ASSESSMENT OF HUMAN EXPOSURES TO LEAD IN DRINKING WATER

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SUMMARY

Water is considered as an important way of human exposures to lead. Neurological symptoms such as encephalopathy, renal failure, arthralgias and myalgias have been identified as the most important acute and chronic human health risks associated with environmental exposures to lead. Concentration of 1,670 µgPb/L has been detected in Port-au-Prince urban wastewater. Since karst aquifers are mostly present in Haiti’s geology, important concentration of lead ranged from 40 to 90 µg/L were measured in groundwater and drinking water. Lead concentrations in groundwater resources were greater than the threshold value (10 µgPb/L) for drinking water. The aim of this study was to characterize human health hazards generated by exposures to lead in Port-au-Prince water supply.

Thirty two (32) samples were taken from the public water supply. The sampling period was between 16th and 22nd April 2004. An important concentration of 250 µgPb/L, greater than the threshold value, had been detected in a water tank. This result needs to be monitored particularly on the different structures of Port-au-Prince public water supply in order to assess the sanitary risk generated by lead in drinking water.

Keywords: Lead; Human health; exposures assessment; drinking water.

INTRODUCTION

Metals exert biological effects that can be beneficial or harmful (Caussy et al., 2003). Heavy metals are renowned for their toxicity towards human beings, aquatic life and the environment. Hence, heavy metals in water have been a major preoccupation for many years because they do not degrade biologically like organic pollutants. Their presence in drinking water is a public health problem due to their absorption and therefore possible accumulation in organisms (Chiron et al., 2003). Nevertheless, some heavy metals such as iron (Fe), copper (Cu), cobalt (Co), manganese (Mn), zinc (Zn) and chromium (Cr) are essential elements for humans, and their deficiency could induce illness like clinical abnormalities. On the other hand, at high doses, essential elements can also cause toxic effects. Mercury (Hg), lead (Pb), cadmium (Cd) and arsenic (As) are not renowned essential for any animals neither the human being (Caussy et al., 2003).

The literature reported many cases of diseases ensue from exposure to Hg, Pb, As and Cd. Hg and Pb have important effects on the somatic and the nervous system development (Académie des Sciences, 1998). As exposure continues, central nervous system effects progress with insomnia, confusion, impaired concentration, and memory problems (Robson, 2003) Humans are continuously exposed to lead from natural as well as anthropogenic sources (Christensen, 1995). Lead targets particularly nervous system, blood and kidney (INERIS, 2002). Gender and age influence the blood concentrations of lead, for example the blood lead (B-Pb) in females is 20-30% lower than B-Pb in
males. Long-term lead exposure may generate irreversible functional, morphological renal changes (Christensen, 1995), distal motor neuropathy and possibly seizures and coma (Robson, 2003).

Age is a critical variable in absorption levels; for infants and children, these levels can reach the range of 40-53% while adults can absorb 7-15% from dietary sources (Robson, 2003). Infants and small children are more sensitive to the effects of lead, which moreover is transported through the placenta to the fetus (Yule and Rutter, 1985; Milman et al., 1988; Shennan and Boyd, 1988; Bellinger et al., 1990; Dietrich et al., 1990; Goyer, 1990; Cleymaet et al., 1991; Christensen, 1995). Fetus and above all children under 2 years old are particularly sensitive to the toxic effects of the neurological comportment of lead, without any electrophysiological or clinical manifestation, but characterized by a decrease of the cognitive faculties, who can be reversible or not, evaluated by psychomotor tests like the verbal IQ test (Emmanuel, 2004). This toxic effect emerges at the time of an antenatal exposition to a critical concentration of 100 µgPb/L in the umbilical cord blood, owning to the relative permeability of the placental barrier (Académie des Sciences, 1998; Emmanuel, 2004). The period when IQ is most affected is from birth to about 4 years of age (WHO, 1995; Watt et al., 2000). Therefore, children are most susceptible to lead poisoning because their bodies are still developing and, pound to pound, absorb a higher concentration of lead than adult (Gavaghan, 2002).

Water supply is one of the major sources of human exposures to lead (INERIS, 2002). The relationship between water and blood lead concentrations has indicated that the EU standard of 50 µgPb/L in any water sample is too high (Quinn and Sherlock, 1990; Watt et al., 2000). In order to minimize the human’s exposition to lead in drinking water, the USA EPA has proposed to lower the level for contamination of water supplied by the system from 50 to 15 µg/L (Gulson et al., 1997). On the other hand, the World Health Organization (WHO) has decided to review guidelines for Pb in drinking water in order to reduce, up to 10 µg/L, the population lead exposure from this source (Watt et al., 2000). The European Union in the Directive n° 98-83 imposed to reach the WHO safety limits of 10 µg Pb/L in tap water, at least on 2013 with an intermediate standard set at 25 µg/L since 2003 (Commission of The European Union, 1998).

Important concentration of lead (1,670 µgPb/L) have been detected in wastewater rejected by paint manufactures in the sewer system of the metropolitan area of Port-au-Prince (Carré, 1997). Groundwater resources contributes largely in water supply of Port-au-Prince’s population. Since karst is the main geological characteristic of the region, and there is any treatment plant for wastewater in Haiti, there is a huge possibility for lead to be transferred into the groundwater by means of the rapid and turbulent recharge and drainage permitted by the karstic system (Denić-Jukić and Jukić, 2003). Especially as rainwater, bearing atmospheric particles of lead from industries or motor vehicles, is an important source of waters contamination (Cabrera et al., 1995). Concentration of 10 µgPb/L has been detected in a private borehole from Port-au-Prince groundwater (Emmanuel, 2004). Therefore, it seems important to verify the local or diffuse characteristics of this pollution, in order to assess human exposures to lead in drinking water. The aim of this study was to characterize human health hazards generated by exposures to lead in Port-au-Prince public water supply.

**MATERIALS AND METHODS**

**Presentation of the study area**

Drinking water supply of Port-au-Prince area is ensured by the “Centrale Autonome Métropolitaine d’Eau Potable (CAMEP)”. The daily water production of this public company is 120 000 m³ coming from 12 boreholes in the Cul-de-sac Plain providing 600 L/s, and 18 spring water of the “Massif de la Selle” (2680m of altitude) providing a flow of 923 L/s (CAMEP, 2001).

The map of the Port-au-Prince public water supply is presented in figure 1. In this study, an area containing 4 boreholes, a water tank of 4600 m³ and 5 domestic water taps have been selected as experimental site.
Sampling

Forty-two samples of water were collected from three categories (table 1) of collecting point (borehole, water tank and consumers directly connected on the system). Five samples per point were collected during 5 days of the rainy season from 16th to 22nd April 2004. Water tank samples were collected by means of a telescopic perch in a 1 L glass flask. Conductivity, TDS, temperature and pH were measured directly on sites after sampling. All water samples were kept at 4°C and transported to the laboratory in less than 3 hours. Storage conditions of samples were in accordance with the Standard Methods (Eaton et al., 1995).

**TABLE 1: Categorization of sample points**

<table>
<thead>
<tr>
<th>SAMPLE POINT</th>
<th>CATEGORY OF POINT</th>
</tr>
</thead>
<tbody>
<tr>
<td>F3</td>
<td>Borehole</td>
</tr>
<tr>
<td>F4</td>
<td>Borehole</td>
</tr>
<tr>
<td>F6</td>
<td>Borehole</td>
</tr>
<tr>
<td>F7</td>
<td>Borehole</td>
</tr>
<tr>
<td>RCS</td>
<td>Water Tank</td>
</tr>
<tr>
<td>AA_1</td>
<td>Consumer before Water tank</td>
</tr>
<tr>
<td>AA_2</td>
<td>Consumer before Water tank</td>
</tr>
<tr>
<td>ADRC_1</td>
<td>Consumer after Water tank</td>
</tr>
<tr>
<td>ADRC_2</td>
<td>Consumer after Water tank</td>
</tr>
<tr>
<td>ADRC_3</td>
<td>Consumer after Water tank</td>
</tr>
</tbody>
</table>
Physicochemical analysis

**pH**: For the measurement of this parameter a pH-meter WTW pH 340 ION was used. This instrument has 2 electrodes: an electrode of reference, metal type and an electrode (specific to the measurement of the pH) out of glass.

**Electric conductivity and TDS**: The contents of these parameters were measured directly on the sites of taking away by the application of the method known as of potentiometry. For the implementation of the method a multipurpose potentiometer WTW - LF 330 provided with specific electrodes was used.

**Chlorides**: The method of Mohr was used for proportioning of this parameter. This method consists in proportioning chlorides with silver nitrate and potassium chromate. In the presence of silver nitrate, the ions Cl are mobilized to form cerargyrite. When all the ions chlorides precipitated under AgCl form, silver nitrate reacts with chromate of potassium and a red precipitate brick appears. Knowing the concentration of the solution of AgNO₃ (Co = 10⁻² M) in 100 ml of solution (E = 100 ml), volume necessary to arrive at equivalence (Ve), the concentration of the ions Cl in the solution is given by the formula: \[ [\text{Cl}^-] = \frac{\text{Co} \times \text{Ve}}{\text{E}} \]

Lead measurements were carried out, on samples filtered at 0.45 µm and pretreated with (HNO₃) nitric acid (pH<2), according to flame atomic absorption spectrometric method (Eaton et al., 1995).

**RESULTS AND DISCUSSION**

The results of the physicochemical analysis are summarized in table 2.

**TABLE 2: Results of the physicochemical analysis of the samples**

<table>
<thead>
<tr>
<th>Sample points</th>
<th>pH</th>
<th>Temp °C</th>
<th>Cond µS/cm</th>
<th>TDS mg/L</th>
<th>Cl⁻ mg/L</th>
<th>Pb µg/L</th>
<th>Hardneees mg/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>F3</td>
<td>7.67</td>
<td>27.7</td>
<td>852.3</td>
<td>844.8</td>
<td>25.08</td>
<td>0</td>
<td>161</td>
</tr>
<tr>
<td>[7.56; 7.83]</td>
<td>[27.0; 28.2]</td>
<td>[746; 960]</td>
<td>[746; 960]</td>
<td>[20.99;30.49]</td>
<td>[142; 187]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F4</td>
<td>7.20</td>
<td>28.3</td>
<td>1167.6</td>
<td>1155.8</td>
<td>26.13</td>
<td>0</td>
<td>242.8</td>
</tr>
<tr>
<td>[7.16; 7.26]</td>
<td>[27.1; 29.3]</td>
<td>[1128; 1297]</td>
<td>[1128; 1238]</td>
<td>[25.33; 27.82]</td>
<td>[233; 251]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F6</td>
<td>7.34</td>
<td>28.4</td>
<td>929.4</td>
<td>920.8</td>
<td>21.13</td>
<td>0</td>
<td>200.2</td>
</tr>
<tr>
<td>[7.33; 7.38]</td>
<td>[27.3; 29.0]</td>
<td>[908; 1004]</td>
<td>[908; 960]</td>
<td>[17.99; 23.33]</td>
<td>[192; 204]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F7</td>
<td>7.33</td>
<td>28.4</td>
<td>1019.3</td>
<td>1004.5</td>
<td>15.83</td>
<td>0</td>
<td>210.5</td>
</tr>
<tr>
<td>[7.30; 7.36]</td>
<td>[27.6; 29.0]</td>
<td>[954; 1089]</td>
<td>[954; 1069]</td>
<td>[12.66; 18.49]</td>
<td>[202; 218]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AA_1</td>
<td>7.27</td>
<td>28.6</td>
<td>1066.8</td>
<td>1052.3</td>
<td>18.99</td>
<td>0</td>
<td>224.5</td>
</tr>
<tr>
<td>[7.26; 7.29]</td>
<td>[27.2; 29.6]</td>
<td>[1014; 1178]</td>
<td>[1014; 1122]</td>
<td>[17.16; 20.83]</td>
<td>[210; 234]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AA_2</td>
<td>7.27</td>
<td>27.8</td>
<td>1098.8</td>
<td>1092.6</td>
<td>22.06</td>
<td>50</td>
<td>228.8</td>
</tr>
<tr>
<td>[7.19; 7.47]</td>
<td>[26.5; 28.3]</td>
<td>[1010; 1197]</td>
<td>[1009; 1203]</td>
<td>[20.33; 22.99]</td>
<td>[208; 238]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RCS</td>
<td>7.08</td>
<td>28.1</td>
<td>1077.0</td>
<td>1068.2</td>
<td>25.86</td>
<td>112</td>
<td>224.6</td>
</tr>
<tr>
<td>[6.5; 7.31]</td>
<td>[26.6; 29.0]</td>
<td>[1010; 1250]</td>
<td>[1010; 1205]</td>
<td>[19.33; 31.66]</td>
<td>[215; 240]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ADRCS_1</td>
<td>7.32</td>
<td>28.3</td>
<td>1099.0</td>
<td>1057.3</td>
<td>19.22</td>
<td>0</td>
<td>229</td>
</tr>
<tr>
<td>[7.26; 7.40]</td>
<td>[27.7; 29.1]</td>
<td>[1021; 1252]</td>
<td>[1022; 1126]</td>
<td>[17.83; 21.49]</td>
<td>[223; 234]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ADRCS_2</td>
<td>7.29</td>
<td>29.2</td>
<td>1035.5</td>
<td>1035.3</td>
<td>23.91</td>
<td>0</td>
<td>225</td>
</tr>
<tr>
<td>[7.27; 7.31]</td>
<td>[28.4; 29.7]</td>
<td>[990; 1121]</td>
<td>[990; 1121]</td>
<td>[22.49; 26.33]</td>
<td>[217; 233]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ADRCS_3</td>
<td>7.38</td>
<td>28.2</td>
<td>1003.3</td>
<td>1002.7</td>
<td>19.38</td>
<td>190</td>
<td>218.3</td>
</tr>
<tr>
<td>[7.33; 7.44]</td>
<td>[28.0; 28.4]</td>
<td>[998; 1007]</td>
<td>[997; 1006]</td>
<td>[18.99; 19.16]</td>
<td>[213; 227]</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The values measured for the pH indicate the presence of a neutral medium. The measured values for chlorides are lower than 250 mg/L. All the obtained results for pH, chlorides are within the limits of the standards for drinking water (OMS, 1996).

The conductivity values indicate the high mineralization of the samples. All the values are greater than 400 µS/cm, the threshold value for drinking water (ERB, 1999). The same observation is made on the obtained values for TDS. Indeed all TDS concentrations are greater than 500 mg/L, value suggested for fresh water (Desjardins, 1988). Furthermore, a value of 0.9 has been obtained for the ratio between
TDS and conductivity. Theoretically, this ratio is an empirical factor which may vary from 0.55 to 0.9 depending on the soluble components of the water and on the temperature of measurement. Relatively high factors may apply where saline or boiler waters, whereas lower factors may apply where considerable hydroxide or free acid is present (Eaton et al., 1995). Since, in this study pH varies from 6.5 to 7.83, it seems evident that studied samples present an important characteristic of salinity.

Generally lead in water supply may come from industrial, mine, and smelter discharges or from the dissolution of old lead plumbing. Tap waters that are soft, acid and not suitably treated may contain lead resulting from an attack on lead service pipes or solder pipe joints (Eaton et al., 1995). Water samples from the boreholes are free of lead. However, important concentrations of lead are observed in domestic tap waters and the water tank. In the studied samples, lead concentrations could be due to lead plumbing or solder pipe joints. Figure 2 illustrates the distribution of lead in the studied zone.

![Figure 2: Distribution of lead in the studied sample of water](image)

Lead concentrations in some compartments of the public water supply system and the high difference observed between these concentrations and the threshold value in drinking water (10 μgPb/L) put in evidence the potential hazards for human health generated by the ingestion exposure. The scientific literature on this subject made it possible to establish "doses-answers functions" between the level of exposure and the degradation of the intelligence quotient (IQ) of the children (INSERM, 1999). These data indicate that, a contribution of +10 μg Pb/L per day in children drinking water leads to a blood-lead concentration increase of +16 μg/L. Otherwise, it is estimated that a child blood-lead concentration of +100 μg Pb/L can be associated to a fall of the intelligence quotient from 2 to 3% (Zmirou and Perrodin, 1999). This information allow to introduce, in the outlook of this study, a preliminary human risk assessment of lead in Port-au-Prince public water supply.

**QUANTITATIVE ASSESSMENT OF THE HUMAN EXPOSURE (CALCULATION OF THE DAILY AVERAGE DOSE (DAD))**

For a chemical matter and an exposure route both fixed, the general equation used for the determination of the daily average dose (DAD), managed by the exposure vector "i", is expressed by the following formula:
DADI = Ci*Qi*ER*ED/BW*WT

Where " Ci " is the toxic concentration in the polluted medium " i ", " Q " is the quantity of this vector brings into daily contact with the organism by the route considered (expressed in L/d for aquatic media), " ER " is the exposure rate (without unit) i.e. the annual number of exposures days brought back to the total number of days for a year, " ED " is the exposure duration (in years), " BW " is the body weight (in kg) and " WT "; the weighting time; WT is the period (in years) over which the dose is balanced.

Conventionally, in this formula, the weighting time is the same than the exposure duration (WT=ED) for effects with threshold: the DAD is getting closer an annual average not holding more account of the total exposure period.

For carcinogenic effects, the value allotted to WT is always 70 years: the estimated dose is in this case proportional to the ratio of the exposure rate over the whole lifespan (whole life DAD). This weighting is carried out under the hypothesis of a concurrent dose drawing: the cancer risk being referred to a unit of daily amount dose received during 10 years is equivalent to the risk related to the half of this amount delivered during 20 years.

DEFINITION OF THE EXPOSED POPULATION VIA THE STUDY OF THE POSSIBLE ROUTES OF EXPOSURE

The populations concerned with this basic evaluation of risk are principally those directly supplied by the water Tank being used as intake point. This population is estimated at over 90,000 inhabitants. With a repartition like 90% are adults and 5 years old children and more and 10% is children of less than five, 9,000 people of this estimated population can be considered as children under 5 years old (IHISI, 2003).

The only exposure route taking into consideration is drinking water consumption provided by the public water supply.

CHEMICAL RISKS

The U.S. EPA (1989) and the ATSDR (1999) for the carcinogenic effects from lead and his inorganic by-products have proposed any value. Age, health, lead load weight, and the exposure time are as many factors that acting upon lead's metabolism and complicated the settling of these values (INERIS, 2002). The calculation of the medical risks generated by lead in water distributed by the public water supply is carried out by the method usually used for the no carcinogenic substances i.e. substance acting with a threshold of effect.

For the calculation of the DAD, an overall consumption of 2 L/day was retained for adults and 0.75 L/day for the children. Body weights of 70 kg and 10 kg were respectively allotted to adults and to children under 10 years old. For the interpretation of the risks, three levels were considered:

R < 1       W : Weak
R= 1        A : Average
R> 1        H : High

Table 3 summarizes the calculated risks levels for lead associated to the drink water distributed in the studied zone.
TABLE 3: Risk calculated for lead:

<table>
<thead>
<tr>
<th>Point</th>
<th>Pb (µg/L)</th>
<th>DAD (mg/kg-day)^{-1}</th>
<th>ADD (mg/kg-day)^{-1}</th>
<th>Quotient of risk</th>
<th>Level</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Adult</td>
<td>child</td>
<td>Adult</td>
<td>child</td>
<td></td>
</tr>
<tr>
<td>RCS</td>
<td>250</td>
<td>1,10</td>
<td>2,89</td>
<td>0,0035</td>
<td>315</td>
</tr>
<tr>
<td>AA</td>
<td>50</td>
<td>0,22</td>
<td>0,58</td>
<td>0,0035</td>
<td>63</td>
</tr>
<tr>
<td>ADRCS</td>
<td>190</td>
<td>0,84</td>
<td>2,20</td>
<td>0,0035</td>
<td>239</td>
</tr>
</tbody>
</table>

A high risk is observed for the adults and as well for the children. Here, the deterioration risk for the psychic development of the exposed children can be assessing, because neurotoxicity is the most frightening consequence of the lead exposure for young child (Zmirou and Perrodin, 1999). It will thus be necessary in the future to carry out a more important characterization of lead in the water distributed by the Port-au-Prince public water supply.

CONCLUSION

The aim of this study was to characterize human health hazards generated by exposures to lead in Port-au-Prince water supply. Forty two samples of water were collected from boreholes, water tank and domestic tap waters of the water supply system of Port-au-Prince. Water samples from the boreholes are free of lead. However, important concentrations of lead are observed in domestic tap waters and the water tank. It will thus be necessary in the future to carry out a more important characterization of lead in the water distributed by the Port-au-Prince public water supply.

BIBLIOGRAPHICAL REFERENCES


