Assessment of physicochemical and metal concentrations in wastewater from the industrial zone of Cotonou Benin

Abstract

The present study aimed to assess the physico-chemical quality of wastewater(s) in order to better control the flow of various pollutants generated by the industries from the industrial zone of Cotonou. Water samples were collected in triplicate in each collector and analyzed for their nutrient and metal content (Cu^{2+}, Fe^{2+}, Cd^{2+}, Al^{3+} and Pb^{2+}) and chemical oxygen demand (COD) and a five-day biochemical oxygen demand (BOD_5) were carried out by spectrophotometry. The results revealed highly mineralized waters, indicated by average pH (6.97± 0.34), dissolved oxygen (5.16 ± 0.29 mg/L), electrical conductivity (2280.58 ± 263.97 µS/cm) and total dissolved solids (1076.04 ± 51.01 mg/L). The values of COD (482.05± 1.18 mg/L) and BOD_5 (291.67 ±2.19 mg/L) were very high, exceeding the standard for industrial wastewater discharge in Benin respectively by 5 and 11 which is indicative of the presence of very poor biodegradable materials coming essentially from industrial discharge in the study area. The concentration of Cd^{2+}, Pb^{2+} and nutrient salts indicative of eutrophication were relatively low in the collectors. However, the concentration of Al^{3+} (2.65±0.03 mg/L) and Cu^{2+} (10.20 ± 0.14 mg/L) were very high with the later cation being four times higher than the wastewater standard in Benin (2.5 mg/L) for the most heavily loaded collectors. In conclusion, the results of this study provide useful insights for implementation of purification system and efficient management of wastewater from industries.

Keywords: industrial zone, lake pollution, metal content, organic load, wastewater

1. Introduction

The pollution of aquatic ecosystems has been an international concern in developing countries for decades given its alarming proportions over the past half century [1- 3]. In the majority of the developing countries, more than 90% of wastewater is discharged directly into nature without treatment according to the United Nations Environment Program (UNEP) report for the year 2006. This could be attributed to lack of defective collection and treatment systems in these countries [4-8]. In Cotonou, the economic metropolis of the Republic of Benin, especially in its industrial zone, this situation is very worrying. Indeed, the open collectors intended for transit of rainwater receives a mixture of wastewater from the industrial area of Cotonou, which is discharged into the Cotonou lagoon [9]. These practices gradually intensify the chemical, organic and microbiological pollution of the outfalls [10,11], leading to environmental degradation and declined productivity of aquatic ecosystems [12,13], as well as deterioration of the living environment of riparian populations [14-16].

To remedy these challenges and help protect aquatic ecosystems, it is imperative to have adequate knowledge of the sources of the various pollutants [17,18] and how they affect the quality of water and fishery resources [11]. In Benin, investigations carried out by [14] revealed quantities of Cu^{2+}, Fe^{2+}, Al^{3+} and Pb^{2+}in raw wastewater flowing from Cotonou into the lagoon. It is noteworthy that, the concentration of the above-mentioned metals recorded in their study were reasonably below the Beninese standard unlike Cd, and Pb whose concentrations exceeded the standard. The concerns are about the continual discharge of these heavy metals into the lagoon because of the serious ecological problems they pose. This is linked on the one hand to their strong capacity to be incorporated into the trophic chains of the aquatic biocenosis and on the other hand to their toxicity. These heavy metals when disposed into water bodies can bioaccumulate and bio amplify in several aquatic species with devastating effects on the aquatic environments [19,20].

Regarding the state of pollution of the wastewater collections from Cotonou, only those of Dantokpa and Midombo have been assessed for phytoplanktonic diversity in relation to physicochemical parameters [14] and the determination of the concentration of heavy metals [15]. These data which prove a substantial input of nutrient salts and heavy metals into the lagoon via the Dantokpa and Midombo collector remain insufficient to identify the major sources of pollution that invade Lake Nokoué. This seems to be a cause for concern since a large part of the population of Cotonou depend on the fishery resources from this lake. It is therefore necessary to assess the contribution of industrial waste discharged through other collectors, particularly those in the Akpakpa area, to the pollution of the lake. The present investigation aims to (i) assess the rate of eutrophication indicators in the collectors, (ii) determine the organic load of these waters, (iii) determine the content of metallic trace elements of the wastewater of each collectors from the industrial zone, (iv) verify the conformity of these contents with the norms of wastewater disposal with a view to concrete proposals to the companies and factories of the study zone. To address this issue, the following hypotheses are made: (i) nitrogenous and phosphate materials are below the eutrophication threshold (ii) the organic matter in these waters is abnormally high (iii) the metallic trace elements are in high content in the lake, (iv)The level of mineral salts in the waters explored are higher than the Beninese standards.

2. Materials and methods

2.1 Study environment

This study, conducted between June and July 2021, took into account the wastewater collectors from areas dubbed the 1st, 2nd and 3rd districts of Cotonou city. The area had a hot and humid equatorial climate with two rainy seasons and two dry seasons, an average rainfall of 1278 mm for a temperature around 29°C. Geologically, it is a plain with an open water table bordered by layers of alluvial sediments, swamps and complexes of sandy barrier beaches and shallows. These collectors run along the Akpakpa agglomerations and discharge their contents into the Cotonou lagoon which connects Lake Nokoué to the Atlantic Ocean. This area of the city of Cotonou remains special because although inhabited by households, it is one of the main industrial zones of Cotonou. The water sampling was carried out considering the length of each collector in accordance to increasing anthropogenic pressures, three sampling stations were retained upstream (1), in the middle (2) and downstream (3) along each collector in order to appreciate the pollution level fluctuations (Fig.1). Thus, 3 stations were selected at the inlet of the wastewater discharge outlet into the lagoon.

2.2 Water sampling and analysis techniques

Four sampling sites corresponding to the four collectors were selected with the three stations on each site. Wastewater samples were collected using 1L plastic bottles that were immediately wrapped with aluminum foil to block any biochemical activity. All samples were kept cold in an insulated cooler with accumulators during transport. Samples were immediately refrigerated at 4°C upon return to the laboratory. In situ dissolved oxygen and temperature were measured using HACH LDO TM oximeter while pH, electrical conductivity and TDS were measured via electrochemical method using HI 991001 pH meter, and HACH sension5 conductivity meter. For each sample, geographical coordinates of the collection points were recorded with GPS GARMIN 60.

2.3 Physio-chemical analyses of organic load, metallic trace elements and nutritive salt contents

NO_3^- and NH_4^+ were respectively measured using colorimetry in the presence of sodium salicylate by the colorimetric method in the presence of Nessler reagent [21,22]. The parameters of organic pollution were determined according to the standards of NFT 90-101 and NFT 90-103. Suspended matters were measured by photochemical method using a HACH DR/890 spectrophotometer according to standard NF EN 872, Total Kjeldhal Nitrogen (TKN) by the Nessler method, nitrite by colorimetry, BOD_5 by oxytop respirometric method in a thermostatic chamber (NF EN 1899-2), COD by spectrophotometer DR 2800 methods. Total phosphorus was computed following the ascorbic acid method (NF EN ISO 15681-2). Cu^{2+}, Fe^{2+}, Al^{3+} and Pb^{2+} were measured by DR 2800 molecular absorption spectrophotometry according to the principle: At a fixed wavelength, the concentration of a substance is proportional to its optical density according to the Beer-Lambert law: DO = ε l C, with ε: proportionality coefficient; l: length of the cell; C: concentration of the measured parameter.

2.4 Statistical analysis

Statistical analysis and calculation of mean values and standard errors were carried out with the "statistical analysis system" version 9.2 after verification of the conditions of normality and homoscedasticity of variance. The mean values obtained were compared to the accepted norms in Benin and WHO. The Pearson correlation test (r) was performed to evaluate the correlation between the different physico-chemical parameters.

3. Results

3.1 Dynamics of physicochemical parameters of wastewater

The water temperature values ranged between 28 and 31°C with an average value of 29.75 ± 0.64 (Table 1). These temperature values were within the range of the WHO standard for wastewater except for collector 4, which recorded 31°C. The dissolved oxygen rate was higher than 5mg/L for collections 1 and 2 (6 mg/L). Collectors 3 and 4 were less oxygenated (values below the threshold for wastewater discharge, 5mg/L). Hydrogen potentials of all collected samples oscillate around neutrality ($6 < pH < 7$) and were comparable with the acceptable values for the standards of industrial wastewater in Benin. Regarding electrical conductivity, two groups of wastewater stood out, i.e. weakly mineralized water with conductivity hovering around 400 µS/cm for samples 1 and 2, and highly mineralized water in samples 3 and 4 with conductivity close to 4000 µS/cm, a value double that of the 2000µS/cm value admitted by the WHO for wastewater discharges. In total, the wastewater discharged into Lake Nokoué, particularly from collectors 3 and 4, is highly mineralized and with high levels of dissolved salts.

3.2 Indicator parameters for eutrophication in sewage

Phosphorus content in the collectors explored ranges from 5.54 to 8.96 mg/L for the most heavily loaded collector. These values remain below the standard for wastewater discharge in Benin. (Table 2) However, the NH_4^+ contents for collector 3 and 4 were 10 times higher than the normal. NO_2^-, NO_3^- and TNK levels in the collectors have remained relatively low compared to Beninese standards. However, the risk exists due to the continuous discharge.

3.3 Flow of organic pollutants in wastewater from collectors

The parameters measured are the BOD_5 and the COD (Table 3). The BOD_5 appeared to be very high in all collectors. The BOD_5 values recorded in collectors 3 and 4 were respectively 6.72 and 11.64 times higher than the accepted standard. These highlights explain the need of a biological treatment of sewage before rejection. Similarly, COD contents were very high in the collectors exceeding the standard for wastewater discharge in Benin by 2.41, 2.80 and 5.35 times for collectors 2, 3 and 4, respectively. This showed that the industrial units discharged a significant amount of non-biodegradable material. Indeed, the COD/BOD_5 ratio exceeds 1.5, which shows that the non-biodegradable fringe of the organic matter discharged in the collectors is important. Analysis of the interactions of COD, BOD_5 and dissolved oxygen level, showed that the collectors (collector C 2) with high dissolved oxygen have relatively low COD and BOD_5 content. (Fig. 4 and Fig. 5).

3.4 Metals in the water

The wastewater from the collectors revealed the presence of metals including Cu^{2+}, Fe^{2+}, Al^{3+} and Pb^{2+} ions (Table 4). Cu^{2+} contents of the four wastewater collectors were 4.06, 1.72, 1.77 and 1.69 times higher than the accepted standard of 2.5mg/L for wastewater discharges in the natural environment. Although recognized as useful for human health, iron levels were very high in the studied collectors, with values ranging from 11.16 ± 0.09 to 4.08 ± 0.08 mg/L. Al^{3+} content varied between 2.72 ± 0.01 and 0.40 ± 0.00 mg/L. The standards in Benin do not rule on the residual levels of these metals in wastewater but in general, they are involved in the event of accumulation in humans in cases of renal, metabolic and reproductive dysfunctions. Some heavy metals such as $Pb^{2+}$and $Cd^{2+}$are non-existent or trace and do not present any immediate danger to aquatic systems. These results show the necessity of water treatment systems before discharge from the collector.

3.5 Correlations between physical and chemical parameters in wastewater collectors

Table 5 shows the correlation among eutrophication indicator parameters, organic load and trace metal elements. With the exception of dissolved oxygen, which showed negative correlation with nutrient salt concentrations and organic matter content, correlations among all the other variables were positive. For example, a positive and highly significant correlation ($r = 0.998$; $p < 0.012$) was observed between BOD_5 and COD. Similarly, total phosphorus content was significantly and positively correlated with BOD_5 ($r = 0.977$; $p < 0.054$), nitrite content ($r = 0.957$; $p < 0.05$) and TKN ($r = 0.974$; $p < 0.0511$). Significant and positive correlations were also observed between increase in pH and electrical conductivity ($r = 0.956$; $p < 0.05$), and between pH and the concentration of ammonium ions in the wastewater collections ($r = 0.956$; $p < 0.05$).

4. Discussion

The results showed that the pH of wastewater analyzed in this study were neutral but average dissolved oxygen levels of collectors (C1 and C2) were higher than 5mg/L discharge standard. Interestly the average dissolved oxygen levels of collectors C3 and C4 were lower than the accepted standard of Benin. The pH values recorded in this study are superior to those reported by [23] and [24] when they analyzed slaughterhouse wastewater from Congo and Morocco, respectively [25]. The low O_2 concentration in C3 and C4, which were found to be lower than the [26] decree on industrial wastewater discharge standard for Benin is indicative of organic pollution marked by biodegradable organic matter. Indeed, the BOD_5 and COD values recorded for C3 (168.33 ± 2.02; 252.64 ± 1.67 mg of O2 per liter) and C4 (291.67 ± 2.19 and 482.05 ± 1.18 mg of O_2 per liter) were on average 6 to 8 times higher than the accepted norm. Here, the above-mentioned collectors are bordered by households that discharge domestic wastewater which is carried along with the industrial wastewater to the lagoon. Similar results have been reported in previous studies [27,28]. The COD/BOD_5 ratio which varied between 1.4 and 1.6 in this study, suggest that the discharged wastewater had satisfactory levels of biodegradable pollutants. The mixed industrial and domestic origin of these waters suggests additional processes for the removal of micro-pollutants. Of the four collectors explored in this study, two were highly mineralized as indicated by their electrical conductivity values of 4545 ± 715.5 and 3871 ± 332.25 µS/cm. This high mineralization values were higher than the 3360 to 3800µS/cm obtained for wastewater from Azilal, Morocco [28] and the 1360.5 µS/cm recorded for slaughterhouse wastewater in Congo [24]. The salt contents of the collectors were very high as indicated by the high values obtained for suspended solids and total dissolved solids. Thus, it is likely that the wastewater from the collectors carries significant amount of organic and mineral matter into lake Nokoue, which progressively contribute to its overflow. This organic matter consumes a lot of oxygen, which falls into the aquatic environment and can contribute to the mortality of aquatic organisms if the discharge is made without prior treatment. Thus, the organic pollution evaluated here from BOD_5 and COD reveals a biodegradable fraction 5 to 10 times higher than the norm and a COD 3 to 6 times higher than the Beninese norm. This testifies to the biodegradability of the collector water as the COD/BOD_5 ratio exceeds 1.5 like those found by [27] which oscillate around 2.07 and 2.87 and lower than those found by [23] and [24] who found ratios of 1.21. It therefore emerges that a biological treatment for example, lagooning would reduce the organic matter discharged into the lake by 70%.

According to our results, the eutrophication indicator parameters, including phosphorus and nitrogen, are at a lower threshold than that allowed for wastewater discharge. Indeed, the mean of total phosphorus (7.29 ± 0.04) mg/L is lower than the threshold of 10 mg/L allowed for the discharge of wastewater in Benin; similarly, NO_3^- for the four collectors averaged 2.92 ± 0.27 mg/L, which was much lower than the threshold value of 50 mg/L [26](decree 2001/109). These nitrate levels are lower than 5.297 mg/L reported for surface water [29]. However, the total phosphorus recorded for the samples in this study were higher than those obtained by [29]. The disparity between our results and those of [29] could be attributed to the differences in origin of the water analyzed. The high NH_4^+ content observed to be 10 times higher than the accepted standards of 0.2 mg/L could linked to intense microbial activities, which could have contributed to increased pH values in the collector (C4) with high NH_4^+. Indeed, [10] and [11] revealed that increases in temperature promote biochemical activities of microbial flora which in turn lead to rapid mineralization of organic matter and thus enriching the environment with NH_3 resulting in alkalinity of the environment. Indeed, the effects of temperature on nitrogen cycle reactions involving nitrite and nitrate shows that increasing temperature is correlated with high nitrate levels. In fact, an increase of temperature is favorable of microorganisms, some of which activate the conversion of organic nitrogen in substrates into mineral nitrogen including NO_3^- and NO_2^-. Increased pH were observed in collections with high TNK and NH_4^+ levels (C3 and C4). Indeed, considering the NH_4^+/NH_3 acid couple, the increase of NH_4^+ in the medium lead, under the action of microorganisms and temperature, the enrichment of the medium in NH_3 so as to maintain the equilibrium; this results in a basification of the environment with a consequent increase of the pH. Generally, wastewater collectors from the industrial zone of Cotonou are low in eutrophication causing pollutants (Fig.2 and Fig.3). In summary, our study revealed that the levels of nutrient salts indicative of eutrophication in wastewater from the industrial zone of Cotonou are below the thresholds allowed for the discharge of wastewater in Benin. However, concerns persist regarding the continuous discharge of water from the collectors into the lake. An assessment of metal pollution in the collected samples revealed that while heavy metals such as Pb^{2+} and Cd^{2+} were in low quantities or almost non-existent, Al^{3+}, Fe^{2+} and Cu^{2+} were in high proportion in the waters. These results contradict the findings of [16] who reported very high levels of lead and cadmium. This could also be explained partly by the differences in the nature of the wastewater explored. [16] analyzed wastewater from hospitals as against the wastewater from industries assessed in this study. The metals found in our samples are related to the various industries in Akpakpa area. These metals, although not incriminated by Beninese standards are associated with Alzheimer's disease and metabolic disorders [3].

Conclusion

At the end of this study, with regard to the hypotheses, it appears that:

-Phosphorus and nitrogen contents are critical and show risks of eutrophication if the discharge is continuous.

-The levels of organic matter, whether biodegradable or not, are abnormally high in some collectors compared to the Beninese norm;

-The wastewater from the various collectors does not contain all the suspected metals.

-The levels of mineral salts are however low compared to the standards of wastewater discharge in Benin.

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Availability of Data and Material All relevant data are within the paper and its supporting information files.

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Table 1: Electrochemical parameters measured in situ in the collectors

Parameters	Collector	Unité	Mini	Maxi	Means & SD	Normes Benin/ WHO
	C1		28.5	30	28.93 ± 0.83	
	C2		29.2	31	30,36 ± 0.49	
Tempreature	C3	°C	28	30.5	29,33± 0.60	< 30
	C4		29	31	30.40 ± 0.64	
	means		28.68	30.63	29.75 ± 0.64	
	C1		6.30	7.20	6.88 ± 0.43	
	C2		6.10	6.50	6.32 ± 0,21	
Dissolved oxygen	C3	mg/L	3.52	4.49	4.03 ± 0.26	≥ 5
	C4		3.21	3.63	3.43 ± 0.27	
	means		5.53	5.46	5.16 ± 0.29	
	C1		5.99	7.13	6.73 ± 0.07	
	C2		6.24	7.40	6.80 ± 0.80	
pH	C3		6.42	7.55	7.04 ± 0,22	6-9
	C4		6.99	7.39	7.32 ± 0.28	
	means		6.41	7.37	6.97 ± 0.34	
	C1		298.69	307.15	305.66 ± 1.76	
	C2		395.24	410.25	400.0 ± 6.65	
Electrical conductivity	C3	µS/cm	3879	5826.7	4545.00±715,5	< 2000
	C4		3659.54	4012.2	3871.67 ± 332	
	means		2058.12	2639.08	2280.58 ± 263.97	
	C1		139.27	148.02	146.45 ± 1.93	
	C2		130.25	140.56	135.39 ±2.54	
Suspended matter	C3	mg/L	135	147.21	140.47 ± 4.58	< 50
	C4		320.22	328	323.60 ± 12.94	
	means		181.19	190.95	186.48 ± 25.99	
	C1		147.2	151.99	149.36 ± 1.21	
	C2		193.13	200	196.10 ± 3.17	
TDS	C3	mg/L	1901.23	2191.67	2084.33 ± 168.45	
	C4		1820.51	1940.25	1876.67 ± 31.21	
	means		1015.51	1120.97	1076 ± 51.01	

Table 2 Dynamics of eutrophication parameters in wastewater collected from the industrial zone of Cotonou

Paramètres	**Collector**	**Unité**	**Mini**	**Maxi**	**Means & SD**	**Normes Benin/ WHO**
	C1	mg/L	4.99	6.10	5.54 ± 0.06	
	C2	mg/L	5.50	7.54	6.92 ± 0.03	
Total P	C3	mg/L	6.79	8.62	7.75 ± 0.054	< 10
	C4	mg/L	7.51	9.21	8.96 ± 0.01	
	means	mg/L	6.20	7.87	7.29 ± 0.04	
	C1	mg/L	0.08	0.15	0.11± 0.01	
	C2	mg/L	0.11	0.20	0.18± 0.01	
NO_2^-	C3	mg/L	0.22	0.30	0.25 ±0,04	
	C4	mg/L	0.24	0.35	0.26± 0.02	< 3
	means	mg/L	0.16	0.25	0.20 ± 0.02	
	C1	mg/L	2.34	2.9	2.66 ± 0.24	
	C2	mg/L	2.34	2.75	2.54 ± 0.43	
NO_3^-	C3	mg/L	2.85	2.99	2.96 ± 0.21	< 50
	C4	mg/L	2.79	3.95	3.50 ± 0.20	
	means	mg/L	2.58	3.15	2.92 ± 0.27	
	C1	mg/L	0.15	0.16	0.16 ±0,01	
	C2	mg/L	0.09	0.11	0.10 ± 0,02	
NH_4^+	C3	mg/L	1.65	1.82	1.74 ± 0.03	0.2
	C4	mg/L	2.1	2.29	2.27± 0.02	
	means	mg/L	0.99	1.09	1.06 ± 0.02	
	C1	mg/L	2.12	2.31	2.22 ± 0.02	
NTK	C2	mg/L	2.51	2.9	2.85 ± 0.04	< 15
	C3	mg/L	3.15	3.34	3.28 ± 0.02	
	C4	mg/L	3.39	3.48	3.44 ± 0.01	

	means	mg/L	2.79	3.00	2.95± 0.02	

Table 3 Indicator parameters for organic pollution of water

Parameters	Collector	Unit	Mini	Maxi	Means & SD	Benin standards/ WHO
	C1	mg/L of O_2	60.24	64.1	62.00 ± 1.73	
	C2	mg/Lof O_2	148.52	155.21	150.01± 1.69	
BOD_5	C3	mg/L of O_2	165.28	170.3	168.33±2,02	< 25
	C4	mg/L of O_2	289.57	295.24	291.67± 2.19	
	means	mg/L of O_2	165.90	171.22	168.00 ± 1.90	
	C1	mg/L of O_2	85.29	96.31	87.72± 1.70	
	C2	mg/L of O_2	215.19	234.25	222.00±1.24	
COD	C3	mg/L of O_2	244.28	260.57	252.64 ± 1.67	< 90
	C4	mg/L of O_2	479.53	490.21	482.05 ± 1.18	
	means	mg/L of O_2	256.07	270.33	261.10 ± 1.44	

Table 4 Comparative values of trace metal content to wastewater standards

Parameters	Collector	Unité	Mini	Maxi	Means & SD	Normes Benin/ WHO
	C1	mg/L	9,98	10,31	10,16 ± 0,10	
Cu^{2+}	C2	mg/L	4,33	4,38	4,32 ± 0,03	2,5
	C3	mg/L	4.39	4,48	4.43 ± 0,03	
	C4	mg/L	4,21	4,24	4.24 ± 0,01	
	C1	mg/L	5,4	5,7	5,53± 0,09	-
Fe^{2+}	C2	mg/L	4,99	5,11	5,03±0,04	-
	C3	mg/L	10,99	11,3	11.16 ± 0,09	-
	C4	mg/L	3,99	4,25	4.08 ± 0,08	-

Al^{3+}	C1	mg/L	0,99	1,08	1,05± 0,03	-
	C2	mg/L	2,69	2,75	2,72 ± 0,01	-
	C3	mg/L	0,45	0,52	0.48 ± 0,02	-
	C4	mg/L	0,39	0,42	0.40 ± 0,00	-
Pb^{2+}	C1	µg/L	45	51	48,33± 1,76	1000
	C2	µg/L	55	60	57.33 ± 1,45	
	C3	µg/L	46	50	47.66 ± 1,20	
	C4	µg/L	59	61	60.00 ± 0,57	
Cd^{2+}	C1	µg/L	nd	nd	nd	1000
	C2	µg/L	nd	nd	nd	
	C3	µg/L	nd	nd	nd	
	C4	µg/L	nd	nd	nd	

NB : C1 : collector n°1 ; nd : not defined by the device

Table 5 Main correlations between physical and chemical parameters at different wastewater collectors

Parameters	MY	BOD_5	COD	NO_2^-	NO_3^-	NH_4^+	NTK	P	pH	Cond	O_2	T	TDS
MY	1												
BOD_5	0,851	1											
COD	0,881	0,998**	1										
NO_2^-	0,53	0,876	0,851	1									
NO_3^-	0,903	0,96*	0,969*	0,831	1								
NH_4^+	0,725	0,839	0,84	0,864	0,932	1							
NTK	0,58	0,907	0,884	0,998**	0,859	0,869	1						
P	0,749	0,977*	0,966*	0,957*	0,946	0,896	0,974*	1					
pH	0,5	0,739	0,725	0,907	0,811	0,956*	0,893	0,852	1				
Cond	0,469	0,692	0,679	0,873	0,782	0,948	0,856	0,812	0,997*	1			
O_2	-0,675	-0,87	-0,862	-0,934	-0,923	-0,987	-0,935	-0,939	-0,973	-0,957	1		
T	0,537	0,74	0,726	0,556	0,535	0,265	0,597	0,655	0,183	0,107	-0,356	1	
TDS	0,506	0,718	0,706	0,88	0,807	0,961	0,865	0,83	0,998	0,999	-0,968	0,133	1

NB: *: $0.01 < p < 0.05$; **; $p < 0.01$

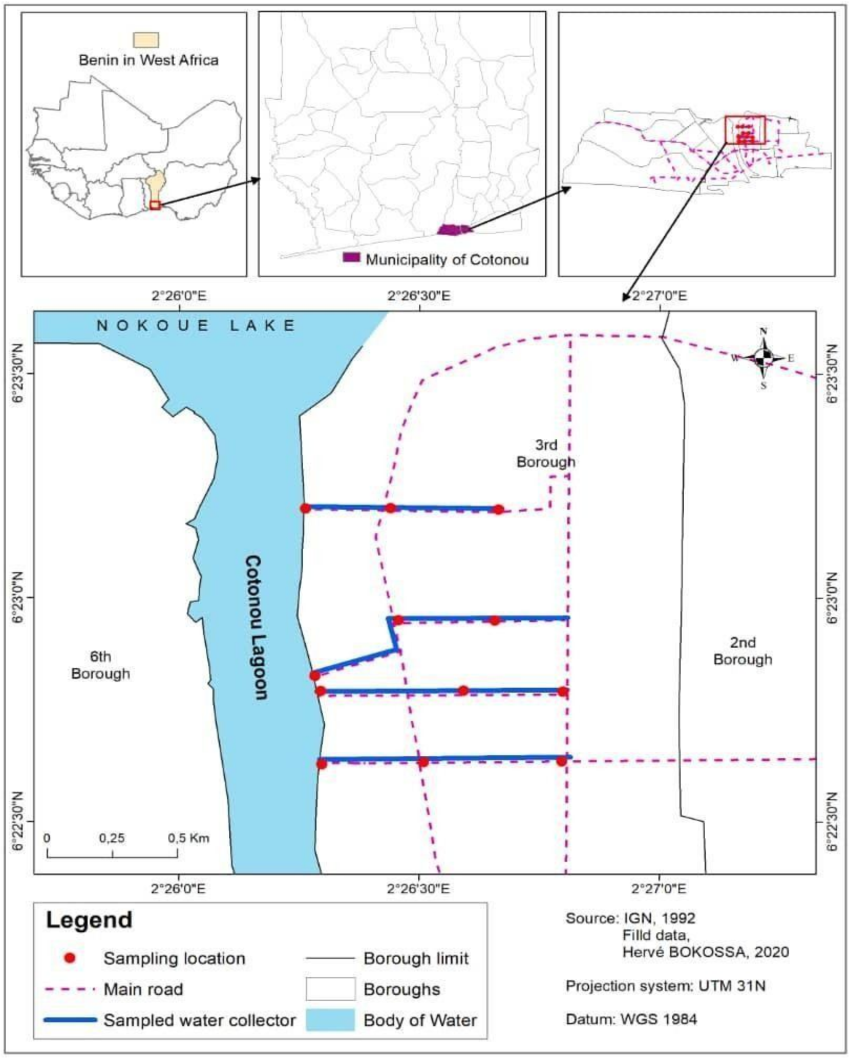

Fig. 1. Study area and sampling sites across the different wastewater collectors

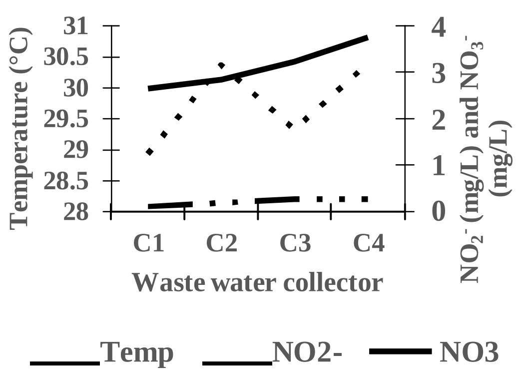

Fig. 2. Interactions between temperature and the dynamics of nitrogenous pollutants

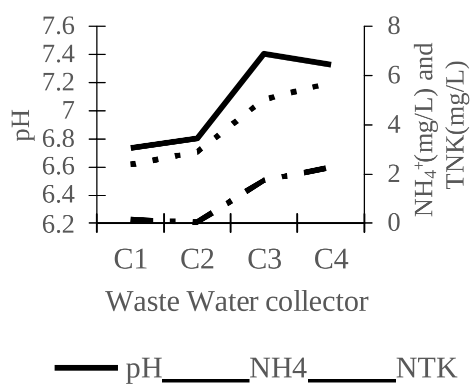

Fig. 3. Ph interaction and dynamics of total nitrogen and nitrite content

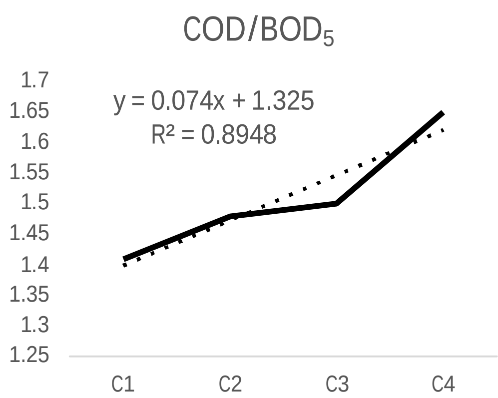

Fig. 4. COD/BOD_5 ratio

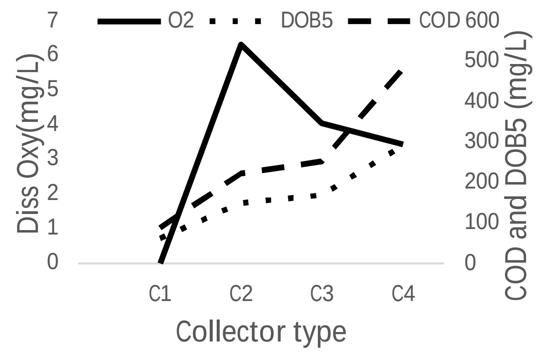

Fig. 5. COD, BOD_5 and dissolved oxygen interaction