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A discussion about public health, lead and *Legionella pneumophila* in drinking water supplies in the United States

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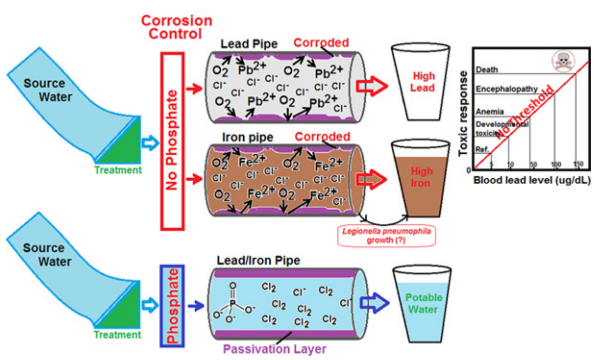
HIGHLIGHTS

- A succinct discussion on environmental lead (Pb) exposures with a focus on Pb in Flint drinking water is presented.
- Water Pb level (WLL) is a strong correlate for blood Pb level and associated health effects.
- Pertinent regulations/responses and their limitations for monitoring/mitigating WLLs are critiqued.
- Potential role of water chemistry influencing Legionnaire's disease outbreak is highlighted.
- Issues in Pb sampling protocols, factors influencing WLLs and future prospects are discussed.

GRAPHICAL ABSTRACT



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ABSTRACT

Lead (Pb) in public drinking water supplies has garnered much attention since the outset of the Flint water crisis. Pb is a known hazard in multiple environmental matrices, exposure from which results in long-term deleterious health effects in humans. This discussion paper aims to provide a succinct account of environmental Pb exposures with a focus on water Pb levels (WLLs) in the United States. It is understood that there is a strong correlation between WLLs and blood Pb levels (BLLs), and the associated health effects. However, within the Flint water crisis, more than water chemistry and Pb exposure occurred. A cascade of regulatory and bureaucratic failures culminated in the Flint water crisis. This paper will discuss pertinent regulations and responses including their limitations after an overview of the public health effects from Pb exposure as well as discussion on our limitations on monitoring and mitigating Pb in tap water. As the Flint water crisis also included increased Legionnares' disease, caused by *Legionella pneumophila*, this paper will discuss factors influencing *L. pneumophila* growth. This will highlight the systemic nature of changes to water chemistry and public health impacts. As we critically analyze these important aspects of water research, we offer discussions to stimulate future water quality research from a new and systemic perspective to inform and guide public health decision-making.

1. Overview of lead

Lead (Pb) is a heavy metal ubiquitous in the earth's crust, the physical properties of which have made it useful to mankind for

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centuries. It continues to be produced through a variety of industrial processes, although less than in prior decades. Through most of the 20th century, Pb was used extensively in gasoline, paints, pesticides, batteries and plumbing fixtures (ATSDR, 2007). It is estimated that environmental Pb levels have increased >1000-fold over the last 300 years due largely to human activities, with the greatest increase occurring between 1950 and 2000 (ATSDR, 2007). A reason for Pb's persistence in the environment, despite its elimination from consumer products including piping and plumbing fixtures, can be traced to its propensity to bind strongly to soil particles (Mielke and Reagan, 1998; ATSDR, 2007; Oulhote et al., 2013). A means for improving the removal of Pb in drinking water can be credited to the Safe Drinking Water Act (SDWA), which regulates utilities with regards to Pb and other hazards (SDWA, 1976). As an enforceable standard, the maximum contaminant level (MCL) for Pb has been set by the USEPA at 15 μg/L in drinking water. Since the inception of the MCL, the unenforceable maximum contaminant level goal (MCLG) has been set at 0 mg/L, due to the recognition that Pb is toxic at any exposure level (USEPA, 2008; CDC, 2012).

In light of the recurring water crises in the United States, through this discussion paper we aim to offer a succinct account of environmental Pb exposures focusing on water Pb levels (WLLs); its correlation with blood Pb levels (BLLs) and the associated health effects; multiple case studies discussing water Pb crises within the United States with a focus on Flint water crisis. Further, this discussion aims to highlight failures at various levels leading to tap water contamination with Pb and *Legionella*; issues inherent to Pb sampling protocols, potential factors influencing WLLs, and areas of research gaps; and pertinent regulations and responses including their limitations on monitoring and mitigating Pb in drinking water. As we critically appraise various aspects of drinking water research, we offer discussions to stimulate future Pb research from a new and systemic perspective to guide public health decision-making.

2. Human health and blood lead tracking

High BLLs are the result of exposure to Pb through air, water, soil or food (ATSDR, 2007). The deleterious effects of high BLLs have been well documented as depicted in Fig. 1. Typically, brain, kidneys (Payton et al., 1994), cardiovascular system (Hu et al., 1996; ATSDR, 2007) and the blood (Roels and Lauwerys, 1987) are the systems mostly affected. With regards to the cardiovascular system both increased incidence of hypertension (Levin, 1986; Hu et al., 1996; Rothenberg et al., 2002) and increased mortality due to heart disease have been observed (Cooper et al., 1985). Another study has shown an increase in overall, and cardiovascular, mortality in men with BLLs above 2 μg/dL, a much lower level than previously observed (Menke et al., 2006).

In children, the brain and central nervous system (CNS) are particularly highly sensitive to Pb (Felter et al., 2015). This susceptibility persists throughout childhood; however, ages 0–3 years tend to show the greatest susceptibility (Chiodo et al., 2004). Children generally absorb a larger fraction of ingested lead due to low tissue calcium than adults (Ekvall and Ekvall, 2005). Due to children's greater susceptibility and larger Pb absorbance, their exposure has particularly been of greater concern (Lanphear et al., 2005). Pb interferes with the development of neuronal connections and migrations including the myelin development (ATSDR, 2007). Specific neurodevelopmental problems due to Pb toxicity include: lower IQ scores, behavioral problems, hyperactivity, seizures and impaired coordination (ATSDR, 2007).

Studying over 1300 children in different cities, Lanphear et al. (2005) found that an increase in BLL from 2.5 μg/dL to 10 μg/dL was associated with a decrement in IQ score by 3.9 points. Children with chronic exposure to higher BLLs are more likely to have lower IQ scores. Further increase in BLL above 10 μg/dL is associated with additional lowering of average IQ score. No threshold is suggested for the effects of Pb on intellectual function in children (Lanphear et al., 2005). Previous studies have reported a strong correlation between BLLs and murder rates in the U.S. over a period of 100 years (Stretesky and Lynch, 2001; Nevin, 2007). This conclusion would seem to corroborate result from Li et al. (2003) that causally linked increased Pb exposure to increased aggression in animal studies.

As could be surmised health impacts from Pb exposure have economic implications, too. Colborn et al. (1996) demonstrated that a five-point drop in average IQ score in a population of 100 million people would increase the diagnosis of intellectual disability from 6 million to 9.4 million, which is a 57% increase. Grosse et al. (2002) advanced this concept and estimated that with each point increment in IQ score would improve workers' productivity by up to 2.38%, and an annual economic gain between $110 billion to $319 billion (in 2000 dollars).

Due to these wide ranging impacts on human health and the economy, it was recognized in the 1970's that Pb exposure needed to be tracked (Brown and Margolis, 2012). BLL is an important indicator of the level of exposure an individual has had to a source of Pb. It is also a correlated indicator of the health risks that individuals are expected to encounter due to their exposure. Therefore, BLL has been used as a means of describing overall exposure and defending mitigation recommendations and decisions. The reference BLL was developed as a means of standardizing the comparison of BLLs nationally for regulatory and mitigation purposes (ATSDR, 2007; CDC, 2012).

As depicted in Fig. 2, prior to 1975 the reference BLL for Pb remained at 60 μg/dL, which was then revised to 30 μg/dL in 1975 by the CDC.

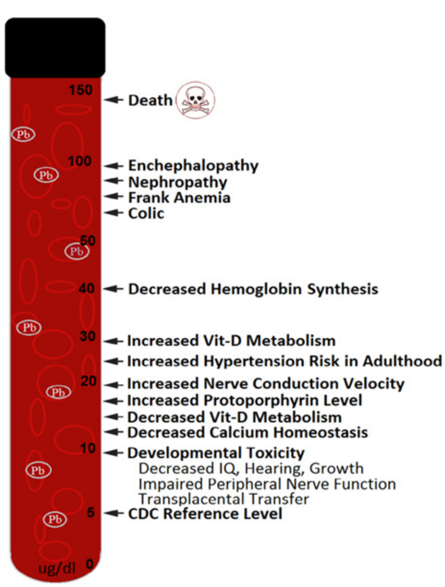

Fig. 1. Known effects of different blood lead levels on human health. (Adapted from ATSDR, 2007).

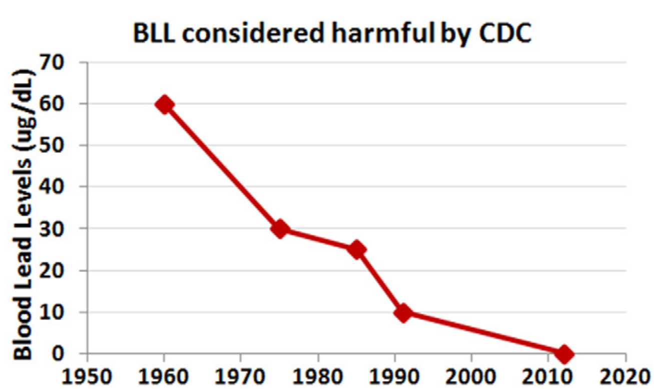

Fig. 2. Evolution of reference blood lead levels (BLLs) considered safe by The Centers for Disease Control and Prevention (CDC) over the past six decades.
(Adapted from Lanphear et al., 2005; ATSDR, 2007; CDC, 2012; Drum, 2016; Raymond and Brown, 2016).

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