivity of the Mbadon bay waters is attributed to the oceanic influence of the bay. The presence of trace metals observed in the leachate can be attributed to the composition of the landfill waste which is typical for a dominant household character. Trace metal concentrations of the groundwater and the Mbadon surface waters are lower than those of the Akouédo landfill leachate. The concentrations of the groundwater and the M'Badon bay waters trace elements were generally higher than the permissible levels specified by WHO.

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