

Original Research Article

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Assessment of the Removal of Trace Metal Elements (Cd, Zn, Pb and As) in Hospital Wastewater from the Cocody–Angré University Hospital Center

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ABSTRACT

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This study assesses the effectiveness of the wastewater treatment plant at the Cocody–Angré University Hospital Centre (CHU) in treating hospital effluent, focusing on the removal of certain trace metal elements (TME): zinc (Zn), cadmium (Cd), lead (Pb) and arsenic (As). Three sampling campaigns collected six samples at the inlet and outlet of the plant. The analyses were carried out in accordance with AFNOR and ISO 5961 (1994) standards. The results were compared with Ivorian regulatory values and revealed a significant improvement in physico-chemical parameters after treatment: turbidity fell from 223 to 34 NTU (a reduction rate of 84.2%), and dissolved oxygen increased from 14.4% to 23.5%, indicating better aeration. The pH remained neutral and within the standards (6.93–7.31). With regard to heavy metals, the plant shows variable efficiency: half of the zinc and lead are removed (reduction rates of 56.3% and 66.4% respectively), while cadmium remains stable (0.05 µg/L) and arsenic increases slightly (0.05 to 0.19 µg/L). Thus, the plant performs well overall in terms of physical-chemical treatment, but has limitations for certain metals.

Introduction

Hospitals produce a wide variety of effluents every day from domestic, urban and medical activities (Verlicchi *et al.*, 2010). This hospital wastewater contains various chemical compounds such as pharmaceutical residues, disinfectants, solvents, chemical reagents and trace

metals (TMs), which are considered emerging contaminants due to their toxicity and persistence in the environment (Kümmerer, 2010; Verlicchi *et al.*, 2010).

TMEs, although naturally present in aquatic environments, become a cause for concern when their concentrations increase due to anthropogenic discharges.

Their non-biodegradable nature and bioaccumulation capacity make them dangerous to fauna, flora and human health (Amiard *et al.*, 2007). According to the Water Framework Directive (WFD), they are among the priority substances to be monitored due to their potential toxicity and persistence (Ettajani *et al.*, 2001; Durrieu *et al.*, 2005).

In Côte d'Ivoire, the management of hospital effluents is a major environmental issue. The Cocody-Angré University Hospital Centre (CHU) has a wastewater treatment plant (WWTP) consisting of a settling system and a bacterial bed for the treatment of its wastewater. Previous studies (Kpazokah, 2020; Chonou, 2023) have shown that this plant has varying degrees of efficiency depending on the pollutants studied. Kpazokah (2020) highlighted good reduction rates for organic pollutants (COD: 76%, BOD₅: 71%), while Chonou (2023) observed uneven removal of antibiotic residues, ranging from 19.81% to 83.63%.

However, no study has yet evaluated the effectiveness of this plant in removing trace metals, even though they pose a serious threat to aquatic ecosystems and public health. This research therefore aims to fill this gap by evaluating the performance of the Cocody-Angré University Hospital treatment system with regard to four priority metals: cadmium (Cd), zinc (Zn), lead (Pb) and arsenic (As).

The results obtained will provide a better understanding of the limitations of the current system and guide actions to improve hospital effluent management in Côte d'Ivoire.

Materials and Methods

Presentation of the study area

The Cocody-Angré University Hospital is located in the municipality of Cocody, in Abidjan, Côte d'Ivoire. More precisely, it is located in the Angré district, in the 8th section, with geographical coordinates of 5°23'20.76" north latitude and 3°57'3.6" west longitude (Figure 1).

Study Materials

The study material consisted of wastewater from all departments of the Cocody-Angré University Hospital, which is transported to the treatment plant, a common discharge point.

Equipment for sampling and determining physical and metallic parameters

1-litre polyethylene bottles were used to collect wastewater for physical and chemical analysis. A cooler containing ice was used to store the samples in the field. A dip tube was used to draw water from the manholes.

For physical parameters, the equipment consisted of a Hanna HI 991001 pH meter to determine pH and temperature (°C), a Hanna HI 9146 oximeter to determine dissolved oxygen (content in mg/L) and a Hanna HI 98703 turbidimeter to determine turbidity. The metal parameters were determined using a Thermo Scientific atomic absorption spectrophotometer (AAS).

Sampling methods

Three sampling campaigns were carried out between 6 May and 3 June 2023 to characterise the effluents from the Cocody-Angré University Hospital in terms of their physical, chemical and metallic properties. Samples were taken at the inlet and outlet of the treatment plant at three times of the day (8 a.m., 11 a.m. and 2 p.m.). At each point, three spot samples were collected and homogenised to obtain a composite sample representative of the daily quality of the wastewater.

A total of six average samples were obtained at the end of the three campaigns: three at the inlet and three at the outlet of the plant. The samples were taken using pipettes and stored in one-litre polyethylene bottles, rinsed three times with the water to be sampled. The samples were acidified with nitric acid to maintain a pH below 2 and ensure the stability of trace metal elements (TMEs). Finally, they were labelled and stored at 4°C in a cooler until they were transported to the laboratory for analysis.

Methods for analysing physical and metallic parameters

The samples were subjected to physical and metallic analyses in accordance with French standards (AFNOR, 2001) and those described by Rodier *et al.*, (2009). The mineralisation method is described in ISO standard 5961 (1994). The analyses were carried out at the Central Analysis Laboratory (LCA) of Nangui ABROGOUA University.

- Instrumental conditions for measuring ETMs

The method was validated by analysing blanks, duplicates and spiked samples. The recovery rates obtained for ETMs ranged from 91 to 98%, demonstrating the effectiveness of acid digestion. The concentrations measured in the blanks were below the detection limits. The precision of the method, assessed by calculating the RPD between duplicates, was less than 15%, confirming good analytical repeatability.

Statistical data processing

Statistical analyses of the raw data were performed using Statistica version 7.1 software. This software was used to perform descriptive analyses, including the calculation of medians, given that the data distribution does not follow a normal distribution (Shapiro-Wilk). The software was also used to perform correlation tests between the measured variables and to calculate the reduction rates (RR) of trace metal elements (TMEs) in order to evaluate the effectiveness of the treatment according to the following equation:

$$TA (\%) = \left(\frac{C.input - C.output}{C.input} \right) \times 100 \quad (Equation 1)$$

With: C.input = metal concentration at the station inlet ($\mu\text{g/L}$) et C.output = metal concentration at the station outlet ($\mu\text{g/L}$).

Results and Discussion

Physical and metallic characteristics of the water at the Cocody-Angré University Hospital station

Table 1 shows the minimum, maximum and median values of the physicochemical parameters (pH, T°, OD, Turb) and heavy metals (Zn, Cd, Pb, As) measured in the raw and treated effluents from the Cocody-Angré University Hospital.

The pH varies from 6.93 to 7.20 at the inlet and from 7.11 to 7.31 at the outlet, remaining neutral and compliant with discharge standards (5.5–8.5). Turbidity, which is very high in raw effluent (126–236 NTU, with a median of 223 NTU), decreases significantly after treatment (27.2–37 NTU, median value of 34 NTU). OD at the inlet varies from 11.1% to 20.3% (median: 14.4%) and from 15.5 to 27.2% at the outlet (median: 23.5%).

The temperature of the raw effluent ranges from 29.23 to 37.83 °C. After treatment, it rises from 28.77 to 35.2°C, remaining below the 40°C limit.

With regard to ETMs, Zn in raw effluent has concentrations ranging from 12.03 to 40.87 $\mu\text{g/L}$, then decreases from 7.44 to 28.07 $\mu\text{g/L}$ (median: 11.74 $\mu\text{g/L}$) after treatment, resulting in a concentration well below the standard (2000 $\mu\text{g/L}$). Cd remains stable at 0.05 $\mu\text{g/L}$, except for one isolated case with a concentration of 13.19 $\mu\text{g/L}$, which is still below the limit (200 $\mu\text{g/L}$). Pb has a concentration of 0.5 to 65.76 $\mu\text{g/L}$ at the WWTP inlet and ranges from 0.25 to 20.6 $\mu\text{g/L}$ at the outlet. Finally, As increases slightly from 0.05 to 0.19 $\mu\text{g/L}$, but remains below the standard (100 $\mu\text{g/L}$).

Relationship between physical and metallic parameters in hospital effluents from the WWTP

Table 2 presents the correlation matrix between the physical and metallic parameters of hospital effluents from the Cocody-Angré University Hospital treatment plant.

Correlation between physical parameters

The correlation between pH and turbidity ($r = -0.739$) is strong and negative, as is that observed between dissolved oxygen and temperature ($r = -0.739$). Furthermore, the relationship between turbidity and dissolved oxygen also shows a high negative correlation ($r = -0.752$).

Correlation between physical and metallic parameters

Correlation analysis highlights several significant relationships between physicochemical parameters and trace metals (TM).

Zinc shows a strong negative correlation with pH ($r = -0.869$). In addition, a moderate negative correlation is observed between zinc and temperature ($r = -0.643$).

Cadmium, meanwhile, is positively and moderately correlated with turbidity ($r = +0.553$). In addition, a strong positive correlation is observed between cadmium and temperature ($r = +0.783$), while a moderate negative correlation is observed between this TME and dissolved oxygen ($r = -0.610$).

Lead (Pb) shows a very strong positive correlation with temperature ($r = +0.931$). However, a moderate negative correlation is observed with dissolved oxygen ($r = -0.687$).

Finally, arsenic shows a very strong positive correlation with dissolved oxygen ($r = +0.963$). Conversely, this ETM is moderately and negatively correlated with turbidity ($r = -0.639$) and temperature ($r = -0.761$).

Correlation between trace metal elements

Lead (Pb) has a very strong positive correlation with cadmium ($r = +0.952$). However, it has a moderate negative correlation with zinc ($r = -0.510$). In addition to cadmium and zinc, lead also has a moderate negative correlation with arsenic ($r = -0.652$).

Furthermore, arsenic also shows a moderate negative correlation with cadmium ($r = -0.527$).

Evaluation of the effectiveness of the removal of the MWEs studied in hospital wastewater by the WWTP

The purification performance of the hospital wastewater treatment plant at Cocody-Angré University Hospital is shown in Table 3. Turbidity shows a very high reduction rate (84.2%). Lead is eliminated at a rate of 66.4%. Zinc shows a moderate reduction of 56.3%. Cadmium shows no significant reduction (0%), despite a peak observed at the inlet. No reduction was observed for arsenic. Concentrations are higher at the outlet than at the inlet.

Physical quality of wastewater from the University Hospital

The physical parameters of the CHU's wastewater show an overall improvement between the inlet and outlet of the treatment plant. The pH remains neutral and stable (7.11–7.27), in accordance with current standards (5.5–8.5). This stability is attributed to the buffering capacity of hospital wastewater and is consistent with the results reported by El Mehdi *et al.*, (2009), Verlicchi *et al.*, (2010), Sadek *et al.*, (2012) and Bouzid *et al.*, (2013).

This favourable pH reflects a good acid-base balance, conducive to the development of microorganisms involved in biological treatments (Tchobanoglous *et al.*, 2014).

Turbidity is greatly reduced after treatment, with an average reduction of 84.2%, reflecting the effectiveness of the WWTP's settling and filtration processes. These performances are comparable to those reported by Daud *et al.*, (2017) in a hospital WWTP in Malaysia, confirming good removal of particulate matter.

Dissolved oxygen increases at the outlet of the plant, rising from 14.4% to 23.5%, indicating improved oxygenation and reduced organic pollution. This change is beneficial for internal biological processes and for the quality of the receiving environment (Zhang *et al.*, 2022).

The temperature of the effluent remains high, with median values close to 30°C, which is characteristic of hospital effluent in tropical environments (Kümmerer, 2009; Kpazokah, 2020; Chonou, 2023). Although it does not compromise microbial activity, this temperature can influence the solubility and mobility of trace metals, unlike studies conducted in temperate zones (Sadek *et al.*, 2012; Bouzid *et al.*, 2013).

Evaluation of trace metals

The zinc concentrations measured in the effluents remain below the Ivorian discharge standard (2000 µg/L). The presence of this heavy metal is generally associated with alloys, medical equipment and galvanized materials (He *et al.*, 2022).

Lead shows a notable decrease after treatment, falling from 5 µg/L to 3.3 µg/L, well below the Ivorian standard (500 µg/L). This reduction is mainly linked to its adsorption on suspended particles, microbial biofilms and bacterial bed materials. Extracellular polymers (EPS), rich in functional groups (–COOH, –OH, –NH₂, –PO₄³⁻), play a key role in lead fixation (Sheng *et al.*, 2010).

Cadmium concentrations are generally low and stable, with one isolated peak suggesting occasional pollution, probably linked to certain specific medical activities, namely the use of reagents and cytotoxic drugs (Pauwels and Verstraete, 2006). Its concentration complies with the discharge standard (200 µg/L).

Conversely, arsenic shows an increase in concentration after treatment, reflecting possible release from biofilms or a physicochemical transformation into more mobile

forms. Although concentrations remain below the standard (100 µg/L), this behaviour is concerning and has already been observed in other studies, particularly under the influence of pH and redox conditions (Smedley and Kinniburgh, 2002).

Correlations between variables

The very strong correlation between lead and cadmium ($r = +0.952$) suggests a common origin and similar behaviours within the treatment system, probably linked to hospital activities and medical devices (batteries, pigments or disinfectants containing these metals) (Karvelas *et al.*, 2003; Verlicchi, 2010; Verlicchi *et al.*, 2015; Meyer *et al.*, 2018).

The negative correlation between lead and zinc ($r = -0.510$) can be explained by competition in sorption and precipitation mechanisms, as zinc is more mobile and generally more soluble than lead (Alloway, 2013; Reddy and Lee, 2014).

Lead and cadmium also show negative correlations with arsenic ($r = -0.652$ and $r = -0.527$), reflecting differences in chemical speciation and behaviour in oxidizing environments.

Lead and cadmium are predominantly cationic, while arsenic is present in anionic form (arsenate AsO_4^{3-} or arsenite AsO_3^{3-}), which strongly influences their transport mechanisms and interaction with solid surfaces (Smedley and Kinniburgh, 2002).

Finally, the negative correlation between cadmium and arsenic ($r = -0.527$) confirms this difference in behaviour.

Cadmium, like lead, is more stable in reduced and slightly oxidized environments, while arsenic, in its oxidized form, becomes more mobile and bioavailable in well-oxygenated waters (Zhang *et al.*, 2020).

These results highlight the importance of redox conditions and pH in the distribution and mobility of these metallic micropollutants in hospital effluents.

However, the significant positive correlation between DO and arsenic ($r = 0.963$) suggests that oxidation could promote the remobilization of arsenic bound to particles or organic matter, a phenomenon also observed by Ghosh *et al.*, (2013).

Evaluation of the effectiveness of the Cocody-Angré University Hospital wastewater treatment plant

The Cocody-Angré University Hospital wastewater treatment plant shows satisfactory overall efficiency for physical parameters, particularly turbidity, with an average reduction of 84.2%, confirming the effectiveness of conventional treatment processes (Tchobanoglous *et al.*, 2014).

With regard to trace metals, performance is more mixed. Zinc shows moderate reduction (56.3%), linked to the predominance of soluble forms that are not readily retained by conventional processes (Papageorgiou *et al.*, 2012). Lead shows a reduction of 66.4%, comparable to the values reported by Fu and Wang (2011), but remains a concern given its toxicity and potential for bioaccumulation.

The increase in arsenic concentration at the WWTP outlet is attributed to desorption or chemical transformation phenomena promoted by the oxidative conditions induced by the aeration of bacterial beds. The strong positive correlation between arsenic and dissolved oxygen ($r = 0.963$) confirms that the increase in redox potential promotes the transformation of reduced arsenic into more mobile forms (Ghosh *et al.*, 2013). These observations are consistent with the conclusions of Kümmerer (2009), who highlights the limitations of conventional treatments for persistent micropollutants such as arsenic.

In conclusion, the main objective of this study was to evaluate the effectiveness of the Cocody-Angré University Hospital wastewater treatment plant in removing trace metals (TM).

The results show that the biological treatment system, based on a bacterial bed, is generally successful in stabilising basic parameters such as pH, temperature and dissolved oxygen. Turbidity, which is a key indicator of particulate load, was significantly reduced with an average reduction rate of 84.2%, reflecting the effective treatment of suspended solids.

With regard to ETMs, zinc and lead are partially eliminated with respective rates of 56.3% and 66.4%, although the concentrations measured are all below discharge standards.

Table.1 Analytical validation parameters for ETMs by SAA

Element	DL (µg/L)	QL (µg/L)	RPD (%)	Recovery (%)
Zn	0.5	1.5	6.5	98
Cd	0.1	0.03	7.9	97
Pb	0.3	0.9	6.9	95
As	0.005	0.015	6.4	91

DL: Detection Limit ; **QL:** Quantification Limit ; **RPD:** Relative Percentage Difference ; **Zn:** zinc ; **Cd:** cadmium ; **Pb:** lead ; **As:** arsenic.

Table.2 Physical and metallic parameters of effluents at the inlet and outlet of the treatment plant

Settings	Entrance			Exit			Ivorian rejection standards
	Min	Max	Median	Min	Max	Median	
pH	6.93	7.20	7.11	7.11	7.31	7.27	5.5-8.5
Turb (NTU)	126	236	223	27.2	37	34	-
DO (%)	11.1	20.3	14.4	15.5	27.2	23.5	-
T° (°C)	29.23	37.83	29.97	28.77	35.20	29.55	40
Zn (µg/l)	12.03	40.87	21.98	7.44	28.07	11.74	2000
Cd (µg/l)	nd	13.19	0.05	nd	nd	nd	200
Pb (µg/l)	0.5	65.76	5.00	0.25	20.60	3.30	500
As (µg/l)	nd	0.13	0.05	0.03	0.19	0.19	100

nd: not detected; **Min:** minimum; **Max:** maximum; **NTU:** Nephelometric Turbidity Unit, **µg/L:** microgram per litre; **Turb:** turbidity; **DO:** dissolved oxygen; **T°:** temperature

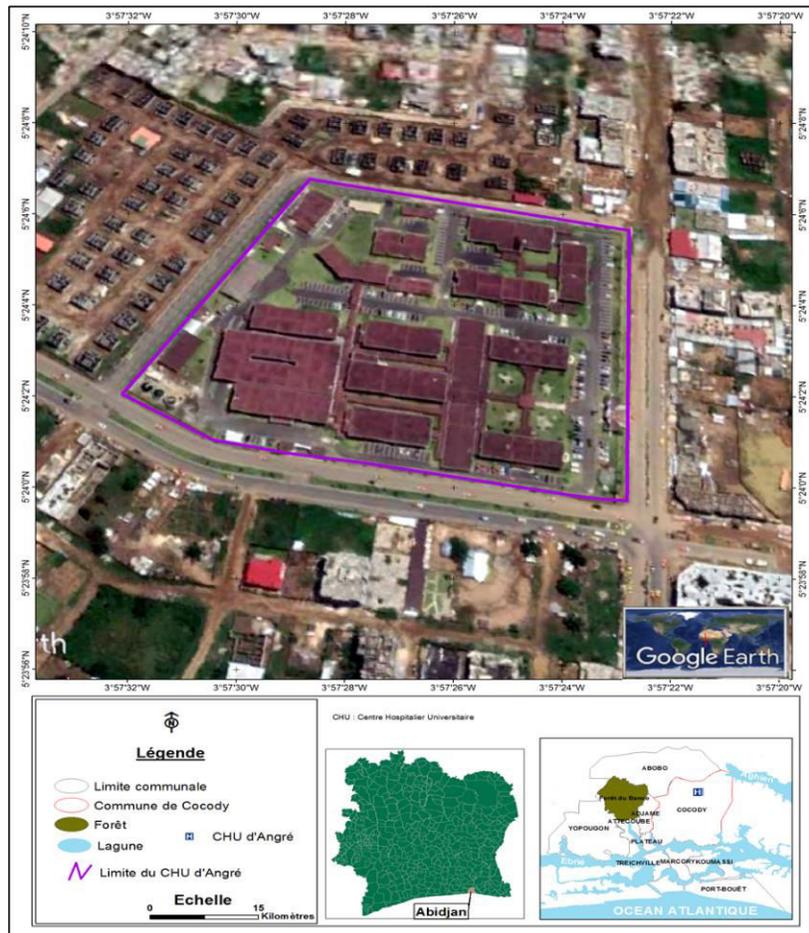
Table.3 Correlation matrix

	pH	Turb	DO	T°	Zn	Cd	Pb	As
pH	1							
Turb	-0.73985	1						
OD	0.25351	-0.75239	1					
T°	0.24172	0.27386	-0.73855	1				
Zn	-0.86963	0.43156	0.11299	-0.64303	1			
Cd	-0.16082	0.55278	-0.61051	0.78326	-0.32377	1		
Pb	0.03433	0.42212	-0.68771	0.93181	-0.51063	0.95272	1	
As	0.21752	-0.63934	0.96363	-0.76167	0.11037	-0.52792	-0.65274	1

Table.4 Purification performance of the physical and metallic parameters of the treatment plant

Settings	Abatement rate (%)
Turbidity	84.2
Zinc	56.3
Cadmium	0 (stable, except for a spike at the start)
Lead	66.4
Arsenic	---

Figure 1. Geographical location of Cocody-Angré University Hospital



The case of cadmium is more worrying: its concentration remains stable overall except for an abnormal peak of 13.19 µg/L, indicating probable sporadic pollution.

Arsenic presents a more critical situation, although it remains below Ivorian standards. Its concentration increased at the outlet (0.19 µg/L) compared to the inlet (0.05), although it remains below Ivorian standards. This increase is thought to be linked to a desorption

phenomenon facilitated by the aeration of the bacterial bed, which is corroborated by a strong positive correlation with dissolved oxygen ($r = 0.963$).

Although these results indicate a certain degree of efficiency of the WWTP, they also reveal its limitations, particularly for the treatment of persistent metallic micropollutants such as arsenic and cadmium, which are not fully controlled by conventional treatments.

Data availability

The datasets analysed during the current study are available from the corresponding author on reasonable request.

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Author contributions

A E J E Y. GNAGNE: Investigation, protocol validation, analysis, writing original draft, reviewing, statistical analysis; O.Y. A. AKO: Student supervising, writing-reviewing, data analysis; T G N. BALLEET: Conceptualization, methodology, writing and data analysis; S. TRAORE: Investigation, data collection and sampling; B. BAMORY: Investigation, data collection and sampling; T. TRAORE: Investigation, data collection and sampling.

Declarations

Ethical Approval Not applicable.

Consent to Participate Not applicable.

Consent to Publish Not applicable.

Conflict of Interest The authors declare no competing interests.

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