# Urban groundwater contamination by *Cryptosporidium* oocysts in Haiti : analysis of risk factors for human health

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**Abstract** *: Cryptosporidium parvum is a protozoan parasite infecting the gastrointestinal tracts of many vertebrates, including humans. An infected animal or human suffers from cryptosporidiosis, a severe diarrheal disease, which lasts 1 to 2 weeks for immunocompetent individuals, but could be fatal for children and immunocompromised individuals as there is no effective therapy. In Haiti, the intestinal cryptosporidiosis is caused by at least three species : Cryptosporidium hominis, C. parvum and C. felis which are responsible for 17 % of acute diarrhea in children less than 2 years and 30 % of chronic diarrhea in HIV patients. Cryptosporidiosis transmission in humans may occur through a number of routes, among which the ingestion of fecal contaminated drinking water is a major source. Contamination of drinking water with Cryptosporidium oocysts is of particular concern since as few as one infective oocysts may cause infection. In previous studies, Cryptosporidium oocysts have been detected in surface water and groundwater from three major cities of Haiti : Port-au-Prince, Cap-Haitian and Les Cayes. Significant concentrations from 4 to 1274 oocysts in 100 liters of filtered water were found in Port-au-Prince ; in the city of Cap-Haitian 741 to 6088 and concentrations ranging from 5 to 100 oocysts have been obtained in groundwater from Les Cayes. Results indicate that water resources in Haiti are widely contaminated with Cryptosporidium oocysts. Therefore, they may constitute potential sources of biological risk particularly for human health. Since Cryptosporidium oocysts are biological colloids, it is important to analyze the different risk factors associated with transfers of Cryptosporidium oocysts in aquatic ecosystems of Haiti.*

**Rezime** *: Cryptosporidium parvum se yon pwotozowè parazit ki enfekte tib dijestif anpil vètebre, bèt tankou moun. Yon bèt oubyen yon moun, ki gen maladi yo rele kriptosporidyoz la (cryptosporidiose an franse), kapab gen yon dyare ki rete sou li pandan 1 pou rive 2 semenn si li gen selil ki kab pwoteje li kont maladi a. Sepandan, pou timoun ak moun ki gen sistèm iminitè yo fèb, maladi sa a ka koze lanmò, paske pa gen okenn bon tretman pou li. An Ayiti, genyen twa kalite pwotozowè, pou pi piti, ki kab lakòz yon moun genyen kriptosporidyoz nan trip li. Non yo se : Cryptosporidium hominis, C. parvum and C. felis. Se yo twa a ki responsab 17 % gwo dyare pou timoun ki gen mwens pase 2-an epi 30 % dyare kwonik pou moun ki gen SIDA yo. Genyen plizyè fason yon moun kab genyen kriptosporidyoz, pami yo genyen ka, kote se paske moun lan bwè dlo ki kontamine ak poupou, se dayè prensipal fason moun Ayiti yo pran maladi sa a. Dlo pou moun bwè, ki kontamine ak oosit Cryptosporidium, (oosit - an kreyòl epi oosyte an franse), bay anpil tèt chaje, paske yon sèl grenn oosit ki kontamine, sifi pou kreye kontaminasyon. Nan etid ki te fèt depi yon bout tan, yo remake oosit Cryptosporidium nan dlo ki anba tè ak nan dlo ki ap sikile nan espas ouvè nan twa gwo vil Ayiti : Pòtoprens, Okap ak Okay. Nan Pòtoprens, yo rive jwenn 4 oosit jouk rive 1 274 oosit nan 100 lit dlo filtre ; nan vil Okap yo jwenn 741 oosit pou rive 6 088 oosit epi nan dlo ki ap sikile anba tè nan vil Okay yo jwenn soti 5 pou rive jouk nan 100 oosit. Kalite rezilta sa yo demontrre dlo Ayiti se yon resous ki jeneralman kontamine avèk oosit Cryptosporidium. Konsa, oosit Cryptosporidium yo kab yon danje byolojik pou sante bèt ak moun nan peyi a, prensipalman moun yo. Kòm oosit Cryptosporidium yo se yon koloyid byolojik (colloïde, an franse), li enpòtan pou nou analize tout kalite danje ki mache ak prezans oosit Cryptosporidium yo nan dlo Ayiti yo.*

## 1. INTRODUCTION

*Cryptosporidium* is an intestinal parasite in humans and domestic animals [1]. It causes cryptosporidiosis, a severe diarrheal disease, which lasts 1 to 2 weeks for immunocompetent individuals, but could be fatal for infants and immunosuppressed people [2]. Cryptosporidiosis is transmitted by the ingestion of an infective oocyst that is shed through the feces of other infected hosts [3]. Outbreaks of cryptosporidiosis occur throughout the year [4]. More than 1000 reports of human cryptosporidiosis over almost 100 countries have been documented [5]. The first human case was reported in 1976 [6]. In addition, waterborne and food-borne outbreaks are reported frequently and represent about 10 % of all cases of *Cryptosporidium* infection [7].

*Cryptosporidium* oocysts can enter surface water systems through runoff from areas with dense animal populations, including agricultural and wildlife populations, and from human populations via wastewater treatment facilities and open defecation [8]. *Cryptosporidium* oocysts are ubiquitous in groundwater; public water supplies are one of the leading causes of impaired drinking water sources and have been a serious public health concern [1, 2, 9]. *Cryptosporidium* oocysts are very resistant to traditional disinfection processes, such as chlorine-based disinfection [10, 11]. The accidental ingestion of oocysts in bathing water [12] or that used for leisure purposes [13] or the consumption of contaminated drinking water [14] constitutes a biological threat to the exposed population.

Cryptosporidiosis generally appears to be closely correlated with environmental causes, mainly in developing countries where most people live in inadequate hygiene conditions [15]. In Haiti, *Cryptosporidium* species are responsible for 17.5 % of acute diarrheas observed in infants under 2 years of age [16] and 30 % of chronic diarrheas in patients infected by HIV [17]. In Port-au-Prince, oocyts of *Cryptosporidium* has been detected in surface water used as drinking water and in the water supplied by the public water service [18, 19]. In the surrounding region of Port-au-Prince, Les Cayes and Cap Haitian, investigations conducted on water resources revealed the presence of

*Cryptosporidium* oocysts in surface and groundwater used by the population for domestic purposes [1, 9, 15, 20, 21]. In order to protect water resources, information about risk factors is essential for risk assessment and development of effective water quality control practices. The purpose of this study is to analyze the various risk factors responsible for the contamination of water resources and to identify contamination sources and actions that could ensure safe drinking water. A conceptual model was developed describing the steps for assessing health risks associated with contamination of groundwater resources.

## 2. MICROBIOLOGICAL RISKS ASSESSMENT IN THE DRINKING WATER IN HAITI

### *General approach of health risks evaluation*

The National Research Council defines the assessment of risks as the activity that evaluates the toxic properties of a chemical product and the conditions of human exposure to this product, in order to observe the reality of human exposure and characterize the nature of the effects that may result [22]. The objectives of this approach are to present explicitly to health authorities, environmental protection organizations and other people concerned, the elements of analysis on which decision-making should rely. The general approach of evaluating health risks is based on four steps: identifying the hazard, studying the dose-response relationship, estimating exposure and characterizing the risk [22]. Each of these steps corresponds to a research phase that gathers existing data from previous studies and data specifically generated for this study.

In the field of chemical risks, methodological guides refer you to the tools available, whether it is models or databases of toxicological and physico-chemical data. On the contrary, in the biological field, the process of analysis is not as advanced [23]. The data to assess the risk of environmental exposures is often lacking. In addition, the biological risk has many characteristics that prevent a simple transposition of the methodology from the chemical to the biological field area. The difference in methodology between the estimate of a chemical risk or that of a microbiological risk lies in the identification of dose-response functions and particularly in the choice of the model of dose-response relationship [24]. Human, animal, and environmental reservoirs are notoriously difficult to control and quantify [25]. This study will focus primarily on hazard identification.

### *Hazard identification*

In this analysis of risk factors associated with transfers of *Cryptosporidium* oocysts in aquatic ecosystems of Haiti, we focused on the "problem formulation" phase of the process of EDR ecological risk assessment phase, and introduce an additional step, "hazard identification" to the general methodology for assessing health risks.

The general approach of the ecological risk assessment includes three phases: (i) problem formulation, (ii) analysis and (iii) risk characterization. The first is equivalent to the hazard identification of EDR health risk assessment. In ecological risk assessment, the central element of the "problem formulation" phase is a conceptual model. This model qualitatively describes some relationships between the pollutant and its environmental components. In order to emphasize the need for program evaluation and data interpretation before the analyses begin, the Agency for Environmental Protection added the analysis plan as an explicit product of the problem formulation [26].

## 3. BRIEF PRESENTATION OF THE STUDY SITES

In the case of this study, three sites were selected: Port-au-Prince, Les Cayes and Cap Haitan.

### 3.1. Port-au-Prince

The metropolitan area of Port-au-Prince (MAPP), the main urban center of the country, has a population of 1,916,133 inhabitants, which is 22.9 % of the total population of Haiti (8,373,750 inhabitants) according to the report of the 4th general census of the population and the habitat [27]. Covering an area of approximately 10,000 hectares, the MAPP has experienced a rapid and significant population growth in recent years. The area of Port-au-Prince is characterized by an alternation of rainy and dry seasons with an average temperature of 20ºC to 35ºC. Geology and hydrogeology are dominated by the presence of a karst. This oversimplifies the aquifers in Port-au-Prince. There is at least one large alluvial aquifer under much of the city which may have salt water at depth. Denić-Jukić and Jukić reported that the main features of karst aquifers are the existence of irregular networks of pores, cracks, fractures and lines of various shapes and sizes [28].

### 3.2. Les Cayes

Les Cayes, the South County's chief city. Its population is currently 137.952 habitants [29]. The city is located at 18º34'00'' Northern Latitude and 72º21'00" west Longitude on the Caribbean coast, on a coastal plain with high rainfall (over 2,000 mm/yr). The average temperature varies from 24 °C to 28 °C. There are several types of groundwater among them: unconfined alluvial aquifers, karst aquifers, giving rise to a variety of resurgences and flows [30]. Variations in the geological structures, geomorphology, rock types, and precipitation contribute to the varying groundwater conditions in different parts of the country [31]. The primary aquifer systems are alluvial aquifers; reef and karstic or highly fractured limestones; and fractured sedimentary rocks. Other aquifers are within low permeability deposits and igneous rocks [31].

### 3.3. Cap-Haitian

Cap-Haitian, capital of the Northern region, is located about 275 kilometers from Port-au-Prince. The county of Cap-Haitian has 3 communal sections: Bande du Nord, Haut du Cap and Petite Anse. The population of the county of Cap-Haitian was around 267,368 inhabitants in 2012. It is bordered to the north by the Atlantic Ocean, to the south by the county of Plaine du Nord, to the east by the county of District Morin and to the west by the county of Bas Limbe. Average monthly temperatures are 25.3 °C to 26.1 °C in the lowlands and 22 °C in the mountains.

### *Analysis of the various factors responsible for groundwater exposure*

Several factors contribute to groundwater exposure

- Animals wandering freely in the city leading to a permanent and significant spread on the ground of their droppings laden with bacteria, viruses and other parasites;
- discharge of urban effluents into rivers without any prior treatment;
- the existence of latrines and septic tanks equiped with infiltration wells in a high-risk flood area;
- the disposal of sludge from latrines and septic tanks in or on alluvial formations;
- the existence of illegal unlined landfills in an alluvial formation;
- open defecation by infected people.

### *Conceptual model and analysis plan*

Haitian cities, where weak urban services contribute significantly to the pollution of groundwater resources, must borrow from the conventional assessment methods of ecological risks, the « conceptual model ». This model could better help to appreciate the dual role played by groundwater, namely: (i) the target surface pollution, and (ii) the source of tap water for human consumption. Figure 1 illustrates the conceptual model for understanding the transfer of *Cryptosporidium* oocysts to groundwater.

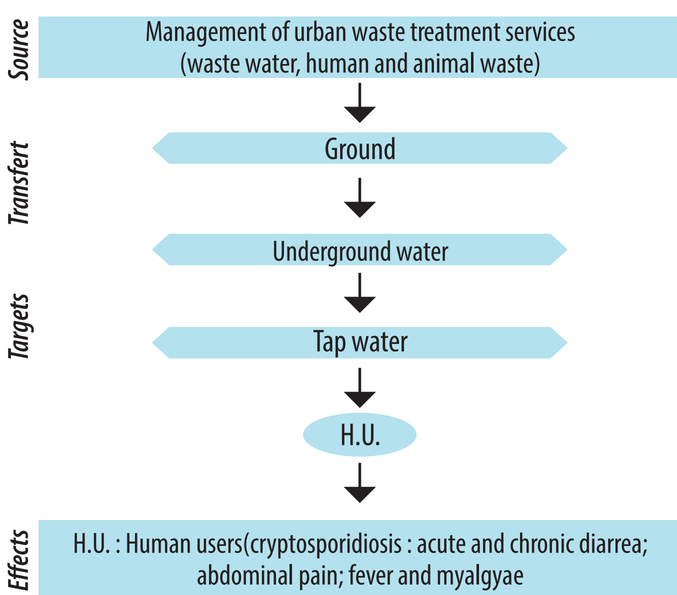


**Figure 1** Conceptual model studied [20]

In this study, the term "transfer" is represented by the ground. It is therefore chosen to assess the impact of "pollution on the surface" on groundwater quality. The surface water is contaminated; we focus on groundwater and attemp to correlate surface water and groundwater contamination by *Cryptosporidium* oocysts. Pathogen agents resistant to the absorption processes (or any other physico – chemical mechanism) of the soil migrate into groundwater. Under these conditions, groundwater exposure to pathogen agents is primarily done by infiltration or percolation (where the porosity of the soil is important). For the assessment of the effects due to the presence of oocysts in tap water, the various symptoms of cryptosporidiosis are listed in the conceptual model.

## 4. ANALYSIS OF RISK FACTORS ASSOCIATED WITH TRANSFERS OF CRYPTOSPORIDIUM OOCYSTS

*Cryptosporidium* oocysts have been detected in surface water and groundwater from three major cities of Haiti: Port-au-Prince, Cap-Haitian and Les Cayes. Significant concentrations from 4 to 1274 oocysts in 100 liters of filtered water were found in Port-au-Prince; in the city of Cap-Haitian 741 to 6088 and concentrations ranging from 5 to 100 oocysts have been obtained in groundwater from Les Cayes. The results obtained were determined according to the standard method based on the filtration, elution and concentration of oocysts and cysts by immunomagnetic separation and by detection and counting under epifluorescent microscopy [32, 33, 34]. This technique reduces the number of false positives and increases microscopic results [35]. From these contaminated points identified in this study, the numbers of oocysts obtained on Cap-Haïtian sites are particularly worrying. Even though the number of water samples collected in Cap Haitian was limited, these samples were the most contaminated, probably due to the large number of stock-farms located around sampling sites [15]. However, a possible impact of the January 2010 earthquake on these results cannot be excluded, as the study was conducted after the earthquake and the subsequent breakdown in infrastructures damaged a large part of the water reservoirs and water distribution network [15]. These cities considered among others may be contaminated by cattle, of wild and domestic animals with access to the area. It was previously reported in Haiti that *Cryptosporidium* species identification had been performed in HIV patients stools [36, 37] and on environmental samples [15].

The study revealed a very poor biological quality of drinking water in the 3 cities. Exposure to such concentrations of *Cryptosporidium* oocysts in drinking water could generate major biological risks for human health mainly for the elderly, children and immunocompromized patients [14, 38, 39]. In fact, the results concerning the high level of *Cryptosporidium* oocysts contamination were not surprising as previous studies conducted in Les Cayes [9, 20] and in Port-au-Prince that led to similar results [40].

The different positive results obtained for *Cryptosporidium* confirmed that the population of Port-au-Prince, Les Cayes and Cap Haitian is exposed to health problems linked to water-borne infections. Indeed, a median infectious dose of 132 oocysts, as determined in healthy adult volunteers, provokes human infection in 50 % of cases [41]. However, a mathematical model based on data from the Milwaukee outbreak suggested that some individuals developed cryptosporidiosis following the ingestion of only one oocyst [42].

Several factors were significantly associated with the presence of *Cryptosporidium* oocysts in the aquatic environment. Regarding the drinking water supply, the socioeconomic conditions of Haiti have led to the use of technologies that favor the use of groundwater rather than surface water [43]. The aquifers of the Plain of Cul-de-Sac in Port-au-Prince and those of the Plain of Les Cayes and Cap Haitian have the highest potential of groundwater reserves for their respective regions. They provide a large proportion of the drinking water supplied to the populations of the three conurbations in question, but reserves are contaminated by *Cryptosporidium* oocysts. The exposure of consumers to this contaminated water is a major health risk factor. To address these risk factors it is necessary to identify not only the determinants that are facilitating pollution, but also the actions to ensure the drinkability of the water from these aquifers [1]. As pointed out by Last, the risk factor is quite inaccurate because it may describe an exposure that increases the probability of a specific result; that increases the probability of occurrence of an infection or other outcome (a determinant) and; a determinant that can be modified by an action, leading to a reduction of the probability of occurrence of results [44].

Analysis of the risk factors responsible for groundwater contamination by *Cryptosporidium* oocysts first requires hydrogeological studies of the aquifers concerned, followed by studies of the mechanisms involved in the transport of oocysts from the non saturated to the saturated zone, finally resulting in the adsorption of this colloid on porous materials [20]. Karstic aquifers distinguish the hydrogeology of Haiti, characterized by irregular pores, cracks, fractures and conduits [45]. Based on its size 3 to 6 µm [46, 47, 48, 49], *Cryptosporidium* oocyst is physically classified as a biological colloid. Surface charges measured by the ξ potential of the oocysts have been found to be neutral to slightly negative in most natural waters. In Haiti, there is no control for the quality of the water distributed by public services [50]. Urban areas lack basic services for the collection and treatment of wastewater and solid wastes, and the removal of excreta. Latrines and septic tanks feed fecal contamination into alluvial and karstic aquifers [1]. Chlorination is the only method used to treat raw water intended for human consumption [51], but it is ineffective in inactivating *Cryptosporidium* oocysts [52].

Considering only the transportation physical process, the phenomenon of advection and hydrodynamic dispersion is expressed by the equation :

$$\frac{\partial C}{\partial t} = D\frac{\partial^2_C}{\partial^2} - \frac{\partial C}{\partial} \quad \text{eq. 1}$$

Where C represents the concentration of the oocysts in suspension; x, the distance; t, time; D, the hydrodynamic dispersion coefficient; and v is the interstitial velocity of the microorganism.

Transportation of any microorganism in porous media is controlled by the movement of the liquid phase of the soil, which is the driving force governing such transport [53]. Microorganisms are driven by the flow of liquid from the soil by broadcasting and advection [54, 55, 56]. For some microorganisms, their movement is effected by means of locomotion (flagella, eyelashes…) unlike *Cryptosporidium* oocysts; their mobility in the porous medium is done using a stream. In the case of an instantaneous absorption, distribution of microorganisms between the liquid phase and the solid phase is rapid compared to transport [20]. In this case, the change in adsorbed concentration is only due to the variation of the concentration in solution.

In addition to transporting oocysts from unsaturated matrix to saturated zone, the groundwater is also contaminated because catchment areas are not protected. This contamination probably stems from the domestic or paradomestic animal reservoir, including rats, which still remains to be assessed in cities and the surroundings, the wild animal reservoir being probably reduced due to the depletion of wildlife in overpopulated regions of the country. In practice, it is important to share that information at government levels and to recommend to HIV-infected patients to use filtered or treated water and also to avoid contact with domestic and wild animals that are important potential reservoirs of the parasite [18].

## 5. CONCLUSION

*Cryptosporidium* is an intestinal parasite that infects in humans and domestic animals, and causes cryptosporidiosis, a severe diarrhea, among mammals including humans. Cryptosporidiosis is life-threatening for infants and immunocompromised people because of the lack of effective therapy. The scattering and resistant form of *Cryptosporidium* sp. is the oocysts, which are eliminated with feces. Oocysts often contaminate drinking water supplies, following their transport from sources such as dairy cattle operations and wastewater effluents. They are ubiquitous in groundwater, public water supplies and surface water. Since groundwater is used more than surface water in

Haiti, this study focused on the need to upgrade the quality of drinking water by analyzing the risk factors involved in the contamination of groundwater by *Cryptosporidium* oocysts. Several factors were used among others to explain the presence of *Cryptosporidium* oocysts in groundwater. In Haiti, there is no control for the quality of the water distributed by public services. Urban areas lack basic services for the collection and treatment of wastewater and solid wastes, and the removal of excreta. Latrines and septic tanks feed fecal contamination into alluvial and karstic aquifers. Chlorination is the only method used to treat raw water intended for human consumption, but it is ineffective in inactivating *Cryptosporidium* oocysts. In addition, geology and hydrogeology of the main city are dominated by the presence of a karst, that is often characterized as having large open conduits that provide little resistance to flow and do not significantly filter groundwater. Variations in the geological structures, geomorphology, rock types, and precipitation contribute to the varying groundwater conditions in different parts of the country. Indeed the higher groundwater velocities and lack of filtration in karst aquifers make them more susceptible to contamination than non-karst aquifers in which groundwater velocities are slower allowing more effective attenuation of contaminants. Groundwater are more and more subject, intensively to voluntary discharges of polluting effluents, sewage or storm water runoff in urban environment. Groundwater contamination by the pathogenic protozoa *Cryptosporidium* is a cause of serious public health concern. In the specific case of urban groundwater in Haitian cities, it would be necessary to evaluate groundwater contamination. Moreover, information about retention and transport is essential to risk assessment and development of effective control practices. ◘

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