Trace Metals Content Of The Sewage From The Sewer Network Of Abidjan (Côte d'Ivoire)

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Abstract

Many studies have incriminated the effluents of the sewer network of Abidjan as major trace metal contamination sources in the Ebrié Lagoon. However, no data are available on wastewater regarding trace metal contaminations in Cote d'Ivoire. Thus, this study aimed at assessing the level of contamination of wastewater by metals copper, iron, cadmium, lead and Zinc. To achieve this objective, six campaigns were carried out from december 2013 to november 2014 in eight specific sites. The samples were analyzed using an atomic absorption spectrophotometer AA20 Varian, after mineralization. The results showed a significant contamination of effluents from the sewer network. The order of metals concentrations was Fe >Zn > Cu> Pb>Cd. Total metal concentrations (µg/L) ranged from 313.4 to 881.5 for Fe, 144 to 240 for Zn, 132 to 318 for Cu, 10 to 30 for Cd and 114.3 to

263 for Pb. Among these values only Cd concentrations considerably exceeded WHO guideline value (10 µg/L).

Keywords: Trace metals, wastewater, sewer network, pollution, Abidjan (Côte d'Ivoire)

Introduction

Trace metals occur in the environment naturally or through human activities. Potential sources include natural aging of the earth's crust, mining, soil erosion, industrial discharges, urban runoff, sewage effluent. The prolonged presence of these contaminants in urban environment and its proximity to the population can significantly amplify their exposure to metals by inhalation, ingestion and dermal contact (Mielke and Reagan, 1998; Boyd *et al.,* 1999; Mielke *et al.,* 1999). Contamination by heavy metals of different environmental compartments, particularly aquatic ecosystems, has been extensively studied because of their resistance to biodegradation, their toxicity and tendency to the phenomena of bioaccumulation and biomagnification along food chains (Callender and Rice, 2000; Morin *et al.,* 2008; Liang *et al.,* 2011; Lenoble *et al.,* 2013). The increase of total concentrations of metals in ecosystems is becoming increasingly worrying in the light of population growth, concomitant expansion of urbanization, industrialization and agriculture in recent decades (Zourarah, 2009; Jayaprakash, 2010). Among these substances, copper (Cu), zinc (Zn), cadmium (Cd), Iron (Fe) and Lead (Pb) have been the subject of several studies in the field of environmental pollution because of their use in many areas of human activities (Tang *et al.,* 2010 ; Oyeyiola *et al.,* 2013). In Cote d'Ivoire, several studies have focused on the determination of the trace metals concentrations in water, sediment and aquatic species in the estuarine part of the Ebrié lagoon (Kone *et al.,* 2008; Affian *et al.,* 2009; Yao *et al.,* 2009; Coulibaly *et al.,* 2012, Bakary and Yao, 2015). Most of these studies have pointed the wastewater from the sewer system of the city of Abidjan as a major potential source of metal pollution of the Ebrié lagoon. In fact, the Ebrié lagoon remains the receptacle of urban and industrial effluent discharges, of runoff and domestic solid waste of the city, containing relatively large amounts of metals. However, to our knowledge, no study has focused on the metal charge of sewage. Thus, the objective of this study is to assess the level of the metals Cu, Zn, Cd, Pb and Fe in the wastewater of the sewer network of Abidjan which is discharged in the Ebrié lagoon.

Materials and Methods

Sewage network of Abidjan

The sewage network is 1158 km long. This network comprises one main collector and many secondary collectors. The main collector, with a length of 25 km, connects Abobo town in the north to Port-bouet town on the seafront (Figure 1). On the main collector, Three (03) sampling points have been selected. In addition, five (05) sampling points have been selected on the secondary collectors (Table I). In this study, six wastewater sampling campaigns were conducted between december 2013 and november 2014. The wastewater samples were collected at each station. A volume of 500 mL was collected in polyethylene bottles and immediately acidified with 0.5 ml of nitric acid (65%). These samples were kept in an icebox at 4°C and then transported to the laboratory according to the procedures outlined by AFNOR (2001) and Rodier *et al.*, (2009).

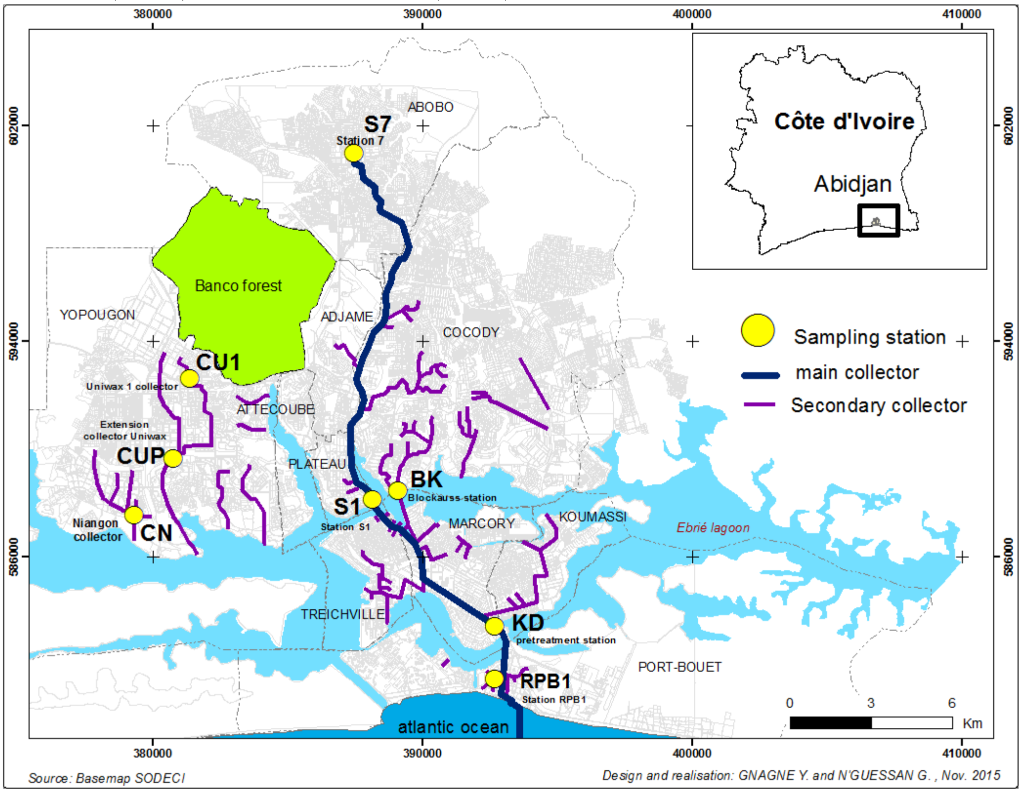


Figure 1: Location of collectors and sampling stations

Table I: Identification and localization of samples on different points of the sewer system

Stations	Positions	geographic Coordinates(UTM)
S7 Station	At the head of the main collector of sewer network, at Abobo township	-X : 388241 -Y : 599508
S1 Station	Located on the main network, at Plateau township	-X : 388028 -Y : 587975
Pretreatment Station (KD)	Last station on the main collector before discharging effluent into the Atlantic Ocean. It is the outflow of wastewater from the main collector and the secondary collectors from all townships except those of Yopougon, Riviera and Port-Bouet. It is located in the townships of Koumassi.	-X : 393011 -Y : 583331
RBP1Station	It represents the outflow of wastewater from secondary collectors in the township of Port-Bouet.	-X : 392869 -Y : 581535
Blockosso Station (BK)	It collects and conveys some of the wastewater of the township of Cocody in the main collector via 7J1 station in Treichville.	-X : 389441 -Y : 588536
CN	Township of Yopougon, sector of Niangon	-X : 378605 -Y : 587499
CU1	One of the manholes in the upper part of the Uniwax collector. This manhole is located in the area of the textile company Uniwax.	-X : 380687 -Y : 592839
CUP	Townships of Yopougon, extension of the Uniwax Collector to Yahosehi	-X : 380545 -Y : 589653

CN: Niangon collector, CU1: Uniwax collector, CUP : Extension Uniwax collector
UTM :Universal Transverse Mercator

Sample processing and analysis

Wastewater from the sewer network being highly loaded with organic matter, a mineralization step was necessary prior to analysis, in order to limit interference related to organic matter. The method of mineralization is described by ISO 5961 (1994) standard. It consists of introducing 100 mL of each homogenized sample in a 250 ml beaker. To this 100 mL sample, 1 mL of nitric acid (65%) and 1 mL of hydrogen peroxide (32%) were added. This mixture was heated on a hot plate and evaporated up to about 0.5 mL. It is essential that the sample is not completely evaporated. The residue (0.5 mL) is dissolved in 1 mL of nitric acid (65%) and 5 mL of ultrapure water. This mixture is transferred to a 100 ml flask and completed to a volume of 100 mL with ultrapure water. Then, this solution is filtered using a filter of 0.45µm diameter. Finally, the filtrate is used for the determination of the concentrations of trace metals by means of an atomic absorption spectrophotometer AA20 Varian. The detection limits of trace metals were 0.0005 mg/L for copper, iron, Zinc; 0.0003 mg/L for lead and 0.0001 mg/L for cadmium.

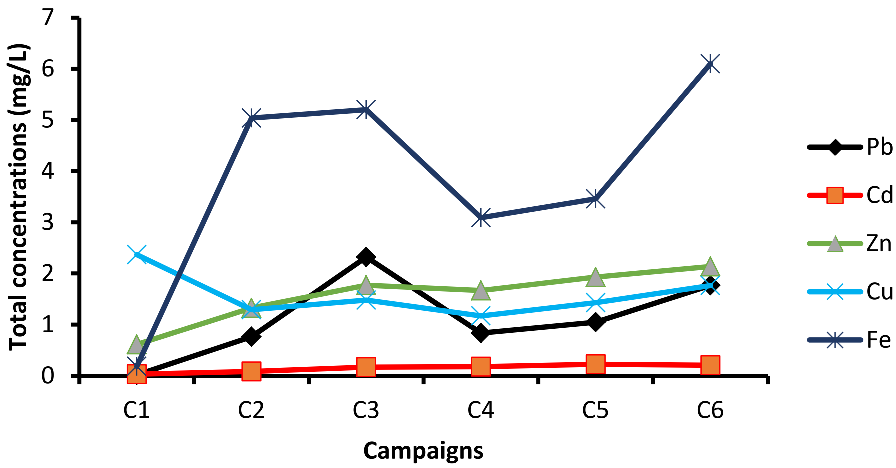
Statistical processing of the data

The collected data were processed using the Statistica 7.1software (Statsoft, 2005). Initially the mean, standard deviation and coefficient of variation of trace metals were determined for each sampling station. Secondly, a Principal Component Analysis (PCA) was used to study and classify the effluents from the sewage network according to their metal compositions.

Results and discussion

Order of abundance of the metals in the wastewater over all sampling campaigns

Figure 2 shows the total concentrations of each metal on all six (06) sampling campaigns. It indicates the presence of Cd, Cu, Fe, Pb and Zn in the effluents of the sewer network of Abidjan. It reveals also that concentrations of Fe are the highest of all metals, and that those of Cd are the lowest. The order of metals concentrations is Fe > Zn > Cu> Pb>Cd. This order is not much different from that found by Bakary and Yao (2015) in open collectors of Abidjan. These authors found the following order: Fe > Zn > Cu > Cr > Cd > Pb. According to them, the total concentrations of Pb in effluent were lower than the detection limit. They postulated that the Pb has been retained by adsorption or by flocculation and deposited along the path of the effluents.



C1: Campaign 1; C2: Campaign 2; C3: Campaign 3; C4: Campaign 4; C5: Campaign 5; C6: Campaign 6

Figure 2: Total concentrations of trace metals over all sampling campaigns

Trace metal concentrations range along the sewer network

The evolution of trace metal concentrations in the wastewater from one site to another of the sewer network is presented in Table II. Total metal concentrations (µg/L) ranged from 313.4 to 881.5 for Fe, 144 to 240 for Zn, 132 to 318 for Cu, 10 to 30 for Cd and114.3 to 263 for Pb. In addition, the coefficient of variation of metal concentrations is between 47.5% and 141.2%. This indicates that there is a high dispersion of concentrations from one campaign to another in the different stations studied. This dispersion can be due to a punctual and intermittent mechanism of sewage contamination by metals.

Table II: Concentrations of trace metals at different sampling stations

Stations		Pb (µg/L)	Cd (µg/L)	Zn (µg/L)	Cu (µg/L)	Fe (µg/L)
S7	Moy ± σ	164,1±171,8	11,8±11,2	178±91,6	156,6±79,6	590,3±513,4
	CV (%)	104,7	94,9	51,4	50,8	86,9
RPB1	Moy ± σ	150,6±153,4	10±8	180,5±94,6	132±97	361,5±275,4
	CV(%)	102	80	52,4	73,5	76,2
BK	Moy ± σ	153,2±164	11,1±7,5	144±98,4	150,6±109,4	315±243,6
	CV(%)	107	67,6	68,3	72,6	77,3
KD	Moy ± σ	263±286	16,2±7,5	145±88,6	144,3±106,2	412,3±345,1
	CV(%)	108,7	47,5	61,1	73,6	83,7
S1	Moy ± σ	141±137,3	13,5±11	197±168	153,8±74	377±308,8
	CV(%)	97,4	81,5	82,2	48,1	95,6
CU1	Moy ± σ	114,3±161,4	30±25,4	240±239,8	318±220	881,5±843,5
	CV(%)	141,2	84,7	99,9	69,8	54
CUP	Moy ± σ	172,3±205,4	16,6±12,5	190±127	178,5±102,5	407,8±220,1
	CV(%)	119,2	75,3	66,8	57,4	185,3
CN	Moy ± σ	160,1±0,182	11,3±13,2	167,6±111,5	154±81,6	313,4±278,6
	CV(%)	113,7	116,8	66,5	53	88,9

Metal concentrations in liquid effluents and standard values

Metal concentrations in wastewater of different localities, national wastewater discharge standards and WHO guideline values are shown in Table III. According to this table, Zn concentrations of the effluents of the sewer network of Abidjan are similar to those obtained by Nassali *et al.* (2001) and Aboueloufa *et al.* (2002) in urban discharges of Morocco. These concentrations are low than the WHO guideline value. The Pb concentrations do not exceed the WHO guideline and the Ivorian standard for wastewater discharge. These concentrations are close to those found by Abdoulaye *et al.* (2013) in the effluents of the WWTP of SEBKA in Mauritania. The concentrations of Cu and Fe found in the wastewater of the sewer network of Abidjan comply with the national standards for wastewater discharge, set respectively at 500 and 5000 µg/L. On the other side, the concentrations of Cu are much higher than those found in other studies on wastewater discharges (Nassali *et al.*, 2001; Fouad *et al.*, 2014; Bakary and Yao 2015). As for Fe, the concentrations are in the same order as those found by Aboueloufa *et al.* (2002). Cd concentrations considerably exceeded the limit value (10 µg/L) recommended by WHO, (2012) in the context of environmental protection (Table III). These values are close to those found by Nassali *et al.* (2001) and Fouad *et al.* (2014) in urban wastewater and sewer discharges in Morocco. The comparison of the average concentrations of metals in the sewage of the two types of collector of Abidjan indicates that the concentrations of Cd, Zn, and Fe measured in open collectors discharges are lower than those found in sewage network discharges. The higher levels of these metals in the wastewater from the open collectors were probably due to the composition of this wastewater. Indeed, this wastewater comprises runoff and domestic sewage. These collectors are the receptacle of trash of all sorts. Unlike Cd, Zn, and Fe, the concentrations of Cu and Pb are lower in open collectors discharges compared to the sewer network discharges. In fact, the sewage effluent is the result of domestic and industrial effluents. High concentrations of Cu could originate from domestic effluents and dyes used in the textile industry. According to Davis (1975), domestic discharges are responsible for a third of the charges (1/3) of copper in wastewater treatment facilities in the US. For lead, they could come from paint waste. The wastewater from the sewer system is a source of water contamination by metals in the lagoon. According to Bakary and Yao (2015), the metal concentrations in the water of the bay of Cocody are 42 µg/L for Cd, 94 µg/L for Zn, 85 µg/L for Cu, 27 µg/L for pb and 51 µg/L for Fe. The presence of metals in wastewater in this study urges preventive measures because the discharges are continuous in the aquatic environment. Therefore it may pose a risk to the health of aquatic life and humans. According to Kone *et al.* (2008) and Coulibaly *et al.* (2012), some fish (Sarotherodon melanotheron) and some gastropods (Tympanotonus fuscatus fuscatus and Tympanotonus fuscatus radula) are contaminated by metal.

Table III: Concentrations (µg/L)of Cd, Zn, Fe, Cu, and Pb in sewageand standard values

Sites or Standards	Cd	Zn	Cu	Pb	Fe	REFERENCES
Abidjan (SW) Côte d'Ivoire	10 - 30	144-240	132 -318	114.3 - 263	313.4-881.5	Present study
Abidjan (UW) Côte d'Ivoire	47	319	93	<DL	1600	Bakary and Yao (2015)
Casablanca (UW) Moroco-	22-23	39-54	14-22	<DL	123	Fouad et al. (2014)
Algeria (UW)	3-500	80 - 1600	-	20 - 60	-	Sadia and **Ahmed (2013)**
Algeria (IW)	4 - 3200	10 - 700	-	03- 500	-	
Mauritanie (WWTP)	-	-	-	104.5-176.5	-	Abdoulaye *et al*. (2013)
Oudja (UW) Moroco	-	220	-	-	950	Abouelouafa et al. (2002)
Kenitra (SW) Moroco-	10.8	498	40	32	2800	Nassali *et al.* (2001)
Kenitra (IW) Moroco-	3.8	186	45	28	3000	
Bay in Ebrie Lagoon Cocody Côte d'Ivoire	42	94	85	27	51	Bakary and Yao (2015)
Ivorian wastewater discharge standards	-	-	500	500	5000	MINEEF (2008)
WHO guideline value	10	2000	200	5000	5000	WHO(2012)

SW: Sewer Wastewater, UW: Urban wastewater; IW: Industrial Wastewater

Types of sewage according to trace metals

The Principal Component Analysis (PCA) was based on five (05) metals descriptors (Pb, Zn, Cu, Cd, Fe) as well as eight (08) sampling points (S7, RPB1, BK, KD, S1, CU1, CUP, CN). The factorial analysis (F1-F2) indicates 93.81% of the expressed variance (Figure 3). The factor 1(F1) alone explains 75.66% of the expressed variance. It is perfectly correlated with Fe, Cu, Cd, Zn (Table IV). According to table V, these variables are best linked to each other (Cd and Cu (0.953), Cu and Fe (0.891), Cd and Fe (0.857), Zn and Cu (0.811), Zn and Fe (0.765) and Cd and Zn (0.740)). In addition, the strongest correlations between Fe, Cu and Cd could indicate that these metals come from the same origin. Thus, from the right to the left, the factor 1 (F1) expresses an increasing gradient of contamination of wastewater in Fe, Cu, Cd, Zn. In contrast, the factor (F2) exhibits18.15% of the variance expressed. It is significantly correlated with Pb. From bottom to top, this factor 2 (F2) indicates an increasing gradient of contamination by Pb.

Table IV: Factorial coordinates of variables

	Factors	
Variables	F1	F2
Cu	-0,971*	0,135
Zn	-0,916*	-0,234
Fe	-0,916*	0,227
Cd	0,906*	0,375
Pb	0,581	0,8*

* Good correlation

Table V: Pearson correlation matrix of metal variables

	Pb	**Cd**	**Zn**	**Cu**	**Fe**
Pb	1				
Cd	-0,231	1			
Zn	**-0,675**	**0,740**	1		
Cu	-0,479	**0,953**	**0,811**	1	
Fe	-0,355	**0,857**	**0,765**	**0,891**	1

The values in red and bold are significantly different from 0 at a level of alpha = 0.05 significance

These data let to interpret the graph of samples with three (03) major classes of stations which are clearly shown on the main plan (F1 - F2) (Figure 3).

Class 1 contains only the effluents at the start of the Uniwax Collector (CU1). These effluents are rich in Fe, Cu, Cd and Zn. Indeed, this collector drains the wastewater from the textile industry Uniwax. So, the presence of high concentrations of these metals in the effluents of this station can be explained by the use of dyes and various chemicals by the textile manufacturing process. Some synthetic dyes such as metal complex dyes contain one or more metal elements in their molecular structure. These include Cu and Fe (Mansour, 2010). Also, according to Rauch and Pacyna (2009) dyes contain Cd.

Class 2 represents the effluents from CUP, BK, S1, KD, CN, S7 and RPB1 stations. These effluents are poor in trace metals. This could be due to a high proportion of domestic sewage at these stations. Indeed, according to Gnagne *et al.* (2015), these effluents have a high domestic character. However, the concentrations of metals encountered in these effluents could come from the corrosion of water mains and the use of metals in domestic activities and household products as suggested by Abdoulaye *et al.*(2013). The low concentrations of these effluents could be also related to the fixation of the metals to the solid fraction of the wastewater.

Class 3 corresponds to effluents from the pretreatment station (KD). These effluents are rich in Pb. This can be linked to the accumulation phenomenon. In fact, this station receives all effluents of the main collector before discharge into the receiving environment. Moreover, this station could receive industrial effluents rich in lead which may come from paint industries located in the industrial area of Koumassi.

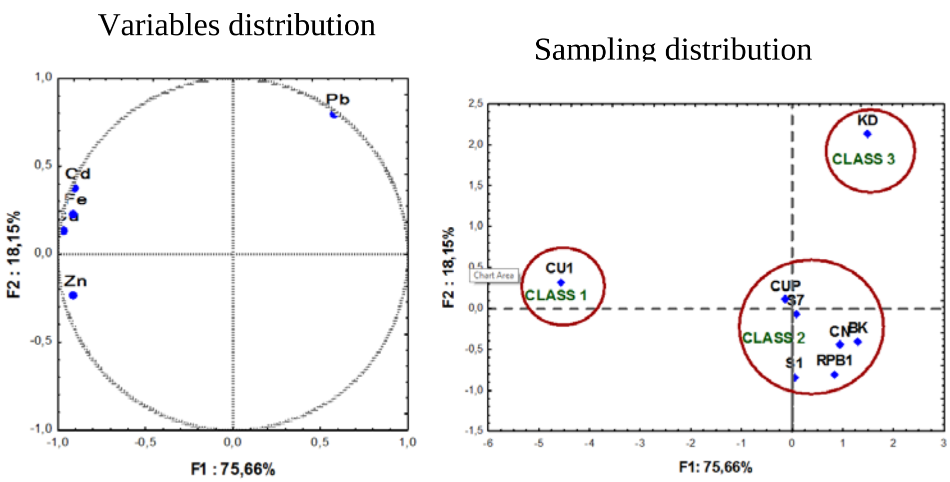


Figure 3: PCA score plot for Factor 1 and Factor 2 for metal contaminants measured in wastewater of sewer network of Abidjan.

Conclusion

This work shows the presence of the trace metals Fe, Zn, Cu, Pb, and Cdinthe wastewater drained by the sewer network of Abidjan. Total metal concentrations (µg/L) ranged from 313.4 to 881.5 for Fe, 144 to 240 for Zn, 132 to 318 for Cu, 10 to 30 for Cd and 114.3 to 263 for Pb. Among the five metals studied, Cd concentrations considerably exceeded the WHO guideline value (10 µg/L). On the other side, the order of metal concentrations is

Fe > Zn > Cu > Pb > Cd. This study shows clearly that metallic pollution is due to a punctual and intermittent mechanism because the variation coefficient of metal concentrations varies between 47.5% and 141.3%.Thus, given the large volumes of wastewater discharged into the receiving water regularly, measures must be taken to prevent environmental disasters. Increased investigations should be conducted for the removal of metal from the wastewater from the sewer system. This treated water instead of being discharged into the lagoon and / or the sea could be reused in agriculture or in industries, as practiced in the countries of northern Africa. This is important in the need to ensure that future generations have access to safe drinking water and a healthy environment.

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