Remarks on the current quality of groundwater in Vietnam

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Abstract This paper reviews the current quality of groundwater in Vietnam. In Vietnam, groundwater is obtained primarily from tubewells, which have high concentrations of pollutants such as As, Fe, Mn, and NH_4^+ . In the areas where groundwater tests were conducted, arsenic levels ranged from 0.1–3050 $\mu\text{g/L}$, which substantially exceed the standard of 10 $\mu\text{g/L}$ which has been established by the WHO. Contamination sources are distributed over a large area from the Red River Delta in the north to the Mekong River Delta in the south, putting as many as ten million people at risk of adverse health effects. Levels of arsenic and iron in sediment are strongly correlated, which indicate that the presence of arsenic in groundwater results from the reduction of arsenic bound to iron oxyhydroxides. It is important to raise awareness of these issues among the Vietnamese public by disseminating information about the negative effects of contaminated drinking water, as well as carrying out long-term research projects to identify other sources of contamination and improving water treatment technology and water management capabilities.

Keywords Vietnam · Red River · Mekong River · Groundwater · Arsenic · Ferrous · Manganese

Introduction

Many regions of the world are faced with diminished water resources. (Moglia et al. 2012). This is due to multiple factors such as decreased water supplies, the contamination and overuse of surface and groundwater, and extended periods of low precipitation. From 1950 to the 1990s, a 100% increase in the global population, combined with declining quantities of freshwater, resulted in a substantial drop in the per capita availability of water resources, from 17,000 to 70,000 $\text{m}^3 \text{capita}^{-1}$. In addition, as much as 90% of wastewater is released into the environment untreated, exacting a heavy toll on public health (WHO 2005). The presence of naturally-occurring sediments in drinking water may also introduce toxic substances such as heavy metals. Each year, there are approximately four billion cases of diarrhea, causing 1.8 million fatalities, primarily of children. The overwhelming majority of these cases result from contaminated drinking water, unsanitary conditions, and deficient hygienic practices (Thuy et al. 2015).

Vietnam is a developing country located in Southeast Asia with an area of 329,566 km^2 , which is shown in Fig. 1 (Moglia et al. 2012). With a population of 90 million in 2011, it is the 13th most populous country in the world (Berg et al. 2001). Seventy percent of the population lives in rural areas, concentrated in the two main agricultural regions of the Red River Delta and Mekong River Delta. Between 2000 and 2010, average daily water consumption in Vietnam increased from 881,100 to 1,079,350 m^3 (Moglia et al. 2012). Rapid industrialization and economic growth have led to a massive population shift from the countryside to the cities, creating increased strain on natural resources and the environment (Norrman et al. 2008). The primary sources of water pollution are untreated municipal and industrial wastewater (Chau et al. 2015). Additionally, climate change and global warming may also affect the quality and amount of rainfall, groundwater,

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Fig. 1 Vietnam geology map (Moglia et al. 2012)

and surface water. It is therefore urgent to concentrate on environmental protection and the management of natural resources in order to have transition toward sustainable development. There is considerable concern about safe drinking water among the Vietnamese public (McArthur et al. 2012). The exploitation of groundwater for domestic use in Vietnam began roughly 100 years ago with the construction of wells operated by hand pumps. The consumption of polluted groundwater has considerable negative health consequences and can cause serious illnesses of various major organs (WHO 2005). In this paper, the current situation and the impact of environment to the Vietnam groundwater are summarized in detail. Then, the water research and management strategies for the sustainable development also are proposed. Hope it can contribute to the world's water understanding, which is in a serious problem until now and the near future.

The situation in the Red River Delta

Extending southeast from the national capital, Hanoi (population 11 million), the Red River Delta has an area of 169,000 km². It has a tropical monsoon climate with a rainy season extending from May to September and a dry season from October to April. Rural residents have switched from using surface water or water from shallow dug wells to using family tubewells from Holocene aquifer and Pleistocene

aquifer (Berg et al. 2001) as their primary sources of drinking water. The removal of groundwater from the Pleistocene aquifer causes water to flow down from the Holocene aquifer (Postma et al. 2007). A water-permeable layer of clay several meters thick separates the Holocene and Pleistocene sediments, allowing water to flow between the two aquifers (Smedle et al. 2002). Table 1 shows the arsenic contamination in the aquifers in Hanoi (Berg et al. 2001). Groundwater in Hanoi and its surrounding region is contaminated by high arsenic concentrations in the Holocene and Pleistocene aquifers, which is shown in Fig. 2. This issue raises the question as to whether arsenic mobilization is anthropogenic (Thuy et al. 2015). Arsenic levels exceeded the current WHO standard of 10 µg/L in as many as 72% of the tubewells included in the study (Agusa et al. 2006) although there was a substantial degree of variation between different areas with concentrations ranging from 0.1 to 3050 µg/L (Berg et al. 2008; Nguyen et al. 2009; Berg et al. 2007; Postma et al. 2010; Agusa et al. 2009; Editorial 2010; Larsen et al. 2008; Nguyen and Itoi 2009; Jessen et al. 2008; Eiche et al. 2008) and an average arsenic concentration from 159 to 430 µg/L (Berg et al. 2001), respectively. The sources of contamination are distributed over a large area in Red River Delta. Figure 3 showed the arsenic contamination in groundwater from the private tubewells (Berg et al. 2001).

Samples of groundwater taken from Hanoi's eight water treatment plants revealed arsenic concentrations of 240–320 µg/L in three of the plants and 37–82 µg/L in the other five (Berg et al. 2001). Of the 29 tap water samples collected at individual homes (Fig. 2b), 27 had arsenic levels ranging from 7 to 82 µg/L with a mean concentration of 31 µg/L. Dissolved arsenic may be binding to iron oxides on the inner surfaces of pipes leading to lower concentrations in the tap water (Agusa et al. 2006). Given the high levels of arsenic found in water from the tubewells (48% above 50 µg/L, and 20% above 150 µg/L), several million people might be at risk of chronic arsenic poisoning (Berg et al. 2008; Nguyen et al. 2009; Berg et al. 2007). The levels of contamination are comparable to Bangladesh and West Bengal, India; however, the population density is higher (Smedle and Kinniburgh 2002). Arsenic is known to cause diseases of many major organ systems. Moreover, chronic arsenic exposure is correlated with an array of cancers (bladder, kidney, skin, and liver), where inorganic arsenic is more toxic than organic arsenicals (Postma et al. 2010; Agusa et al. 2009; Editorial 2010).

Because of naturally occurring organic matter in the sediments, the groundwater is anoxic and rich in iron. Arsenic concentrations from 25 to 91 µg/L were reduced by up to 80% by aeration and filtering through sand of arsenic concentration removed to discharge in the Red River delta (Berg et al. 2007) but 50% samples remained above the Vietnamese drinking water standard of 50 µg/L (Berg et al. 2001). Sediment in the Red River Delta showed a correlation between arsenic and iron levels, which is shown in Fig. 4

Table 1 Arsenic contamination in the aquifers in Hanoi (Berg et al. 2001)

District	Number of sample	Concentration (µg/l)	Range (µg/l)
Dong Anh	48	31	1–220
Tu Liem	48	67	1–230
Giai Lam	55	127	2–3050
Thanh Tri	45	432	2–3010
All	196	159	1–3050

(Berg et al. 2001). It is possible that arsenic is bound to iron oxyhydroxides in the sediment and that the reduction of iron when it is dissolved in groundwater causes the arsenic to be released. Arsenic occurring in the sediment is most likely due to the deposition of arsenic-enriched oxyhydroxides which result from erosion and are transported by river currents. Brown to black-brown clay layers showed arsenic concentrations of 6–33 mg/kg with lower concentrations found in gray clay (2–12 mg/kg) and brown to gray sand (0.6–5 mg/kg) (Berg et al. 2001).

The primary form of arsenic found in the groundwater is As(III) with some As(V). Arsenic levels are closely related to levels of ammonium, which is released by the breakdown of organic matter. As(III) concentration peaks in the middle part of the aquifer with a distribution highly similar to that of ammonia and methane. This indicates that there may be a direct relationship between the release of As into the groundwater and the decomposition of organic material. The high alkalinity (up to 810 mg/L) and high nitrogen concentrations (10–48 mg N/L)

Fig. 3 Arsenic contamination in groundwater from the private tubewells (Berg et al. 2001)

of the groundwater strongly support this possibility (Lawati et al. 2012; Minh et al. 2010; Guillot et al. 2008).

Fe and Mn levels in groundwater were higher than those of alkaline earth metals such as Sr and Ba. Both Mn (500 mg/L) and Ba (700 mg/L) (WHO 2005) were found in concentrations exceeding the WHO limit for drinking in some samples taken in Hanoi. Groundwater in Hanoi had an average Mn concentration exceeding 1000 mg/L. Seventy percent of the groundwater samples exceeded WHO drinking water guidelines for Mn and 12% exceeded those for Ba of 0.05 mg/L

Fig. 2 Arsenic contamination in Hanoi. **a** In groundwaters pumped from private tubewells. **b** In groundwater of the lower aquifer and treated water treatment plants (*split rectangles*) and tap water of supplied households (*dots*) (Berg et al. 2001)

Fig. 4 Correlation between arsenic and iron in sediment core layers in Hanoi (Berg et al. 2001)

(Fig. 5a). Rainwater and surface water in Hanoi also had low concentrations of As. As, Mo, Ga, and Ba concentrations in groundwater showed a strong positive correlation, while there was a negative correlation between concentrations of As and Pb and V. It is not yet clear what the reasons for these relationships but they may be due to the subsurface geology and geochemistry of the Red River Delta. These results indicate that the use of groundwater in the Red River Delta may be exposing people not only to As but also to other metals like Mn and Ba (Duong et al. 2003).

Fig. 5 Arsenic in groundwater of the Mekong River Delta (1) Kien Giang, (2) An Giang, (3) Dong Thap, and (4) Long An (Hoang et al. 2010)

The situation in the Mekong River Delta

The Mekong River Delta is located in southern Vietnam and neighboring Cambodia, between the East Sea in the southeast and the Gulf of Thailand in the west. The Mekong River Delta consists of two main arteries (the Tien and Hau rivers), which branch into eight smaller rivers. The Mekong River Delta covers an area of 39,713 km² and contains delta sediments with characteristics similar to the Ganges Plain (Hoang et al. 2010). Low-lying floodplains (2 m above sea level) with highly acidic sulfate soils comprise approximately 60% of the Mekong Delta. The local climate is tropical monsoonal, with average temperatures of 27–30 °C and a rainy season lasting from April to November. Local water resources include rainfall, surface water, and groundwater. Household shallow tube-wells access groundwater at a depth of 80–120 m (Buschmann et al. 2008). The wells for water supply units and industrial uses access groundwater at a depth of 100–250 m, with 60% of wells accessing the Pleistocene aquifer. The main trends threatening the sustainability of groundwater in Mekong River Delta are declining groundwater levels and declining groundwater quality.

In a study of 460 wells in the Mekong River Delta, 26% of groundwater samples were found to exceed the WHO standard for drinking water of As (10 µg/L), 74% to exceed the standard for Mn (0.05 mg/L), and 50% that for Fe (0.3 mg/L). These data were shown in Fig. 5 and Table 2 (Hoang et al. 2010). As levels ranged from 0.1 to 1351 µg/L, Fe concentrations from 0.01 to 38 mg/L, and Mn from 0.01 to 14 mg/L (Hoang et al. 2010). Arsenic was found in groundwater in wells less than 60–70 m deep in this region (Buschmann et al. 2008). High Fe concentrations were found in the groundwater of Dong Thap, Kien Giang, and Long An provinces. High levels of As were found primarily in An Giang and Dong Thap provinces, with almost 50% of groundwater samples exceeding the WHO standard for As (10 µg/L). In addition, Mn concentrations exceeded the WHO standard of 0.05 mg/L in approximately 72% of samples from An Giang and 64% of samples from Dong Thap. Consumption of untreated groundwater in these two provinces could be exposing nearly two million people to the risk of chronic arsenic poisoning. In

Table 2 The percentage of groundwater samples exceeding the WHO standard (Hoang et al. 2010)

Element	Percentage exceed the standard (%)			
	An Giang	Dong Thap	Kien Giang	Long An
As (10 ppb)	43	38	24	12
Mn (0.05 ppm)	87	69	66	81
Fe (0.3 ppm)	13	54	55	71

addition, the excessive intake of manganese can result in developmental problems in children.

Well depth and distance from the Mekong River are the primary factors determining the levels of As in groundwater, particularly in An Giang and Dong Thap. In An Giang, As levels in samples taken within 2 km of the Mekong River were nearly 1000% greater than those in samples taken at distances beyond 2 km. Samples taken within 10 km had average As concentrations of 64 µg/L, while samples taken at distances of more than 10 km had an average concentration of 8 µg/L. In An Giang, shallow wells (less than 60 m in depth) had As concentrations of 115 µg/L, while deeper wells had an average of only 19 µg/L. In Dong Thap, the equivalent figures were 63 µg/L for shallow wells (less than 70 m deep), and 3 µg/L for deeper wells. Another issue directly impacting the health of people relying on groundwater is urban runoff and pollution from municipal wastewater. Groundwater samples taken from wells in Can Tho, the largest urban area in the Mekong Delta contain high levels of total coliforms. It is therefore very important to analyze the quality of groundwater in the Mekong River Delta (Nguyen et al. 2009).

Sedimentation in the delta began with the deposition of silt carried by the river during the transition from the Pleistocene to the Holocene. The sediments in the Mekong River Delta are high in organic compounds which create anoxic conditions that may promote the reduction of dissolved iron(hydro)oxides and cause the release of arsenic. There is a need for increased awareness about the potential health impacts, especially the co-contamination involving multiple toxic elements. In the early Holocene, fluvial deposits displaced tidal deposits as the primary source of sedimentation, resulting in an outward movement of the coastline (Berg et al. 2007). Groundwater in the lower Mekong Delta is highly saline with 4 g/L total dissolved solids (TDS). Shallow groundwater has been exploited as a drinking water source by the rural population as a replacement for surface water, which is contaminated by microbes. Other heavy metals such as Cd, Ni, Pb, and U are known to cause numerous health problems such as DNA damage, cancer, and disorders of the central nervous system. Because Ni, Pb, and Cd exceeded the WHO standard around ~1%, they are not likely to have a significant public health impact. Uranium, however, can damage the kidneys and is also deposited on bone surfaces, where it emits alpha radiation and releases highly toxic decay products such as radon (Berg et al. 2007).

Comparison with other countries in the world, the As contamination in groundwater in Vietnam is quite high. It was estimated that around 150 million people in the world are probably affected by arsenic contamination in groundwater, especially in some Asian country as China, India, and Bangladesh (Ali et al. 2012). As was found in shallow tubewells in the low-lying Mekong Delta at Prey Vêng province, Cambodia. The As contamination in wells at this region

were 100 times higher than the WHO standard with maximum concentration of 1052 µg/L, nearly the same level with Arsenic contamination in Mekong delta in the south of Vietnam, while much lower compare with the north of Vietnam (O'Neill et al. 2013). The Jiangnan Plain in China has 87% of the groundwater in wells with depths of 5–230 m containing As level at 10–2330 µg/L (Xiaoming et al. 2017). In West Bengal of India, 48.1% of groundwater contains As above the WHO standard and 23.8% were above the Indian standard of 50 µg/L. The wells in Holocene sediments at 35–45 m depth in Beldanga contain high As concentrations at 10–4622 µg/L (Harshad et al. 2017). A recent study in the Kolkata, India analyzed 262 groundwater samples in 144 wards and reported that 100 wards in alarming arsenic contamination. About 51 wards (35.4%) have arsenic concentration above the Indian standard of 50 µg/L while 49 wards got arsenic level 11–50 µg/L. As daily intake was estimated 0.95 µg/kg from drinking water and the cancer risk was 1425/106 (Dipankar et al. 2017). Based on studies conducted in the Brahmaputra River, the As levels were found from 0.07–0.60 µg/L (Runti et al. 2015). As contamination in groundwater in the Nawalparasi District, Terai province in Nepal is a serious issue with the average concentration of 350 µg/L, and 98% groundwater exceeded the WHO standard of 10 µg/L. Higher As contamination at more than 400 µg/L in wells with depth at 18–22 and 50–80 m. As concentration over 500 µg/L in shallower wells were detected at Patkhauli, Mahuawa, Thulokunwar, and Goini (Akiko et al. 2014). In Mongolia, As concentrations are found in the range of 300–553 µg/L at the SO_4^{2-} reduction stage, possibly results reduction of Fe oxide minerals from HS^- (Yongfeng et al. 2017). High As levels was found in bedrock aquifer in western Quebec, Canada with more than half of the 59 bedrock wells exceed the WHO standard of 10 µg/L with As concentration ranges from 1.1–263.3 µg/L (Raphaël et al. 2017). The As contamination in aquifers groundwater of Pliocene terrestrial layers is a significant issue in Sarkisla (Turkey) with concentration up to 345 µg/L and the average of 60.38 µg/L (Celalettin et al. 2013). As also was found in the range of 0–180 µg/L from 992 drinking water samples in households of New Hampshire, USA. Significantly arsenic in the domestic drilled bedrock wells more than water from municipal sources (Qiang et al. 2009). Middleton et al. 2016 reported that 5% private water supplies of 497 wells in Cornwall, South West England exceeded the WHO As standard of 10 µg/L.

Conclusions

Concentrations of heavy metals such as As, Fe, and Mn in groundwater from the Red River and Mekong River Deltas exceed WHO drinking water guidelines, putting at risk the millions of Vietnamese people relying on groundwater in

these regions as sources of drinking water. This situation suggests solution for drinking water suppliers together with efficient water treatment technologies for groundwater or alternative drinking water sources such as surface water or tap water. Vietnam has an expanding population and growing economy, and is undergoing rapid industrialization and urbanization. It is of the utmost importance that good strategies be developed for the management of safe drinking water for both public and private supply, in the cities as well as the countryside. Educating residents of rural areas to understand the effects of contaminated drinking water on their health is essential. A long-term water quality monitoring program with more frequent testing should also be considered.

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