Environmental lead exposure and its impact on the health of children, pregnant women and the general population in Haiti

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Abstract: *Exposure to lead is well known to have detrimental effects on the environment and human health, including almost every organ and system in the body. In Haiti, although leaded gasoline has been banned since 1998, lead is still present in the environment due to its persistence and bioaccumulative capacities. In addition to lead air emissions, urban groundwater resources are exposed to lead. The Haitian population is exposed to a widespread urban health problem that especially affects children and pregnant women who are more vulnerable. In order to understand environmental lead pollution in Haiti, a literature review in the MEDLINE/PUBMED database was conducted on lead in drinking water from 1997 to 2016. The inclusion criteria included all studies that reported the prevalence of blood lead levels in the general population and studies assessing the risk of exposure to lead in drinking water in different regions of the country. This work gives an overview of exposure to lead in the environment, its impact on the health of the Haitian population and indicates requirements for future policy responses and interventions.*

Rezime: *Kontak ak plon se bagay moun konnen byen poutèt gwo dega sa fè sou anviwonnman an ak sou sante moun, san konte dega li fè sou preske tout ògàn ak sistèm nan kò moun. Nan peyi Ayiti, menm si yo entèdi gaz ki gen plon depi 1998, plon an toujou kanpe kinalaganach nan anviwonnman an akoz pèsistans li ak kapasite byoakimilasyon li genyen. Anplis, plon an gaye nan lè a (emisyon atmosferik), rezèv dlo anba tè nan vil yo riske kontamine ak plon. Popilasyon ayisyen nan vil yo ap viv ak yon pwoblèm sante an jeneral ki afekte sitou timoun yo ak fanm ansent ki pi fèb (vilnerab) yo. Pou nou konprann polisyon anviwonnman an sou zafè plon nan peyi Ayiti, nou fè yon revi leterati nan baz done MEDLINE / PUBMED sou plon nan dlo potab soti 1997 rive 2016. Kritè yo te rasanble tout etid ki te rapòte depasman limit kantite plon ki menase popilasyon an an jeneral ansanm ak etid ki evalye ris espozisyon plon ki genyen nan dlo potab nan diferan kalite rejyon nan peyi a. Travay sa a bay yon apèsi sou espozisyon ak plon nan anviwonnman an, sou enpak li genyen sou sante popilasyon ayisyen an epi li bay egzijans pou genyen bon jan repons ak bon jan entèvansyon politik pou lavni.*

INTRODUCTION

The World Health Organization (WHO) has recognized that environmental pollution can affect the quality of human health [1]. The demographic explosion contributes considerably to environmental pollution [2]. Indeed, this explosion results in increasing demands for foodstuffs, leading to the utilization of excessive amounts of organic and inorganic fertilizers to increase the unit output of agricultural production. Most of these fertilizers come from farm manure, municipal solid waste, sludge and industrial waste, all of which contain large amounts of heavy metals (HM) [3]. HM is an imprecise term that covers a group of elements having a specific density greater than 5 g/cm^3 [4].

Metals are natural constituents of the Earth's crust. The distribution and fate of metals in the environment is governed by their properties and the influence of environmental factors. Many metal compounds are stable, which explains their wide use and their ubiquity in the environment. The release of metals through natural processes, such as volcanic activity, erosion and bioaccumulation; intentional anthropogenic processes, such as mining, smelting, industrial uses and cultural practices, and unintentional human processes, such as incineration and fossil fuel combustion, all lead to the environmental exposure of humans and ecosystems [5]. HM constitute an ecological and human health problem because they do not undergo biological degradation, unlike certain organic pollutants [6]. Although their effects can be harmful some of them are also essential for human life. For example iron (Fe), copper (Cu), cobalt (Co), manganese (Mn), zinc (Zn) and chromium (Cr) are essential for humans and deficiencies are characterized by clinically diagnosed abnormalities. Other metals are known to be non-essential for any animals. These metals are mainly mercury (Hg), cadmium (Cd), arsenic (As) and particularly lead (Pb) [5].

Pb is the most common persistent toxic metal in the environment [7]. It has been widely distributed in the environment since prehistoric times and causes adverse effects on human health [8]. During the industrial revolution, environmental contamination increased considerably with an increase in the incidence of diseases related to Pb [9]. It can cause physiological, biochemical, and behavioral dysfunctions in humans and animals [10]. Despite its toxicity, it is difficult for humans to avoid its use due to its valuable properties such as softness, malleability, ductility, low conductivity and high resistance to environmental corrosion [7]. Human contamination by Pb can occur occupationally or environmentally through inhalation, smoking, water and dietary intake [11]. Generally, Pb is highly toxic, especially to children [12]. Its concentration in surface water ranges from 10 to 30 µg/L [13]. This level can be increased by many factors such as the drainage of untreated urban and industrial wastewater into the subsoil [14]. After drinking water, the different sources of Pb contamination are house paint containing Pb [15], automobile exhausts containing leaded gasoline [16], Pb-glazed household ceramics [17], industrial emissions and mining activity [18], Pb in interior dust [15] and soil [19]. However, the severity of the adverse effects of this metal in the environment depend on the duration of exposure, its bioavailability, how much of it enters the body and how much reaches the critical target organ(s) [6].

In developing countries, HM concentrations have been detected in groundwater samples and some of them are higher than the threshold values fixed by WHO [20]. In Haiti, the presence of Pb in the urban wastewater of Port-au-Prince has been reported [6], [21]. Groundwater resources are exposed to the risk of pollution by Pb infiltration due to poor solid waste management [22]. Moreover, Pb has been detected in drinking water [23]. The aim of this article is to develop a synthesis on the general effects of Pb on human health and on water resources in Haiti. It will allow us to: i) better define the most vulnerable populations, ii) understand the contamination of drinking water in the Haitian urban areas, and iii) suggest interventions to determine Pb levels in acquifers in urban areas.

MATERIALS AND METHODS

The MEDLINE/PUBMED databases were searched using the keywords “Haiti” and “heavy metals”, “lead toxicity”, “Port-au-Prince”, “children”, and “water supply”. Our search focused on 46 scientific papers. Among of them, 35 were peer-reviewed articles, 8 were book chapters and 3 were oral communications at international conferences. These scientific papers comprised 32 that included data from other countries and 14 that included information on the Haitian population. Of the 32 scientific papers used, 28 were peer-reviewed articles. Databanks from the World Health Organization and 25 of the 28 publications were used to estimate heavy metal exposure. In addition, 3 of the 28 articles give detailed descriptions of water resource management and recommendations for the medical management of exposure to Pb.

To understand the Haitian context of human exposure to Pb in drinking water, we used 7 peer-reviewed articles, 5 book chapters and 2 oral communications at international conferences. One of these reports confirmed the presence of Pb in the blood of Haitian children, while 6 of them studied the presence of Pb in drinking water, wastewater and soils. A book chapter was chosen to understand the sewage-drainage system in Port-au-Prince. We excluded all studies evaluating exposure to Pb via atmospheric emissions because we focused on exposure to Pb in drinking water. In general, drinking water is a potential source of Pb contamination for the population. In addition, 2 other articles on the situation in Haiti were rejected because they did not address exposure to Pb. A summary of the different publications used in the development of this work is shown in Table 1.

Table 1 **This table summarizes the different publications used in the development of this work.**

	INTERNATIONAL DATA			HAITI DATA			TOTAL
Scientific papers	32			14			46
	*PRA	*BC	*CO	*PRA	*BC	*CO	
	28	3	1	7	5	2	
Lead exposure and toxicity	24	3	1	1	4	x	32
Water resource management	4	x	x	x	x	x	5
Drainage and sanitation system	x	x	x	x	1	x	1
Risk assessment/water and soil	x	x	x	6	x	2	8

* PRA: Peer-reviewed articles * BC: Book chapter * OC: Oral communication

GENERAL EFFECTS OF Pb ON HUMAN HEALTH

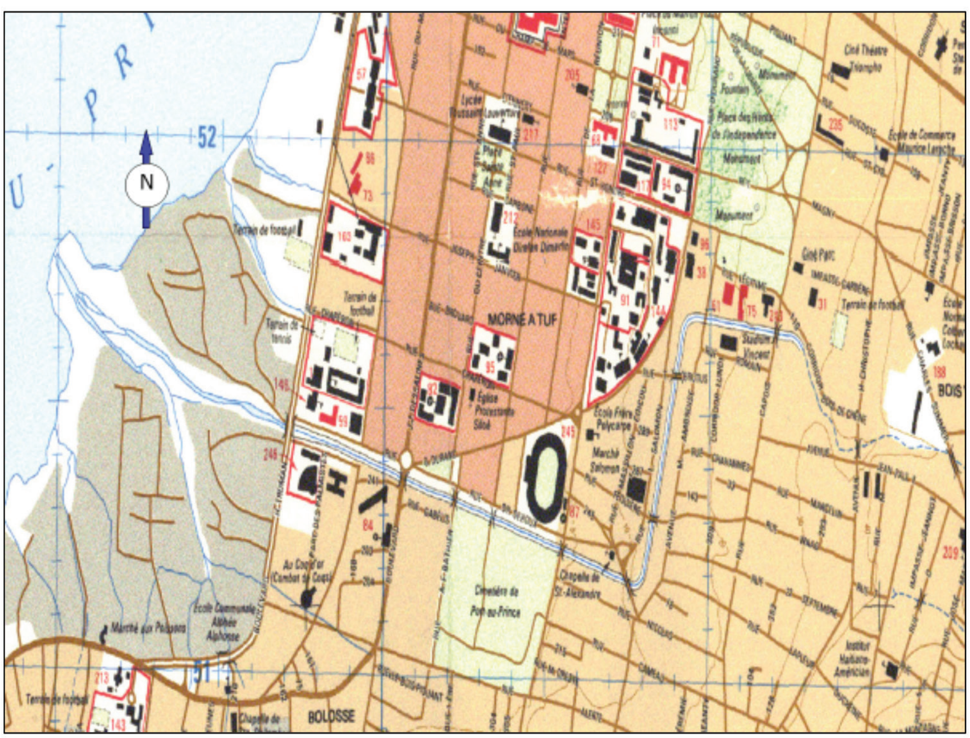
In developing countries, the management of Pb poisoning remains a public health problem, more in young children than in adults [24], [25]. Its effects can be neurotoxic, nephrotoxic and carcinogenic, and it can affect reproductive and neurobehavioral/development [24]. Many of its toxic properties are due to its capacity to mimic or compete with calcium in a variety of cellular and physiological processes such as calcium transport [11, 24, 26]. It inhibits the entry of calcium into cells, cellular respiration and calcium kinetics [11]. Its capacity to interfere with biochemical events in body cells may explain the multi-systemic adverse effects observed in adults and children [27]. What is more, the toxicity of Pb in children is higher than that in adults [7, 24]. It is responsible for decreased intellectual capacity, loss of hearing, reduced hand-eye coordination, and impaired ability to pay attention [12]. Exposure to Pb in children can start *in utero* [11, 28, 29].

Maternal Pb exposure leads to risks of spontaneous abortion and affects the transport of calcium through the placenta. It can also cause low birth weight associated with endocrine disorders and may also be responsible for metabolic disorders apparent during later life [29]. It has been reported that a low level of Pb exposure during pregnancy, even at levels considered safe for adults, can harm the development of the fetus [11]. Another aspect of the problem is the impact of tobacco smoke on the concentration of Pb in pregnant women's blood. The results of Chelchowska *et al.*, demonstrated a significant increase in Pb concentration in blood during each trimester of pregnancy among pregnant smokers compared to non-pregnant women [28]. At low doses, chronic Pb exposure can lead to metal accumulation in many tissues, particularly bone [28]. As the fetus grows, there is an increase in calcium which mobilizes the calcium stored in the mother's bones. In turn, this calcium level increases not only the blood calcium level, but also the blood Pb concentration [30].

EXPOSURE TO Pb IN DRINKING WATER: A CASE STUDY IN HAITI

Haiti is located on the Caribbean island of Hispaniola, shared with the Dominican Republic to the east. With 10 911 819 inhabitants, it is geographically divided in 10 departments consisting of 42 *arrondissements* and a total of 140 *communes* [31].

Figure 1 **Discharge of the urban effluents from Port-au-Prince into the bay**



The capital city of Haiti, Port-au-Prince, was founded in 1743. It faces the island of *La Gonâve* in the gulf and is currently the home 2 618 894 inhabitants [31]. Over the years, the Haitian health system has faced many challenges in a context of chronic limitations of financial and human resources [32]. The public health system is faced with the onerous burden of managing responses to an array of infectious diseases [33]. However, the pollution of groundwater by heavy metals is a well-known and significant environmental problem [6]. Despite many studies conducted on the risks of these pollutants on the environment, they have not been considered in any Haitian public health policies. Indeed, groundwater resources in Port-au-Prince are vulnerable to contamination due to leachates, cesspools and septic tanks, storm water runoff, waste oil discharging, over-irrigation and industrial discharging [34]. In this study, the authors focused on Port-au-Prince, but assume that the scenario is probably the same in other cities in Haiti. To understand the issue of effluents in Port-au-Prince, it should be borne in mind that all the sub-basins of the city flow into the bay of Port-au-Prince (Figure 1).

The bay of Port-au-Prince receives untreated rainwater and urban wastewater from residential areas and commercial and industrial activities, all sources that contribute significantly to the pollution of the bay [35]. The hazards of urban effluents are related to chemical (for example Pb) released in the effluents and which can induce modifications in the structure and function of aquatic ecosystems [36]. These hazards are also a consequence of high concentrations of organic matter in urban discharges which lead to an increase in the consumption of dissolved oxygen, and potentially to a decrease in the concentration of dissolved oxygen in the natural environment [37]. The different consequences of this situation generate risks for the environment and for the local population.

Thus, the health risks caused by this situation can have an impact on fish morbidity and the bacterial contamination of seashells and beaches [38]. Furthermore, Port-au-Prince is considered a typical example of a city whose drainage systems are relatively poorly developed and badly managed. The density of the population living in the urban area and the paved surfaces of the latter significantly modify the physical properties of the land, with a decrease in infiltration. This results in fast runoff with high peak flows and significant pollution problems [39].

Various studies have been carried out on the risk to human health caused by chronic exposure to lead in the public water supply of Port-au-Prince, to wastewater from paint manufacturing and to lead in soil. Emmanuel *et al.*, found a mean Pb concentration of 245µg/L in a public water tank serving a population of 90 000 [23]. In another study, Angerville *et al.*, [40] measured levels of Cu and Pb in wastewater from the paint industry, as they can be present in the pigments used. The contact of paint manufacturing effluents with aquatic ecosystems leads to a risk directly related to the existence of the hazardous substances in these which can have potentially negative effects on the biological balance of natural environments [41]. Thus, a high concentration of metallic pollutants can cause biological imbalances in aquatic ecosystems [40].

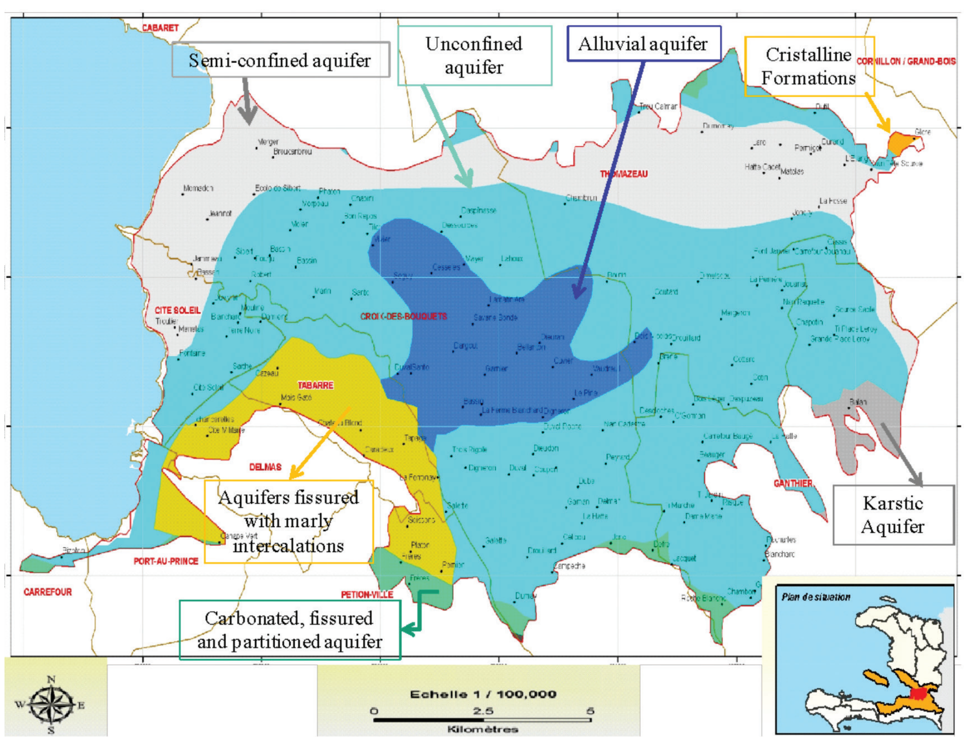
However, the lack of wastewater treatment plants and a policy aimed at eliminating the pollutants in effluents means that the wastewater from paint manufacturing is discharged directly into the aquatic ecosystem of Port-au-Prince bay. The presence of contaminants in untreated municipal wastewater poses a risk to aquatic organisms and greatly affects the balance of the bay's ecosystem [42]. In the context of discharges into the aquatic ecosystem, Angerville *et al.*, evaluated the ecological risk of heavy metals, particularly Pb in the paint manufacturing effluents discharged in Port-au-Prince [40]. In this study, their effects on different levels of the marine food chain were measured on the algae (*Asterionella glacialis* and *Asterionella japonica*) and the crustacean (*Cancer anthonyi*). The results showed a maximum concentration of 700µg/L of Pb, and demonstrated the need for complete physicochemical and ecotoxicological analyses to characterize the paint production effluents discharged in the Port-au-Prince bay to understand the potential toxic impacts on the bay's resources [40]. Following the results obtained by Emmanuel *et al.*, showing the presence of Pb at concentrations ranging from 10 $\mu g \cdot L^{-1}$ to 90 $\mu g \cdot L^{-1}$ [6], Fifi *et al.*, investigated the potential capacity of Pb, Cu and Cd to sorb on soils of the Cul-de-Sac plain [34].

The Cul-de-Sac plain (Figure 2) is the largest source of groundwater used by the population of Port-au-Prince area for its water consumption. This situation may explain the overexploitation of this aquifer. Despite this, the city of Port-au-Prince is not subject to water stress. However, some scientists think that this problem could be topical in the next 3 decades [22]. Fifi's study showed that the soil of Port-au-Prince has a high capacity to sorb metal ions, especially $Pb^{2+} > Cu^{2+} > Cd^{2+}$ [34]. The results (10-245 µg/L) of these different studies showed that the concentration of Pb measured in drinking water in Port-au-Prince exceeds the level of 15 µg/L set by the US Environmental Protection Agency (US EPA) [33]. In a previous study, the dosage of blood Pb was a parameter considered in the medical check-ups carried out on adopted children who had immigrated to France. This study was conducted in France on 24 Haitian children adopted between 2005 to 2006. On their arrival in France, high levels of Pb, i.e. between 102 and 236 µg/L, were found in the blood of 9 of them while 6 had a normal blood Pb level [43]. These studies confirmed the urgent need for the ongoing health risk assessment of urban water supplies and the monitoring of human exposure to heavy metals.

DISCUSSION

Despite the studies carried out in Haitian university laboratories on the chemical hazards of heavy metals, especially Pb, no policy has been developed by the Haitian government to

Figure 2 Map of the *Cul-de-sac plain* (Fifi *et al.*, 2010).



protect the population against HM. No laboratory specialized in the treatment of wastewater or in monitoring the quality of the environment and food safety has been set up. There are several reasons why Pb exposure should be taken seriously. Pb poisoning has been associated with low iron levels in the serum. In addition, the correction or prevention of iron deficiency in the newborn would reduce blood Pb levels. However, excess Pb in children can also be transmitted during pregnancy from mother to child [43]. To date, we have no data on the level of Pb contained in the blood of mother-child pairs. We believe that this information would make it possible to: i) evaluate the correlation between the Pb level in women's blood before and during pregnancy, and in that of their babies at birth; ii) better appreciate any possible correlation between birth weight, the level of maternal blood Pb and the level of Pb in breast milk.

Many studies found associations between low level environmental Pb exposure and chronic kidney disease, a general term for heterogeneous disorders affecting the structure and function of the kidney (CKD) [7, 24, 44, 45]. Benjelloun *et al.*, reported that chronic Pb nephropathy is correlated with years of Pb exposure [46]. This nephropathy is characterized by chronic tubulo interstitial nephritis with fibrosis that reflects tubular injury (such as moderate focal atrophy, loss of proximal tubules, and prominent interstitial fibrosis) revealed by kidney biopsy [44]. Other studies indicated that Pb is nephrotoxic even at blood Pb levels lower than 5 µg/dL. This situation is observed particularly in susceptible populations, such as those with hypertension and diabetes mellitus, which are among the main causes of CKD [7, 44, 45]. In addition, it is known that the cumulative load of Pb in the body tends to increase with age, as does the risk of kidney disease due to other factors [45].

In the case of Haiti, the prevalence of diabetes (12%) and hypertension (47%) led nephrologists to predict exacerbated CKD levels and an increase in the number of patients requiring dialysis as a renal replacement therapy in the future [47]. In this context, it is necessary to conduct research to better define the contributions of Pb exposure to the health state of CKD patients. However, the situation of Haitian patients with CKD is very complicated. According to Exantus *et al.*, the average weekly cost of three hemodialized sessions is US$600 in private centers and ranges from US$66 to US$460 in public hospitals. In addition, patients are sub-dialyzed with one to two sessions due to the number of stations available in public hospitals compared to the number of patients treated in them [47]. The low economic level of the population, (72% of Haitians live on less than US$2 a day), and the lack of health insurance for all, are factors that must be considered so that politicians can establish a health policy focused on the prevention of chronic kidney disease. It should be recalled that Haiti is located in an area exposed to natural disasters such as hurricanes and earthquakes. The country is also subject to violent tropical storms that cause severe floods (2008: Fay, Gustav, Hanna, Ike, 2004: Jeanne, 1998: Georges, 1994: Gordon, 1963: Flora, 1954: Hazel). With regard to earthquakes, the history of Port-au-Prince has been marked by two major earthquakes in 1751 and 1770 [39] and more recently in January 2010 the earthquake of magnitude 7.3 on the Richter scale almost destroyed the city [39]. Unfortunately, risk management has focused on preventing hurricanes because earthquakes are less common. To date, no studies have been conducted to determine which pollutants were released into the environment as a result of collapsed building, as most of these buildings were painted with paints containing Pb. To this end, we believe that new public health strategies must involve environmental actions to improve human health in order to ensure sustainable development for future generations.

The reality of environmental pollutants requires understanding the legal framework for regulating them. In developed countries, Environmental Risk Analysis (ERA) is not only a scientific framework for analyzing problems of environmental protection and remediation but also a tool for setting standards and formulating guidelines in modern environmental policies [22]. However, the application of international conventions and even national laws relating to environmental issues may be difficult to apply in some countries because of their socioeconomic, political and ecoclimatic realities. To protect the environment, French legislation in support of the European Commission's directives considers quantitatively restrictive standards [48].

In the case of Haiti, the country's legislation has addressed the issue of environmental pollution since 1962. Thus, the Rural Code published in the same year prohibits the discharge of wastewater from industrial facilities and residences into natural watercourses, and irrigation and drainage canals. In 1977, Haitian environmental laws empowered the Haitian government to develop control standards to prevent biological hazards for the aquatic system [49] (COHPEDA, 1995). Recently, in January 2006, standards were established for the treatment of industrial wastewater [50] (Moniteur, 2006). However, these standards are not well defined and are not known by the population. On the other hand, programs to combat biological contaminants are often established, which is not the case with environmental pollutants. When such programs do exist, the standards determined are not always disclosed to the public. Most often they have been proposed by non-governmental organizations or other foreign institutions that finance these programs. Do the standards proposed by these international institutions take into account the results of the studies conducted in Haiti? Most often these standards stem from the results of studies conducted in other countries that do not share the same socio-geographic reality as Haiti, so they are not adapted to the Haitian situation. These reasons explain why health and environmental problems have always remained as they are in Haiti, despite the funds disbursed to solve them.

Generally, the development of standards must take into account scientific results on the issue of environmental pollutants in Haiti. This will bring together government authorities, enterprises and scientists in decision-making. In this framework, the government fulfils its sovereign function by working to regularize standards. Enterprises that produce pollutants must be aware of the danger to which the public is exposed. Science stands at the interface and plays a mediating role. It must take into account the different variables so that once standards are established, they do not become obsolete.

CONCLUSION

Several studies conducted in Haiti by Quisqueya University in collaboration with French laboratories on the physicochemical characteristics of urban effluents have reported the presence of Pb and its inorganic derivatives in urban effluents [34, 51, 6, 40, 42]. Furthermore, the pollutants in urban effluents can significantly disrupt terrestrial and aquatic ecosystems, by causing the loss of biodiversity and higher levels of Pb and other heavy metal pollutants than the thresholds imposed by the regulations on the discharge of wastewater into the natural environment [51]. If we consider that in developing countries fish is an important source of protein for poor families [52], it is therefore logical to assume that seafood is a source of Pb contamination. In Haiti, awareness of chemical hazards must be a priority for governmental authorities. To solve this problem, it would be interesting to develop joint work involving several actors: politicians, industrial companies and scientists. As suggested by some scientists working on the water resources and environment of Haiti, "joint actions must be carried out by these different actors to ensure the integrated management of urban liquid discharges and aquatic biodiversity" [51].

We are interested in the environmental effects of pollutants on the Haitian population. To this end, we intend to characterize Pb concentrations in various operational boreholes used to supply the population with water. Knowing the impact of leaded gasoline car exhausts as a source of contamination, we aim to conduct a Pb characterization campaign in urban areas. This campaign will: (i) focus on urban areas with dense automobile traffic; (ii) test the quality of gasoline distributed in Haiti; (iii) characterize the concentration of Pb in the different aquifers. This study will lead to the production of a Pb concentration map for the Haitian urban environment. Furthermore, we will be able to set up absorption facilities with inexpensive materials and simple experimental procedures. At the same time, we intend to carry out epidemiological studies on the exposed population: children, pregnant women, workers in gas stations, patients with CKD. Given the high prevalence of CKD in adults in Haiti, it would be interesting to check whether there is a relationship between chronic exposure to Pb and this kidney disease. These epidemiological studies will update data on the prevalence of Pb poisoning and CKD in the most vulnerable communities. These studies will identify Pb-intoxicated patients, sources of contamination, and allow developing therapeutic protocols to care for these patients. Thus, we will educate health professionals to carry out routine screening of Pb in individuals in at-risk populations. ◘

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