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Heavy metals in drinking water: Occurrences, implications, and future needs in developing countries

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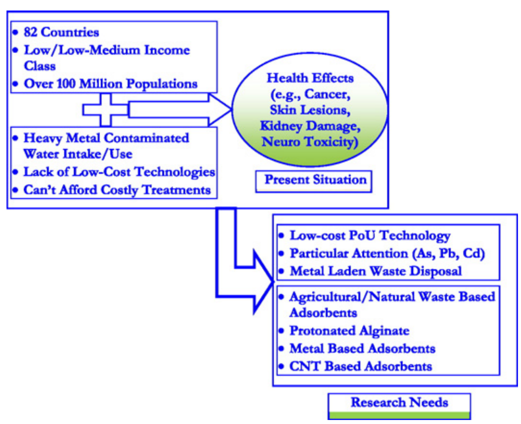
HIGHLIGHTS

- Co-exposure to multiple heavy metals in drinking water needs better understanding
- Low-cost technologies for arsenic removal needs urgent attention
- Protonated alginate needs further research for drinking water applications
- Community level and PoU devices need improvement and cost reduction
- Developing countries are most affected by heavy metals in drinking water

GRAPHICAL ABSTRACT



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ABSTRACT

Heavy metals in drinking water pose a threat to human health. Populations are exposed to heavy metals primarily through water consumption, but few heavy metals can bioaccumulate in the human body (e.g., in lipids and the gastrointestinal system) and may induce cancer and other risks. To date, few thousand publications have reported various aspects of heavy metals in drinking water, including the types and quantities of metals in drinking water, their sources, factors affecting their concentrations at exposure points, human exposure, potential risks, and their removal from drinking water. Many developing countries are faced with the challenge of reducing human exposure to heavy metals, mainly due to their limited economic capacities to use advanced technologies for heavy metal removal. This paper aims to review the state of research on heavy metals in drinking water in developing countries; understand their types and variability, sources, exposure, possible health effects, and removal; and analyze the factors contributing to heavy metals in drinking water. This study identifies the current challenges in developing countries, and future research needs to reduce the levels of heavy metals in drinking water.

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Contents

1. Introduction

Supply of safe drinking water is crucial to human life, and safe drinking water should not impose a significant risk to humans (WHO, 2011). Although few heavy metals are essential for human health, an excess amount of these metals can have negative effects (USEPA, 2015). The heavy metals are released into the environment through natural process and anthropogenic activities. The industrial processes generate wastes, which are mostly discharged into the environment. Industrial activities, especially electroplating, metal smelting and chemical industries, and manufacturing processes are few sources of anthropogenic heavy metals in water (He et al., 2008). Poorly treated domestic, industrial, and agricultural wastewater contains high concentrations of metals, which are often discharged into the environment in many developing countries (Gupta, 2008). Liu et al. (2011, 2012) identified industrial effluents and background sources as the main sources of heavy metals in the Hongfeng Lake sediments in China. Heavy metals can also enter into the environment through a bio-geo process (Szefer et al., 1999). The concentrations of arsenic in groundwater in 50 districts of Bangladesh were much higher than 50 μg/L, the limit established for Bangladesh (Uddin and Huda, 2011; Jiang et al., 2013). The floodplain and deltaic region were contaminated with arsenic (Chakraborti et al., 2010), and the main source was subsurface contamination (Karim, 2000). Heavy metals can be accumulated in sediments below the water columns and act as a source of metals through resuspension (Chowdhury et al., 2004; Wu et al., 2014; Wang et al., 2015). Few heavy metals, such as lead and mercury, can also enter the atmosphere due to traffic pollution and industrial activities, which can be deposited in soils around the reservoir and then enter the water along with the surface runoff (Wang et al., 2015). It is important to note that arsenic (As) is a metalloid and we will use the term “heavy metal” in this study.

The sources of drinking water (e.g., surface water, groundwater, and seawater) are likely to be polluted by heavy metals (Bryan and Langston, 1992). Leaching of metals from water distribution system (WDS) can contaminate drinking water (Al-Saleh and Al-Doush, 1998; Alabdula'aly and Khan, 2009). Although metals are removed during desalination of seawater, desalinated drinking water might contain various metals, possibly due to treatment and stabilization, blending with treated groundwater and leaching of metals from pipes of the WDS (Guo, 1997; Alabdula'aly and Khan, 2009). Heavy metal pollution in drinking water and the associated effects have been of increasing interest (Volety, 2008; Karavoltsos et al., 2008; Delpla et al., 2009; Liu et al., 2009, 2011; Montuori et al., 2013; Mandour and Azab, 2011; Shanbehzadeh et al., 2014). A number of heavy metals can induce cancer (e.g., inorganic arsenic [As]) and/or non-cancer (e.g., mercury [Hg]) risks in humans (USEPA, 2014, 2015). Studies have reported various chronic and sub-chronic effects from exposure to heavy metals. As in drinking water has affected >40 million people in Bangladesh (Karim, 2000; Chakraborti et al., 2010; Uddin and Huda, 2011). The Jinzu River water was found to be contaminated with cadmium from the Kamioka Zinc Mine in Japan, leading to kidney problems among the population (Yoshida et al., 1999). Few other studies have noted various health problems due to heavy metals in drinking water (Jaishankar et al., 2014; Zhang et al., 2014; Colak et al., 2015). To minimize the effects of heavy metals, regulatory agencies have proposed the maximum allowable limits in drinking water (e.g., WHO, 2011; USEPA, 2015).

Past studies have reported heavy metals in drinking water, including their types and quantities, factors affecting metal concentrations, sources, human exposure, risk, and removal. Despite significant progress, research is needed to ensure safe drinking water. Of particular concern, many low- and medium-income countries are faced with the challenge of reducing few heavy metals below the proposed limits, possibly due to their limited economic capacities (World Bank, 2016). Small and rural communities and individuals often consume water with a higher level of heavy metals than the guideline values (WHO, 2011). To date, the removal of all heavy metals from drinking water with a comprehensive technique has not been reported. Further, populations are exposed to drinking water from taps inside the building, where the metal concentrations increase due to stagnation of water in the WDS, cooler, hot water tanks (HWTs), and plumbing pipes (PP) inside the building.

In this paper, the research to date was divided into four major categories focusing on the occurrences and sources of heavy metals, human exposure and risks, removal, and critical gaps. The review identified the state of research to date, and summarized the findings of past research, limitations, and future research directions. The problems faced by developing countries were given particular attention. Finally, research strategies were identified to protect human health in developing countries.

2. Heavy metals in drinking water and their sources

Many heavy metals were reported in drinking water (Table 1). Drinking water is mainly produced from surface water, groundwater, and desalinating seawater, with desalination satisfying a significant fraction of the drinking water demand in water-scarce regions (Kim et al., 2015). Bottled water, spring water, and harvested rainwater are also used as drinking water in these regions (Sullivan, 2011). The sources of water, treatment, finished water quality, length and materials of the pipes of WDS, and PP may significantly contribute to the concentrations of heavy metals in drinking water.

In Sonora, Mexico, drinking water from wells and storage tanks were found to have elevated levels of As, Cd, Cu, Hg, and Pb. Approximately 43% of samples exceeded the action level for Pb (e.g., 15 μg/L) and 8.9% samples exceeded the guideline value of As of 10 μg/L (Wyatt et al., 1998; WHO, 2011; USEPA, 2015). The industrial, mining, and agricultural activities in the surrounding areas polluted the drinking water sources (Wyatt et al., 1998). In another study, the steel, plastic, and battery industries were found to be the major contributors of heavy metals in drinking water (Mandour and Azab, 2011). The concentrations of Cd, Co, Cu, and Pb in drinking water wells in 10 cities of Saudi Arabia were in the ranges 2–10, 5–30, 10–180, and 1–5 μg/L, respectively, which were attributed to the Gulf War and the Kuwaiti oil fires (Hashem, 1993). Tamasi and Cini (2004) reported higher levels of Fe, Cu, Zn, and Pb at the dead end of WDS than in the origin (e.g. treatment plants) in