ECOLOGICAL HAZARD ASSESSMENT OF THE EFFECTS OF HEAVY METALS AND NUTRIENTS CONTAINED IN URBAN EFFLUENTS ON THE BAY ECOSYSTEMS OF PORT-AU-PRINCE (HAITI)

EVALUACIÓN DEL RIESGO ECOLÓGICO DE LOS EFECTOS DE METALES PESADOS Y NUTRIENTES CONTENIDAS EN EFLUENTES URBANOS SOBRE LOS ECOSISTEMAS DE LA BAHÍA DE PUERTO PRÍNCIPE (HAITÍ)

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Abstract

The bay of Port-au-Prince is a body of water into which flow rain water and untreated urban wastewater from residential zones, and commercial and industrial activities. The presence of pollutants in untreated urban wastewater constitutes a hazard to aquatic organisms and can greatly affect the balance of the ecosystem of the bay. The aim of this study was: (i) to implement an environmental hazard assessment framework for untreated urban wastewater; (ii) and to apply it to urban wastewater discharged by an open channel of the combined sewage system of Port-au-Prince. COD, heavy metals, NO_3^-, PO_4^{3-} and dissolved oxygen were chosen as the main parameters for this assessment. 69 samples were collected from the experimental site from September 2003 to May 2005. High concentrations of NO_3^- (23 mg/L), PO_4^{3-} (62 mg/L) and COD (1500 mg/L) were detected. These concentrations are much higher than the threshold values set by the regulations relating to wastewater discharges into natural environments. Metals in solution were mostly below the detection limit of the apparatus used. DO contents were very low, highlighting heavy organic load, combined with a low dissolution rate in the water of the channel before discharge into the sea. In view to enriching these initial results, it is now necessary to carry out a thorough environmental hazard assessment of the wastewater channel discharge in Port-au-Prince bay and, in particular, establish the proportions of organic pollutants in the discharge by implementing ecotoxicity tests. In the future, it appears necessary to perform the physicochemical and ecotoxicological characterization of the contaminated sediments in the channel, in order to develop ecohydrological tools for managing the ecological hazards and risks related to effects of the channel's total pollution on the environment of Port-au-Prince.
Keywords: heavy metals, nutrients, bioaccumulation, eutrophication, urban wastewater, ecological hazard assessment.

Resumen

La bahía de Port-au-Prince constituye el medio receptor de las aguas pluviales y aguas negras urbanas no tratadas que provienen de las zonas residenciales y de las actividades comerciales e industriales. La presencia de contaminantes en las aguas negras urbanas no tratadas representa un peligro para los organismos acuáticos y puede ampliamente afectar el equilibrio biológico del ecosistema de la bahía. El objetivo de este estudio era (i) poner en práctica una metodología de evaluación de riesgo ambiental de las aguas residuales urbanas no tratadas, (ii) y aplicarla sobre las aguas negras no tratadas que venían de un canal abierto del sistema de alcantarilla combinado de Port-au-Prince. DQO, metales pesados, NO3-, PO43- y oxígeno disuelto han sido considerados como los parámetros para llegar a cabo esta evaluación. 69 muestras fueron colectadas de septiembre 2003 hasta mayo 2005 sobre el sitio de experimentación.
Concentraciones importantes en NO3- (23 mg/L), en PO43- (62 mg/L) et en DQO (1500 mg/L) han sido detectadas. Estas concentraciones son muy superiores a los valores umbrales impuestos por la reglamentación sobre la descarga de aguas negras a medios naturales. Los metales en solución en su mayoría se encuentran por debajo de los límites de detección de las técnicas analíticas utilizadas. Las concentraciones de oxígeno disuelto eran muy bajas e implican una carga orgánica muy importante, junto con una mezcla pobre de las aguas del canal antes de la descarga al mar. Con el fin de completar estos primeros resultados, es ahora necesario efectuar una evaluación más profunda de los riesgos que las descargas de las aguas negras del canal en la bahía de Port-au-Prince implican en especial respecto de los contaminantes orgánicos, por medio de la realización de pruebas de ecotoxicidad. En el futuro, parece necesario para realizar el physicochemical y caracterización ecotoxicological de los sedimentos contaminados en el canal, a fin de desarrollar instrumentos ecohydrological para manejar los riesgos ecológicos y riesgos relacionados con efectos de la contaminación total del canal en el ambiente de Port-au-Prince.
Palabras clave: metales pesados, nutrientes, bioacumulación, eutrofización, aguas residuales urbanas, evaluación de riesgo ecológico.

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INTRODUCTION

Aquatic ecosystems including streams, rivers, lakes, and estuaries have been subjected to increasing anthropogenic stress over the past decades (Adams and Greeley, 2000), particularly in regions where wastewater is discharged directly into the natural environment without preliminary treatment. Indeed, surface waters often serve as a means for disposing wastes loaded with nutrients and heavy metals (Streck and Richter, 1997) from residential areas, industries and manufacturing plants (Dyer, 2003). In this specific context, aquatic organisms are subjected to variations of physicochemical factors (varying hydraulic, temperature, and salinity regimes), changes in food and habitat availability, exposure to pollutants, and increases of nutrients (eutrophication) inputs (Adams and Greeley, 2000).

In Haiti, the bay of Port-au-Prince, a narrow area 15 km wide, is the natural receptacle of all effluents generated by human activities. These urban wastewaters carry household wastes, sludge from pit latrines, sewage and industrial wastewater, all of which greatly contribute towards polluting the bay (Emmanuel et Azaël, 1998). The discharge of contaminants (heavy metals, nutrients, etc.) into bodies of natural water gives rise to serious concern about water quality and the health of aquatic organisms, not only due to the varied types of pollutants that impact these systems, but also to the many ways in which pollutants can effect the health of aquatic organisms (Adams and Greeley, 2000).

Heavy metals do not degrade biologically like organic pollutants. They are known for their toxicity for human beings and aquatic life. Their presence in aquatic ecosystems is an important environmental issue due to their absorption and therefore possible accumulation in organisms (Chiron et al., 2003). Both nitrogen and phosphorous play a major role in the eutrophication of aquatic ecosystems (Elser et al., 1990; Horne and Bliss, 1994). Concentrations of unionized ammonia greater than 10 $\mu gNH_3/L$ can be expected to impair aquatic communities (USEPA, 1984; Versteeg et al., 1999) while a phosphorus value higher than 0.5 mg/L constitutes a factor of pollution (Rodier, 1996).

The marine ecosystem of Port-au-Prince's is liable to suffer very serious local damage caused by the direct discharge of urban effluents. The discharge of untreated wastewater into the bay highlights major risks for the local population and the environment: (i) human health risks due to fish morbidity, bacteriological contamination of shell-fish and beaches, (ii) ecotoxicological risks due to ecological modifications such as the sterilization of seabeds, decreased transparency due to suspended matter, and the supply of supplementary nutriments, (iii) a risk of economic imbalance (MTPTC, 1998). Indeed, in developing countries fish represent the only source of protein for poorer families and fishing is a major source of employment (Pollard and Simanowitz, 1997).

This work focuses on environmental risk assessment, a process that evaluates the likelihood of one or more stressors (USEPA, 1992). This process is based on two major elements: the characterization of effects and the characterization of exposure. These provide the focus for conducting the three phases of risk assessment (USEPA, 1998): problem formulation (including the intrinsic hazard assessment linked to pollution sources), the analysis phase (consisting in the examination of the two primary components of risk, exposure and effects, and their relationships between each other and the characteristics of the ecosystem) and the risk characterization phase (which is the culmination of planning, problem formulation, and analysis of predicted or observed adverse ecological effects related to the assessment endpoints). This study focuses specifically on the "intrinsic hazard assessment" step of the problem formulation phase.

The ecological hazards concerned are the consequences of elevated levels of organic wastes in urban wastewater, which may cause increases in oxygen demand due to the concomitant increase in biological decomposition (Dyer et al., 2003). The chemical constituents of Port-au-Prince untreated wastewater (PAPUW) may produce adverse effects of reduced dissolved oxygen (DO) on the bay ecosystems. Concentrations of illicit DO less than 5 mgO_2/L impaired fish and invertebrate communities (USEPA, 1986).

The constant discharge of chemical substances into aquatic ecosystems may also cause changes in biotic community structure and function, otherwise known as biotic integrity (Karr, 1991). The mineralization of carbon and nitrogenous wastes from Port-au-Prince untreated wastewater decreases DO and increases ammonia concentrations (Lacour et *al*., 2006), which would have negative effects on the biotic integrity of the bay's ecosystems. In this general context, this study aimed: (i) to implement a low cost environmental hazard assessment framework for untreated urban wastewater in Haiti; (ii) and to apply it to urban wastewater from an open channel of the combined sewer system of Port-au-Prince.

EXPERIMENTAL SECTION

The notion of hazard is linked to the possibility of a chemical substance, due to its intrinsic properties and its characteristics, to harm humans and the environment under determined exposure conditions (Razafindradtandra and Seveque, 1998). Its characterization above all requires choosing representative compounds of the source of pollution concerned. Urban wastewater (Streck and Richter, 1997), and rainwater (Valiron and Tabuchi, 1992) are loaded with different pollutants (anions, cations, heavy metals, organic pollutants, etc.). In these kinds of mixtures, heavy metals are present in dissolved form (free cations or chelate compounds) and in particle form, i.e., linked to suspended particles (Artières, 1987).

Everywhere in the world, the precautionary principle predominates in the assessment of wastewater discharges and effluents, i.e. the reduction of specific pollutants or substances in the framework of emission policies (Kinnersley, 1990). European Commission Directive 98/15/EEC (1998) proposes a wastewater pollutant emission limit for all the member states of the European Union. Haiti does not yet have regulations on pollutant emission limits in wastewater, therefore French (MATE, 1998) and European (EC, 1998) legislations were considered in this study to assess the hazard generated by PAPUW for the bay ecosystem, in the absence of preliminary treatment.

The conceptual framework for the primary hazard assessment of PAPUW (figure 1) is based on a characterization of urban wastewater as a function of its chemical composition (measurement of global parameters, heavy metals and nutrients). The main parameters selected for the primary hazard assessment of urban wastewater were COD, heavy metals (Cd, Pb, As, Cr, Ni, Zn), nutrients (NO_3^-, and PO_4^{3-}), and DO.

In this study, COD was used to globally characterize the concentrations of organic pollutants. Its measurement corresponds to an estimation of the oxidizable materials present in wastewater, whatever their organic or inorganic origin (Rodier et al, 1996). COD can also provide information on the presence of organic substances that cannot be oxidized by aerobic biological process (U.S. EPA, 1993). Among the selected heavy metals studied, Cd and Pb are known to be highly toxic with a strong tendency to bioaccumulate (Förstner and Wittman, 1979; Nriagu, 1987). In order to understand the contribution of PAPUW to the bay's eutrophication, urban effluent NO_3^-, and PO_4^{3-} were determined. Finally, dissolved oxygen was measured in order to roughly characterize the adverse effects of the untreated urban wastewater studied on the biological balance of the bay ecosystems.

The experimented framework consisted in comparing the results obtained for COD, heavy metals and nutrients contained in PAPUW with the established threshold values (TV) of regulations governing effluent discharges (table 1). For any ratio CC/TV> 1 (CC: Chemical characterization of a pollutant; TV: threshold values), the framework considers PAPUW as a hazardous effluent for ecosystems, with the presence of toxic substances, and recommends the determination of dissolved oxygen. Moreover, concentrations of DO less than 5 mgO_2/L represent potentially persistent toxic hazards for aquatic organisms, with the possible risk of biological unbalance and eutrophication linked to high concentrations of nitrates and phosphates.

Besides the selected assessment endpoints, other physicochemical parameters such as temperature, pH, conductivity, NH_3, chlorides and total organic carbon (TOC), were used in order to compare PAPUW composition with certain physical and chemical constituents of conventional urban wastewater.

MATERIALS AND METHODS

Experimental site and sampling points

The *Bois de Chêne* channel, the biggest collector of Port-au-Prince's rain sewage system was chosen as the experimental site for performing this study. It runs from east to west inland of Port-au-Prince's bay (Léger, 2002). This channel of about 10 km long starts at Dull hospital at an altitude of more than 400 m in the Pétion-Ville area. The rainy periods of the experimental site occur during the months April, May, June and August, September, October while the dry period extends from December to March (Simonot, 1982). This channel currently functions as a combined sewage system. The existence of such a network could increase the concentration of nitrogenous substances during the first rainy days and the dilution of all the pollutants during the other rainy days (Harremoes and Sieker, 1993). This network could also increase the concentration of certain heavy metals. The sampling points were positioned on the channel and noted: P1, P2, P3, P4, P5, P6, P7 and P8 (figure 2).

Sampling

Four sampling campaigns were performed between September 2003 and May 2005, at a rate of 3 samples per intake point. The samples were representative of dry and rainy seasons. The first campaign was conducted during the period from 2 to 6 September, 2003, the second from 10 February to 9 March, 2005 and the last from 20 April to 11 May, 2005. NO_3^-, NH_3 and PO_4^{3-} were determined only for the samples collected during the two campaigns of 2005. P3 was not chosen for the chemical characterization of NO_3^-, NH_3 and PO_4^{3-}. Measurements of heavy metals were carried out on the samples collected only on the 8th point from 16 to 18 March, 2004. All water samples were collected by using a telescopic perch with a 1-L glass flask. The samples were carefully labeled. All wastewater samples were kept at 4°C and transported to the laboratory in less than 3 hours.

Physicochemical analysis

DO, pH and electric conductivity were measured on the sampling points. A WTW Cellox 325 oxygen sensor was used to determine the dissolved oxygen. The pH of the collected water samples was measured using a WTW pH 340 ION pH meter fitted with reference and pH electrodes. A WTW - LF 330 multipurpose potentiometer coupled with specific electrodes was used to measure electric conductivity.

The chlorides were determined by the Mohr method, consisting in proportioning chlorides with silver nitrate and potassium chromate. In the presence of silver nitrate (AgNO3) Cl ions are mobilized to form cerargyrite. When all the chloride ions precipitate as AgCl, silver nitrate reacts with potassium chromate to form a brick red precipitate. Knowing the concentration of $AgNO_3$ (Co = 10^{-2} M) in 100 ml of solution (E = 100 ml), the volume necessary to obtain equivalence (Ve), the concentration of Cl ions in the solution is given by the formula: [Cl -] = Co * Ve/E.

COD was determined on diluted and filtered samples at 0.45 µm and measured by the potassium dichromate method using a HACH 2010 spectrophotometer and the test procedure provided by the supplier.

Heavy metals were determined only for the samples collected from 16-18 March 2004, as per the ISO 11 885 protocol. The samples were filtered (0.45 µm) and acidified with nitric acid (pH<2) and subjected to ICP-AES (Inductively Coupled Plasma-Atom Emission Spectroscopy).

NO_3^-, NH_3 and PO_4^{3-} were measured by molecular absorption spectrophotometry by using a NOVA 60 spectrophotometer and the test procedure provided by the supplier.

In this study, Total Organic Carbon (TOC) values were estimated by linear regression between TOC (y dependent variable) and COD (x independent variable) in wastewater [y = 0.1707x + 85.10] assessed by a good linear correlation (r = 0.95, r2 = 0.9, Durbin-Watson statistic DW = 1.96, P = 0.0039) determined by Emmanuel et al. (2004).

Results and discussion

Water temperature is a very important parameter because of its effect on chemical reactions and reaction rates, aquatic life, and the suitability of the water for beneficial uses (Metcalf and Eddy, 1991). In the present study, the temperature during the different sampling periods ranged from 26 to 33°C. The PAPUW temperature range is greater than the representative value considered as the mean annual temperature of wastewater, which varies from 10 to 21.1°C (Metcalf and Eddy, 1991). Elevated temperatures, resulting from discharges of domestic heated water and industrialized wastewater, may have significant ecological impact on natural water bodies (Eaton et al., 1995). Indeed, increased temperature can cause a change in the species of fish that may exist in the receiving water body (Metcalf and Eddy, 1991). Moreover, elevated temperature plays a role in the solubility of salts and especially of gases, in the dissociation of dissolved salts and thus in electric conductivity and in the determination of pH (Rodier, 1996). Temperature can also intervene indirectly on nitrification by modifying DO concentration, or NH3 content, jointly with pH (Laudelout et al., 1976).

The composition of PAPUW refers to the amounts of its physical and chemical constituents. These elements were determined by measuring COD, TOC, DO, conductivity, pH, chlorides, heavy metals, NO_3^-, NH_3 and PO_4^{3-}. Except for two samples from sampling point P2, for which two acid values were obtained: pH=1.63 and pH=5.07, all the other samples were always in an alkaline range (7.19 – 8.5).

Variation of conductivity (890 – 3000 µS/cm) indicates considerable mineralization of PAPUW, with a variable contribution of anions and cations probably related to untreated urban and industrial water discharges. In conventional urban wastewater, Chloride concentrations usually range from 30 to 100 mg/L (Metcalf and Eddy, 1991), whereas in the samples studied here the values obtained for this parameter ranged from 149 to 708 mg/L. Since the salinity of PAPUW samples, expressed by conductivity and chloride results, was lower than that of the sea, it seems pertinent to state that the salinity of the samples could be due to metallic salts, which are toxic to aquatic organisms. The results of the physicochemical characterization of PAPUW samples are summarized in Table 2.

Results of heavy metal measurements

Arsenic concentrations were lower than the detection limit of the apparatus used (Table 3). The same observation is made for the cadmium concentrations in samples 1 and 2, and for the chromium and the lead concentrations in sample 3. The results for the other measurements carried out are higher than the detection limit but lower than the established threshold values. In addition, certain authors have shown that the further urban wastewater flows through a watershed, the higher the amount of heavy metals detected in particulate form (Garnaud, 1999). Under these conditions, it will be necessary in future to carry out the measurement of particulate metals before concluding on the real hazards related to the presence of heavy metals in the water from the channel.

Results of COD, TOC and COD/TOC ratio

COD concentrations, where included, reached 130 and 1500 mg/L (Table 2). These values are higher than the discharge standards given by international regulation 125 mg/L (MATE, 1998). This could be attributed to the presence of toxic substances. They are close to certain average contents reported in the literature (Fresenius et al., 1990; Grommaire-Mertz, 1998) for untreated domestic wastewater (250 to 1000 mg/L of COD). These high concentrations of COD could be due to the massive presence of domestic solid waste at the bottom of the channel. TOC values ranged from 107 to 341 mg/L.

TOC and COD concentrations are greater than the values proposed by Metcalf and Eddy (1991) for domestic wastewater. The preservation of the biological balance of the natural ecosystem against untreated urban wastewater can, initially, be evaluated by biodegradability studies of pollutants contained in the effluents. Indeed, COD and TOC were reacted to completion (Gray and Becker, 2002). The information reported in the literature gives a COD/TOC ratio of 3 frequently found in many wastewaters (Seiss et al., 2001). Gray and Becker (2002) formulated a semi-empirical equation to determine the ratio between COD expressed in mg O_2/L and TOC in mg C/L: COD = 2.67 TOC. This empirical value (COD/TOC = 2.67) is based on volatile fatty acid (VFA) content in wastewater as CH_3COOH (for TOC = 24/60 gC/gVFA as CH3COOH and COD=64/60 gO_2/gVFA as CH3COOH; so COD/TOC = 64/24 = 8/3 ≈ 2.67).

The COD/TOC ratios found in the wastewater studied range from 1.21 to 4.40 (Table 2). The most important results stem from the samples collected in September 2003. The COD/TOC ratios for the samples ranged from 3.67 to 4.20, far greater than 2.67. The presence of inorganic oxidizable substances in COD concentrations could be responsible for values higher than 3. The biodegradability of organic substances occurs as a function of the speed and completeness of their biodegradability by microorganisms (Sponza, 2003). Therefore BOD5/COD and COD/TOC ratios could be used to analyze the difficulty or ease of degradation of organic substances. In this study, precise knowledge of the biochemistry of PAPUW, which is necessary in order to analyze biodegradability by using the ratios of global parameters, was not completed, because BOD5 was not taken into account. However, regarding this, when compared with the information reported in the literature, the data obtained from the COD/TOC ratio can be arranged in two groups: (i) COD/TOC from 1.21 to 3.00, and (ii) COD/TOC from 3.01 to 4.40. In the first group, the degradation of organic substances by microorganisms would occur without difficulty; however, in the second group the substances would be difficult to degrade (Emmanuel et al., 2004).

Results of NO_3^-, NH_3 and PO_4^{3-}

Nitrate concentrations for dry and rainy seasons ranged from 1 to 23 mg/L. A normal situation was observed for all NO_3^-< 5 mg/L, while moderate pollution can be considered for any NO_3^- concentrations ranging from 5 to 25 mg/L (Agence de l'Eau, 1995). Figure 3 summarizes the variations of Nitrate contents between the seasons considered.

In this study, the most alarming case of pollution was generated by PO_4^{3-} . Indeed, PO_4^{3-} concentrations ranged from 2 to 62 mg/L, higher than the selected threshold value of 1 mg/L. In spite of considerable dilution of these ions during the rainy season, the minimum concentration (3.9 mg/L of PO_4^{3-}) was 3 times higher than the standard (MATE, 1998). Variations of phosphate concentrations between the seasons considered are summarized in figure 4.

The eutrophication of the bay ecosystem and the possible toxicity of PAPUW to aquatic organisms could be attributed to the high concentrations of nitrogenous substances such as NO3- and NH3 detected in the samples. Ammonia nitrogen is well known to be toxic to aquatic organisms (Dyer et al., 2003). Aquatic communities should be adversely affected by ammonia at ≥ 1.04 mg total NH3/L or 0.01 unionized NH3/L (Versteeg et al., 1999). In this study, the value of NH4/L was not measured. Theoretically, ammonia nitrogen exists in aqueous solution as either the ammonium ion or ammonia, depending on the pH of the solution, in accordance with the following equilibrium reaction: NH3 + H20 NH4+ + OH- (Metcalf and Eddy, 1991).

At pH levels above 7, equilibrium is displaced to the left while at levels below pH 7, the ammonium ion is predominant (Metcalf and Eddy, 1991). Since in all the samples studied, pH was always in an alkaline range (7.7 – 8.8) above 7, the displacement of equilibrium may lead to the existence of NH3 at concentrations probably greater than 1.04 mg total NH3/L or 0.01 unionized NH3/L. Based on the equilibrium reaction criteria and on sample pH, ammonia makes a major contribution to the adverse effects of PAPUW observed on aquatic organisms (Emmanuel et al, 2005), as well as to the eutrophication of the bay ecosystem (Lacour et al., 2006). The average concentrations of ammonia obtained for the seasons studied are shown in figure 5.

Results of DO measurements

The values obtained for dissolved oxygen ranged from 1.47 to 3.90 mgO_2/L (Table 2), which are lower than 5 mgO_2/L. These results indicate the massive presence of organic matter in the wastewater studied, coupled with their poor breakdown. As the wastewater arrives in the bay, the transported organic matter may have a major ecological impact on fish and invertebrate communities (USEPA, 1986; Kosmala, 1998; Eriksson et *al.*, 2002). Indeed, it has been established that the effluents of wastewater treatment plants, whose DO concentrations are generally lower than 4mg O_2/L at the moment of their rejection, cause disturbances right across benthic invertebrate communities (Kosmala, 1998). It should be noted that the biological degradation reactions of the organic matter contained in the channel, leading to the low oxygen concentrations measured, can also produce ammonia from nitrogenized organic compounds, and thus possibly increase their effects on aquatic fauna.

TABLES

Table 1: Threshold values established for the hazard characterization of urban wastewater

Parameters	DCO (mg/L)	As (mg/L)	Cd (mg/L)	Cr (mg/L)	Ni (mg/L)	Pb (mg/L)	Zn (mg/L)	NO3- (mg/L)	PO43- (mg/L
Threshold values	125	0.05	0.2	0.5	0.5	0.5	2	10	1
Sources	EC, 1991	MATE, 1998							

Table 2: Physicochemical characterization of PAPUW

Parameters	Units	Means	Minima	Maxima	SD	n	Threshold values
pH	U	7.63	1.63	8.5	0.87	66	-
Conductivity	µS/cm	1763	890	3000	431,15	66	-
Chlorides	mg/L	380.34	148.82	708.40	114.34	66	-
NO3-	mg/L	5.37	0,88	22.88	4.89	42	10
NH3	mg/L	4.41	0.23	16.06	3.78	42	-
PO43-	mg/L	20.25	2.40	65	16.68	42	1
DO	mg/L	2.28	1.47	3.90	0.71	66	5
COD	mg/L	587.68	130	1500	402.52	66	125
TOC	mg/L	185.41	107.29	341.15	68.71	66	-
COD/TOC	-	2.83	1.21	4.40	0.96	66	-

Table 3: Results of heavy metal measurement

	Unit	As	Cd	Cr	Ni	Pb	Zn
Detection limit	µg/L	0,928	4,6	1,77	1,71	3,26	0,327
Sample 1	mg/L	<DL	<DL	0,024	0,007	0,015	0,085
Sample 2	mg/L	<DL	<DL	0,028	0,006	0,012	0,229
Sample 3	mg/L	<DL	0,011	<DL	0,005	<DL	0,056
Threshold values	mg/L	0,05	0,2	0,5	0,5	0,5	2

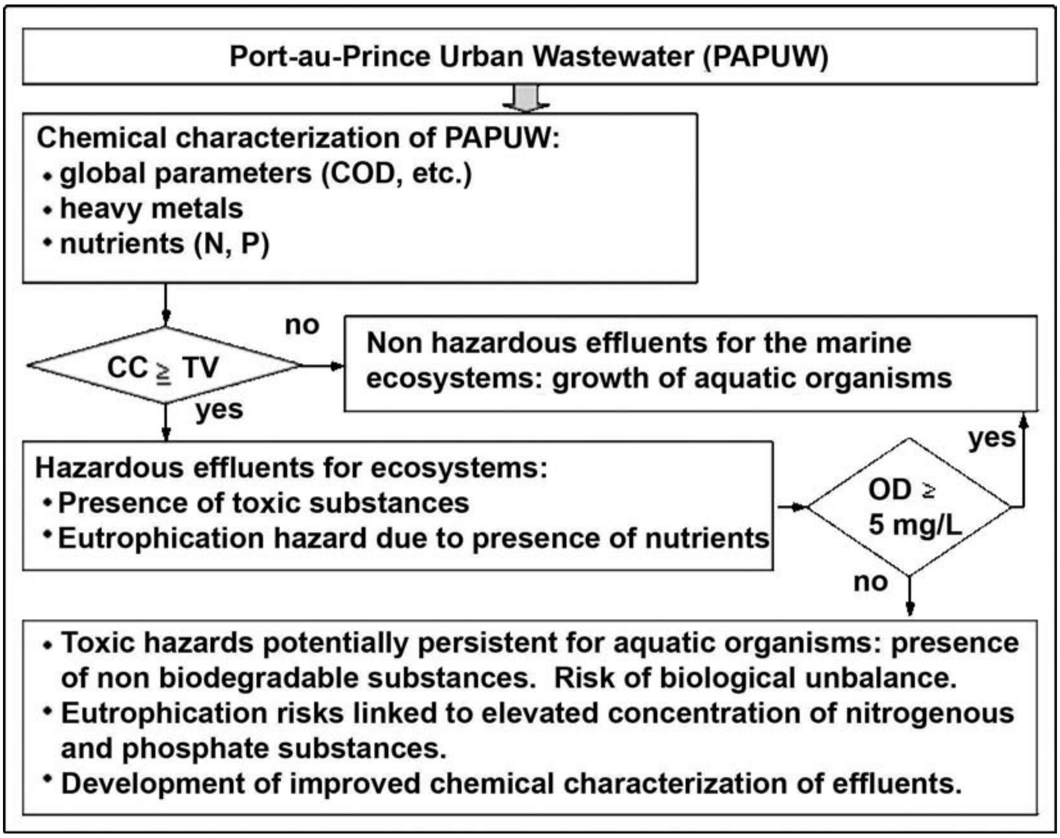

Figure 1: Conceptual framework for environmental hazard assessment of PAPUW

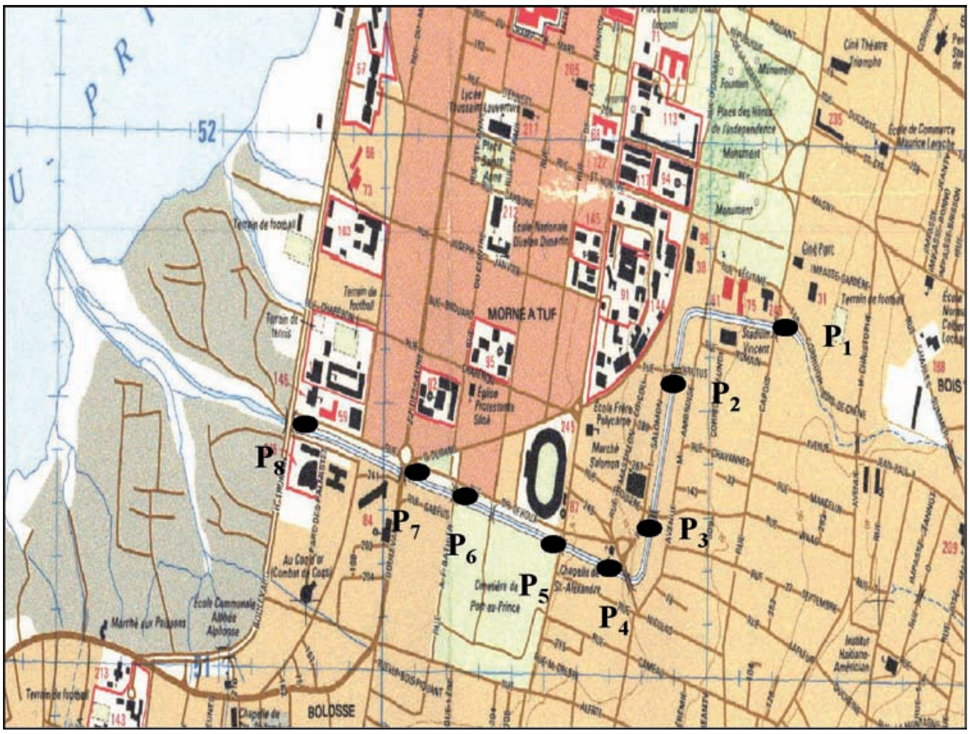

Figure 2: Experimental site with sampling points

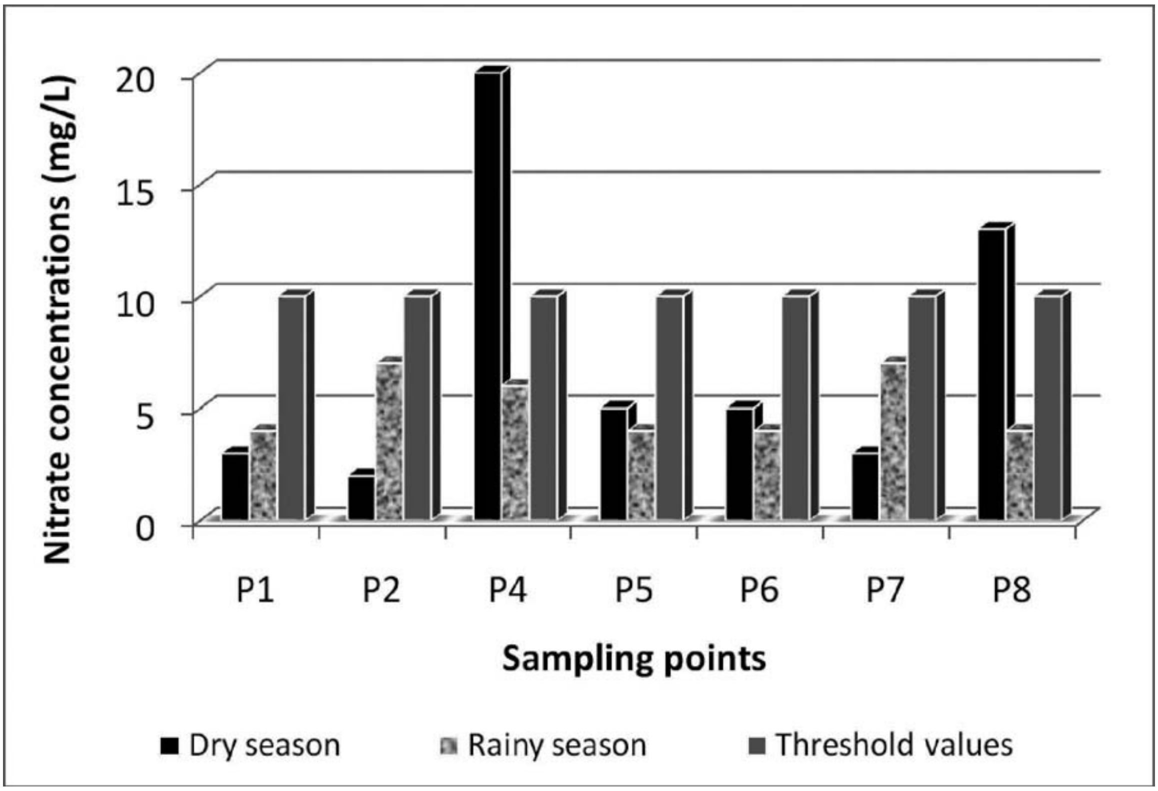

Figure 3: Variations of nitrate concentrations between dry and rainy seasons

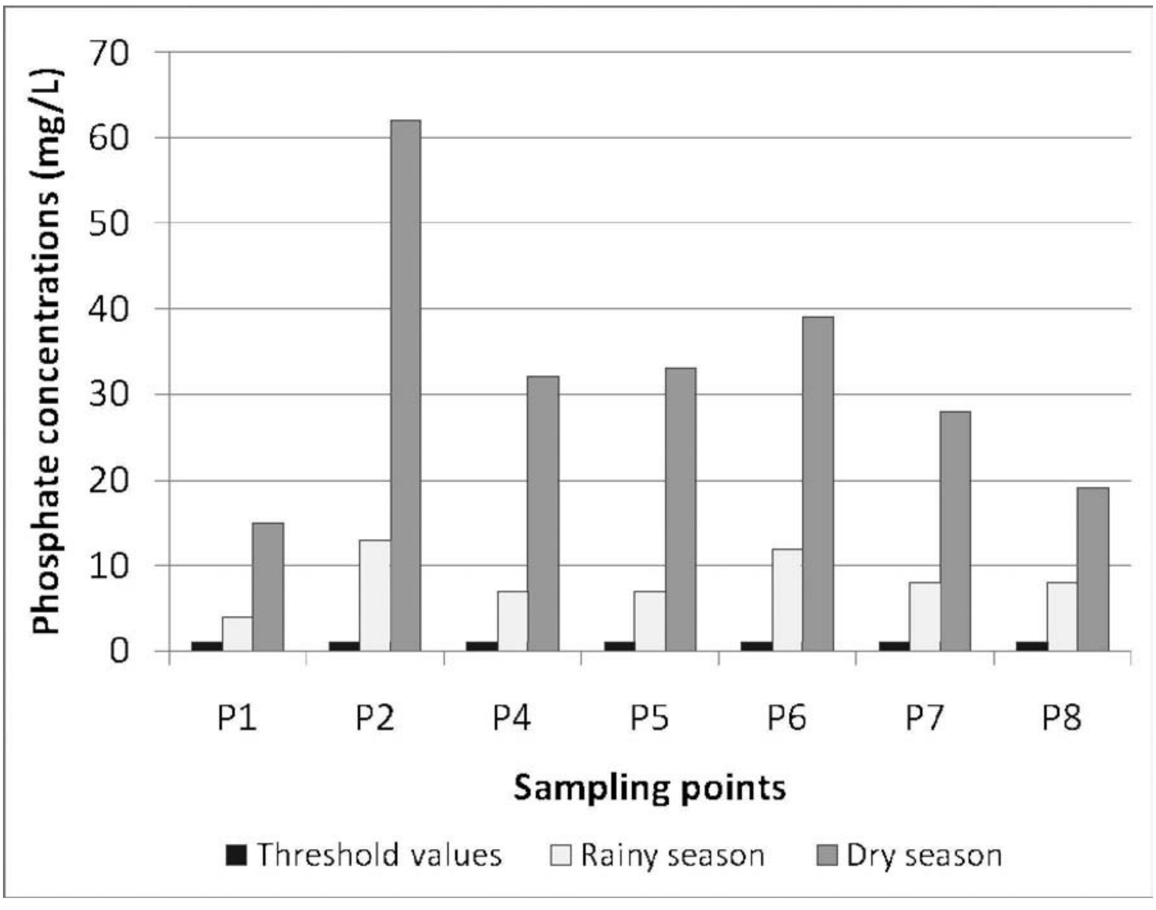

Figure 4: Variations of phosphate concentrations between dry and rainy seasons

FIGURES

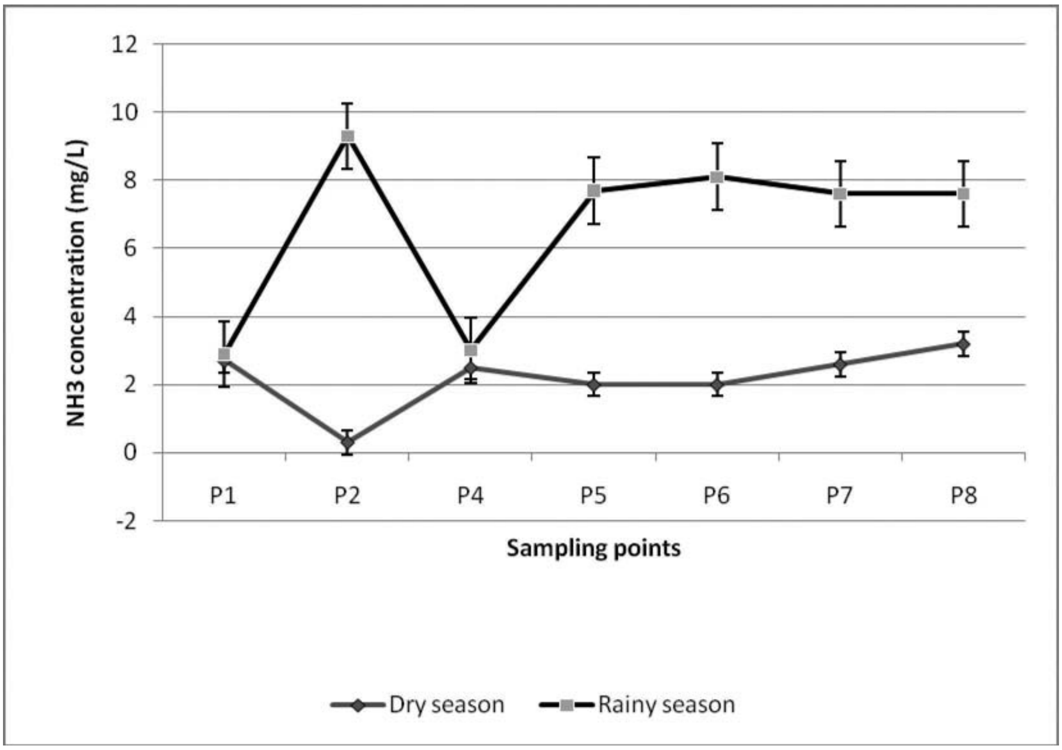

Figure 5: Average concentrations of NH_3 for dry and rainy seasons

CONCLUSION

The aim of this study was: (i) to implement an environmental hazard assessment framework for untreated urban wastewater, (ii) and to apply it to urban wastewater from an open channel belonging to the combined sewer system of Port-au-Prince. The first results obtained from the framework application showed that PAPUW is a major hazard to the Port-au-Prince bay ecosystem, and its discharge into natural water bodies could have significant negative effects on aquatic organisms. These effects could be due to high concentrations of ammonia and other pollutants. Indeed, the oxygen demand of the organic matter contained in these wastewaters is high and degradation by biological processes is difficult. Under these conditions, it is now appears important to continue the assessment by performing bioassays on these effluents.

This present study is the first work realized on PAPUW. In accordance with the obtained results, there is no pollution by heavy metals in the aquatic ecosystem, although these pollutants can be in the sediments. In case of unfavorable environmental conditions, particularly pH modification of effluents, heavy metals may change chemical forms and become soluble in aqueous phase, therefore they would be bioavailable for aquatic organisms. In order to analyze the heavy metal risks on sediments and bay ecosystems, it seems important to follow their behavior in aqueous and solid phase of the canal.

As with any environmental risk assessment (USEPA, 1998; Emmanuel et al, 2005), this evaluation will inevitably be accompanied by an evaluation of uncertainties, and the identification of the most important and urgent critical points, in order to improve the management of the effluents concerned. It now appears necessary to carry out a physicochemical and ecotoxicological characterization of the contaminated sediments in the channel, to develop ecohydrological tools for managing the ecological hazards and risks related to the effects of its complete pollution on the Port-au-Prince environment.

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