Arsenic and polymetallic contaminants in groundwater of the arid regions of South Africa

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ABSTRACT: In South Africa, the majority of rural water supply comes from groundwater hosted within the weathered and fractured crystalline rocks. The main minerals that are responsible for arsenic release into groundwater in South Africa are arsenopyrite (FeAsS), lollingite (FeAs_2) and scorodite ($\text{FeAsO}_4 \cdot 2\text{H}_2\text{O}$), where scorodite is an alteration product of arsenopyrite due to prolonged water-rock interaction process. Owing to the release of arsenic from highly mineralized rocks, its concentration in the groundwater reaches up to $253 \mu\text{g L}^{-1}$ (south western part of the country), $6150 \mu\text{g L}^{-1}$ (west of Johannesburg), about $500 \mu\text{g L}^{-1}$ in the Karoo aquifers. Acid mine drainage is also found to be important source of arsenic and other toxic metals in the environment.

1 INTRODUCTION

In regions that are characterized by climatic aridity and minimal rainfall, groundwater from weathered and fractured crystalline rock aquifers is a primary source of water supply for various community activities. The development of groundwater resources from these aquifers has been regarded as a very important driver for economic growth of the country owing to its availability at shallow depth ($\approx 40 \text{ m}$) and scarcity of surface water sources often characterized by poor water quality due to arsenic (As) and polymetallic contaminants. In several parts of the world, especially in south-east Asia, high As concentration is prevalent in groundwater from the sedimentary aquifers with enriched organic matter (Ahmed *et al.*, 2004; Bhattacharya *et al.*, 2002a,b, 2004; Mukherjee *et al.*, 2011; Nriagu *et al.*, 2007) related to organic rich sediments. The geology of aquifers that host As in South Africa have undergone large-scale mineralization, where As occurs in sulphide ores such as auriferous, stanniferous and antimonial deposits (Hammerbeck, 1998) that is being released into groundwater through leaching process. Arsenic, U and Se are more mobile under a wider range of naturally occurring groundwater conditions; hence they pose a potentially more widespread problem than other trace constituents (Sami & Druzynski, 2003). Extensive mineralization of rocks is also responsible for the release of toxic metals into the groundwater.

2 MATERIALS AND METHODS

Extensive literature assessment was conducted in order to gather relevant information on the arsenic and toxic metal concentration in the groundwater system of South Africa. In order to get a first-hand information,

twenty groundwater samples from granitic aquifers were collected and analyzed for 24 metals, including arsenic. The water samples were diluted in 50 mL polypropylene volumetric flasks with ultra-pure water and acidified with 2% HNO_3 and analyzed by IC-PMS.

3 RESULTS AND DISCUSSION

The geology of the main aquifers in South Africa is represented by weathered and fractured basement rocks, Bushveld igneous complex (basic and felsic intrusive rocks), dykes (pegmatite, syenite and dolerite), the Witwatersrand and Transvaal Supergroup meta-sedimentary rocks (quartzite, sandstone, shale, dolomite), the Karoo and Kalahari sedimentary rocks, meta-volcanic rocks (basalts, andesites and rhyolites) and unconsolidated coastal sediments. The main minerals that are responsible for arsenic release into groundwater in South Africa are dominated by arsenopyrite (FeAsS) that has a widespread occurrence in the country, lollingite (FeAs_2) and scorodite ($\text{FeAsO}_4 \cdot 2\text{H}_2\text{O}$). Scorodite is a main mineral phase in the withering zone. Arsenopyrite and other sulphide minerals are known to be susceptible to oxidation in near surface environments (Herath *et al.*, 2016), where most boreholes tap water for community supply.

Owing to the release of arsenic from highly mineralized rocks into groundwater, its concentration in the groundwater reaches up to $253 \mu\text{g L}^{-1}$ (south western part of the country), $7000 \mu\text{g L}^{-1}$, west of Johannesburg (Sami & Druzynski, 2003), about $550 \mu\text{g L}^{-1}$ in the Karoo aquifers, within the boreholes having variable depth. In general the arsenic content in the groundwater falls above the WHO drinking water limit ($10 \mu\text{g L}^{-1}$).

The abandoned gold tailings dams around the city of Johannesburg contain very high metal concentration that release metals into surface and ground water resources. For example, in the tailings dams the content of some metals such as Cr ranges from 170 to 310 mg L⁻¹, Co = 10–240 mg L⁻¹, Cu = 15–254 mg L⁻¹ and lead 6–34 mg L⁻¹. High uranium rich mine water with acidic pH decants continuously from abandoned mines into streams (Winde, 2006; Hobbs, 2011; Abiye, 2014; Abiye, *et al.*, 2018). The high concentration of polymetallic contaminants in the groundwater was regulated by oxidation, leaching and precipitation processes besides water-rock interaction. The metal concentration in groundwater is in the order of Fe>Sr>Zn>B>Mn>Ni>Ni>Li>Cr>As>U that falls within the range of 14 µg L⁻¹ for U and 3128 µg L⁻¹ for Fe in the Namaqualand groundwater (Abiye & Leshomo, 2013). Fe is also the main component in the gold and coal mining regions as a result of acid mine drainage that reaches 890 mg L⁻¹ (Abiye *et al.*, 2011). In addition to the leaching of arsenic from sulphide minerals facilitated by oxidation process, oxidation of iron is also believed to contribute for the concentration of arsenic in the groundwater. The lack of aquifer flushing due to low groundwater recharge condition facilitates concentration of metals in the shallow aquifers besides severe evaporation process in the region. This zone is readily accessible by groundwater users for various economic activities.

4 CONCLUSIONS AND RECOMMENDATIONS

South Africa is endowed with a variety of economic minerals both metals and non-metals, which also host minerals responsible for arsenic and other toxic metals release into aquifers. Complex geochemical processes that involve oxidation and precipitation at acidic pH conditions are among few that mobilizes metals from host rocks into groundwater. It was also noted that acid mine drainage in the gold and coal mining areas is the primary media for arsenic and other toxic metal mobilization from sulphides and eventually contaminates water supply systems.

Due to the health related risk associated with arsenic, it is essential to take precautionary measure on boreholes with high content.

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