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Multiple inorganic toxic substances contaminating the groundwater of Myingyan Township, Myanmar: Arsenic, manganese, fluoride, iron, and uranium

Thomas Bacquart [a], Seth Frisbie [a,b], Erika Mitchell [a], Laurie Grigg [c], Christopher Cole [b], Colleen Small [d], Bibudhendra Sarkar [e,f,*]

[a] Better Life Laboratories, Calais, VT, USA
[b] Department of Chemistry and Biochemistry, Norwich University, Northfield, VT, USA
[c] Department of Earth and Environmental Science, Norwich University, Northfield, VT, USA
[d] Vermont Department of Health Laboratory, Burlington, VT, USA
[e] Department of Molecular Structure and Function, The Research Institute of The Hospital for Sick Children, University of Toronto, Toronto, Ontario, Canada
[f] Department of Biochemistry, University of Toronto, Toronto, Ontario, Canada

HIGHLIGHTS

- We analyzed Myanmar ground and surface waters for multiple inorganic contaminants.
- Arsenic, manganese, fluoride, iron, or uranium exceeded safe levels in most wells.
- Most wells contained more than one contaminant above health-based reference values.
- Arsenic was positively and uranium negatively correlated with iron and manganese.
- Mitigation, including testing and treatment, must address multiple contaminants.

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ABSTRACT

In South Asia, the technological and societal shift from drinking surface water to groundwater has resulted in a great reduction of acute diseases due to water borne pathogens. However, arsenic and other naturally occurring inorganic toxic substances present in groundwater in the region have been linked to a variety of chronic diseases, including cancers, heart disease, and neurological problems. Due to the highly specific symptoms of chronic arsenic poisoning, arsenic was the first inorganic toxic substance to be noticed at unsafe levels in the groundwater of West Bengal, India and Bangladesh. Subsequently, other inorganic toxic substances, including manganese, uranium, and fluoride have been found at unsafe levels in groundwater in South Asia. While numerous drinking water wells throughout Myanmar have been tested for arsenic, relatively little is known about the concentrations of other inorganic toxic substances in Myanmar groundwater. In this study, we analyzed samples from 18 drinking water wells (12 in Myingyan City and 6 in nearby Tha Pyay Thar Village) and 2 locations in the Ayeyarwaddy River for arsenic, boron, barium, beryllium, cadmium, cobalt, chromium, copper, fluoride, iron, mercury, manganese, molybdenum, nickel, lead, antimony, selenium, thallium, uranium, vanadium, and zinc. Concentrations of arsenic, manganese, fluoride, iron, or uranium exceeded health-based reference values in most wells. In addition, any given well usually contained more than one toxic substance at unsafe concentrations. While water testing and well sharing could reduce health risks, none of the wells sampled provide water that is entirely safe with respect to inorganic toxic substances. It is imperative that users of these wells, and users of other wells that have not been tested for multiple inorganic toxic substances throughout the region, be informed of the need for drinking water testing and the health consequences of drinking water contaminated with inorganic toxic substances.

1. Introduction

Over the past 50 years, populations throughout South and Southeast Asia have undergone a cultural shift to using groundwater instead of surface water for drinking, resulting in a consequent decrease in the

* Corresponding author at: Department of Molecular Structure and Function, The Research Institute of The Hospital for Sick Children, University of Toronto, Toronto, Ontario, Canada.
E-mail address: bsarkar@sickkids.ca (B. Sarkar).

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rate of disease from water borne pathogens. However, this shift has also resulted in an unfortunate increase in diseases due to chronic exposures to naturally occurring inorganic toxic substances such as arsenic. In Bangladesh and West Bengal, India as many as 47 million people are at risk from drinking arsenic contaminated groundwater (Flanagan et al., 2012; Rahman et al., 2014). Arsenic in groundwater in Bangladesh and India has been extensively studied over the past 20 years and found to result from natural mineral deposits common throughout the region (British Geological Survey, 2001; Frisbie et al., 2002; Thambidurai et al., 2013). However arsenic contaminated groundwater is not limited to the Ganges river delta (Berg et al., 2001; Frisbie et al., 2002). Recent studies have identified potential areas of concern for arsenic contamination of groundwater in the Red River area (Nguyen et al., 2009), the Mekong Delta (Berg et al., 2007; Chanpiwat et al., 2011; Hoang et al., 2010; Nguyen and Itoi, 2009) and the Chao Phraya basin (Winkel et al., 2008), all due to geologic origin. Several studies measuring arsenic in drinking water from tubewells in the Red River area and Mekong delta have showed that between 56 and 90% of the tested tubewells have arsenic concentrations that exceed the World Health Organization (WHO) drinking water guideline of 10 μg/L (Berg et al., 2007; Chanpiwat et al., 2011).

In response to the finding that natural contamination with arsenic might be widespread in groundwater throughout South Asia, the United Nations Children's Fund (UNICEF) and other organizations began testing drinking water well samples throughout the region for arsenic. In Myanmar, preliminary testing in 1999 by the Water Resources Utilization Department (WRUD) found traces of arsenic in some tubewells (Talbi et al., 2005). UNICEF, in conjunction with Save the Children UK began screening wells for arsenic in Myanmar in 2000. In a preliminary water quality survey of 145 shallow wells in 63 communities of Ayeyarwaddy Division in the southwest region of the country, 35% of the tested wells were found to have arsenic concentrations above the proposed Myanmar national standard of 50 μg/L (Tun, 2003). An expansion of the UNICEF survey to 1912 wells in this region using Atomic Absorption Spectroscopy (AAS) found 21% of the tested wells with arsenic concentrations above 50 μg/L, as well as some discrepancies between the AAS and the field testkit results for some wells that were retested in the later survey (Tun, 2002, 2003). The initial UNICEF survey in Myanmar was further expanded nationwide; as of 2008, UNICEF had tested over 200,000 wells for arsenic throughout the country using field test kits (Jakariya and Deeble, 2008). The nationwide UNICEF surveys in Myanmar have found arsenic in drinking water above 50 μg/L in numerous districts throughout the country, mainly in the alluvial plains, with scattered hot spots in other areas (Jakariya and Deeble, 2008). In addition to the nationwide UNICEF surveys for arsenic, the United Nations Development Program (UNDP) conducted a groundwater survey in NyanungShwe, Shan State in central Myanmar, where it found arsenic above 50 μg/L in 125 samples (Smedley, 2005).

In contrast to arsenic, relatively little is known about the distribution of other toxic inorganic contaminants in the drinking water of Myanmar. As part of the nationwide arsenic survey, water from 10,000 wells was additionally tested for iron and manganese (Jakariya and Deeble, 2008), but results from these tests have not been published in the scientific literature. Surface water in the Chatthin Wildlife Sanctuary in the northeastern part of the country was found to have concentrations of aluminum, boron, chromium, copper, manganese, nickel, lead, antimony, thallium, and vanadium above reference values in addition to arsenic; this contamination was likely anthropogenic in origin (Aye et al., 2009). In a small survey of different types of urban water sources in Nay Pyi Taw and Yangoon that included bottled water, municipal water and at least one deep well in Nay Pyi Taw, arsenic was detected at 7.9 μg/L in the deep well; concentrations of other inorganic contaminants tested were not reported (Sakai et al., 2013).

Arsenic and other toxic inorganic contaminants have been reported in drinking water in other countries bordering Myanmar. Arsenic, boron, barium, manganese and uranium were found to exceed international drinking water guidelines in Laos; these contaminants were likely due to geologic sources (Chanpiwat et al., 2011). A broad survey of well water in the northeast Indian states of Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, Tripura found levels of arsenic, cadmium, copper, fluoride, iron, lead, manganese, nickel, and zinc above health-based reference values (Singh et al., 2008). Arsenic, iron and manganese concentrations were found to exceed national standards in some wells in rural Yunnan Province in China (Wang et al., 2009). Manganese, fluoride, and iron at concentrations above the national standards were found widely distributed in the Chiang Mai basin of Northern Thailand (Margane and Tatong, 1999), and concentrations of cadmium, chromium, iron, lead, nickel, and selenium in lake surface water used for drinking in northern Thailand exceeded WHO drinking water guidelines or health-based limits (Tupwongse et al., 2007). Studies in Bangladesh and India have shown that even if a well has a safe concentration of arsenic, it may have unsafe concentrations of manganese, uranium, lead, nickel, chromium, or boron (Bacquart et al., 2012; Frisbie et al., 2009).

In this study, we present a small-scale survey of multiple inorganics testing in drinking water from Myingyan Township in central Myanmar to investigate the presence and distribution of toxic inorganic contaminants in a region where previous results have suggested the concentration of arsenic may vary widely from well to well. Based on the results of our multiple inorganics analyses, we evaluate possible mitigation strategies for providing safe water in these areas, including well switching and filtration.

2. Materials and methods

2.1. Study area

Myingyan Township is located on the east bank of the Ayeyarwaddy River in the Mandalay Division of Central Burma; see Fig. 1: Map of study areas and sampling locations.

Myingyan City, with approximately 140,000 inhabitants, is the seat of Myingyan Township. The village of Tha Pyay Thar is located about 15 km to the southwest of Myingyan City, between the Ayeyarwaddy River and National Highway 2. Myingyan Township is located in the central plain of Myanmar, known as the Dry Zone, and is characterized by a flat terrain and dry climate with less than 90 cm of annual rainfall. Most precipitation arrives in the wet season of May to October, while very little rain falls from November to April. Soils are alluvial, consisting of gravel, sands, silts, and clays (McCartney et al., 2013). Sampling sites in Myingyan City are located adjacent to the floodplain of the Ayeyarwaddy River at elevations of ca. 60–70 m. Sampling sites in Tha Pyay Thar are located within the floodplain of the Ayeyarwaddy River at elevations between ca. 40 and 50 m. There has been rapid growth in exploitation of groundwater over the past 10 years in this area for drinking, watering livestock, and irrigation of crops (Sellamuttu et al., 2013). The quality of the groundwater in the region as judged by taste shows great variation, even within single villages, with water from some wells deemed undrinkable due to high salt or iron content (Sellamuttu et al., 2013).

2.2. Sample collection

Twenty systematic random water samples were collected in Myingyan Township in May of 2013. Of these samples, 12 were collected from household drinking water wells in Myingyan City. To the extent possible, the wells sampled in this group were distributed at 500-m intervals along perpendicular axes that radiated in 4 equal lengths from the center; see Fig. 2: Sample locations in Myingyan City.

Six samples were collected from household drinking water wells in the nearby village of Tha Pyay Thar. To the extent possible, the tubewells sampled in this group were distributed at 500-m intervals along the