



Hydrogeochemical processes controlling groundwater quality around Bomboré gold mineralized zone, Central Burkina Faso

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ARTICLE INFO

Article history:

Received 6 March 2016

Revised 28 July 2016

Accepted 16 August 2016

Available online 22 August 2016

Keywords:

Borewells

Dug wells

Arsenic

Trace metals

Groundwater quality

ABSTRACT

This study investigates the processes that control dug well and borewell water chemistry in crystalline basement aquifers in semi-arid environment. Changes in SO_4^{2-} and NO_3^- were observed in both dug well and borewell samples. Six dug wells and seven borewells had high NO_3^- concentrations relative to SO_4^{2-} suggesting prevailing oxidizing redox conditions in these samples. The highest NO_3^- and SO_4^{2-} concentrations were found in few borewells. These high concentrations could be attributed to low recharge rates and chemical weathering of sulfide minerals. The acidic conditions may have promoted As_T adsorption in the majority of dug wells. The saturation indices and correlation coefficients showed that most dug wells and some borewells were supersaturated with respect to Fe-bearing minerals, implying that trace elements such as As_T , Cu, Cr, Ni and Zn were likely to coprecipitate with residual Fe minerals. The low mobility of As_T in dug wells could be also explained by the limited carbonate mineral abundance in the weathered layer. By contrast, the elevated As_T concentrations observed in the majority of borewells reflected an extended water–rock interaction that had led to deportation of surface charges of the aquifer minerals, thereby inhibiting As_T adsorption. The average concentration of Fe_T and total coliform content of dug well samples exceeded the World Health Organization (WHO) limits for drinking waters. Likewise, the average concentrations of Fe_T , As_T (~55% of samples) and Pb in borewells were higher than the WHO permissible limits. The study showed that the local groundwater resources are exposed to both anthropogenic and geogenic sources of pollution.

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1. Introduction

In Central Burkina Faso, where surface water availability is limited, groundwater is the main source of water supply for the local communities. Much of the groundwater resources in the area occur in crystalline basement aquifers which is subdivided into a shallow weathered layer and deep fractured bedrock (Wright, 1992; Gamsonré, 2003). Traditional hand-dug wells are used to extract groundwater from the saturated weathered layers, while borewells equipped with handpumps are used to source groundwater from discrete horizontal fractures within the basement (Acworth, 1987; BGS, 2002; Wyns et al., 2004). The weathered layer and fractured bedrocks are products of the combined effects of prolonged in-situ chemical weathering of the parent rock and tectonic movement, respectively (Wyns et al., 2004; Dewandel et al., 2006). Therefore, the groundwater chemistry of the crystalline basement aquifers is directly related to the mineralogical composition of the parent rock and the various weathering processes (Hem, 1985). Elevated concentrations of potentially toxic trace elements, often

encountered, in crystalline bedrock aquifers have been mostly attributed to chemical weathering (BILAN D'EAU, 1993; MEE, 1998; Smedley et al., 2007).

Once in the aquifer, trace element distribution and mobility are controlled by several geochemical processes such as oxidation-reduction reactions (Smedley and Edmunds, 2002), dissolution-precipitation and cation exchange (Ayotte et al., 2003). However, the mobility of trace elements in aquifers varies with individual elements. For example, Pb, Cd, Fe and Mn are preferentially mobilized under acidic conditions, whereas As, along with Fe and Mn, are more soluble under reducing conditions. High population density and intensive agricultural and artisanal gold mining activities in the study area are also likely to exacerbate trace element mobility, putting enormous pressure on dug well and borewell water quality and availability.

In contrast to groundwater availability, groundwater quality has received little attention in Burkina Faso, and the available data indicate that groundwater resources are frequently exposed to various sources of contamination (e.g., Groen et al., 1988; Yaméogo and Savadogo, 2002). By far, arsenic is the groundwater contaminant that poses the most serious health hazard to humans across the country (Somé et al., 2011). Few studies have reported the occurrence of high arsenic concentrations (> 10 µg/L) in groundwater around gold mineralized zones

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in the north-central region of Burkina Faso (de Jong and Kikietta, 1981; COWI, 2004; Smedley et al., 2007). This so-called localized arsenic pollution has been attributed to sulfide mineral oxidation (Lipfert et al., 2006; Smedley et al., 2007) and, to a lesser extent, dissolution of westerveldite (FeAs) and scorodite ($\text{FeAsO}_4 \cdot 2\text{H}_2\text{O}$) in granitic rocks (Peters and Blum, 2003; Utsunomiya et al., 2003). However, the mechanisms that control As and other trace element mobilization within mineralized crystalline basement aquifers have not been well studied in the country.

Understanding the spatial distribution and mobility of trace elements in mineralized basement aquifers is an important factor for a long-term dug well and borewell water quality monitoring program. In the present study, geochemical modeling and multivariate statistical techniques were used to: (1) provide insight into the geochemical processes that control dug well and borewell water chemistry (2); determine the extent of water–rock interaction; and to (3) assess the groundwater quality for human consumption. The underlying hypothesis is that groundwater from shallow dug wells and deep borewells from two different aquifers with a similar bedrock lithology, or that have experienced similar geochemical processes and anthropogenic activities would be geochemically different.

2. Geological and hydrogeological context

The study area lies within a strongly arcuate volcanosedimentary northeast-trending belt in the central domain that is bounded to the east by the Tiébélé-Dori-Markoye Fault (Fig. 1). The geological formations of the area are composed of mafic to intermediate metavolcanic rocks intruded by ultramafic rocks, diorite and granodiorite of Birimian age (2300–2150 Ma). The oldest formations date back to Proterozoic and later Eburnean age (2150–2095 Ma), and they consist mainly of crystalline (plutonic and metamorphic) rocks such as amphibolite, diorite, granodiorite, granite, metagabbro, metasediment and green schists (Sattran and Wenmenga, 2002; Castaing et al., 2003). These rocks, often

associated with gold mineralization and a network of quartz veins and sulfide minerals, were mostly deformed and metamorphosed during the Eburnean orogeny. The gold mineralization can also be associated with disseminated sulfide minerals in alteration zones. In the latter case, gold may be either free-milling or refractory (Milési et al., 1992; Bamba et al., 1997). Depending on the nature of the parent rock, other sulfide minerals such as arsenopyrite in metasedimentary units or chalcopyrite and pyrrhotite within biotite schists may be associated with pyrite (Béziat et al., 2008). Oxidation of the sulfide minerals through natural processes (geogenic sources) or anthropogenic activities may generate acid drainage that will enhance trace element mobility in the environment.

Artisanal gold miners in the area have been targeting the oxidized ore, and hence the risks related to the occurrence of acid drainage are limited. However, if the sulfide wall rocks are reached, these risks will be high with a possible mobilization of potentially toxic trace elements within the groundwater systems (Bamba et al., 2013). In July 2014, Orezone Gold Corporation, a Canadian gold mining company, carried out a heap-leaching test on three cores of extractable ores in the Bomboré gold mineralized zone, and concluded that mobility of As, Cu and Fe was of great concern from water resources perspectives. The fate of As, Cu, Fe and other trace elements in the local crystalline basement aquifers will depend primarily on lithological and hydrogeological characteristics of weathered and the fractured bedrock layers (Dewandel et al., 2006). Together the weathered and fractured layers form the weathering profile of the crystalline basement aquifers with each layer having specific hydrogeological properties (Groen et al., 1988; Detay et al., 1989; Taylor and Howard, 2000).

Thus, the weathered layer is capped by a thin lateritic layer, rich in Fe and/or Al. Based on its mineralogy and the degree of weathering, the weathered layer is subdivided into upper and lower layers (Chilton and Foster, 1995). The upper layer has a high proportion of secondary clay minerals (e.g., kaolinite), whereas the lower layer is characterized by high content of primary weathering materials associated with earlier

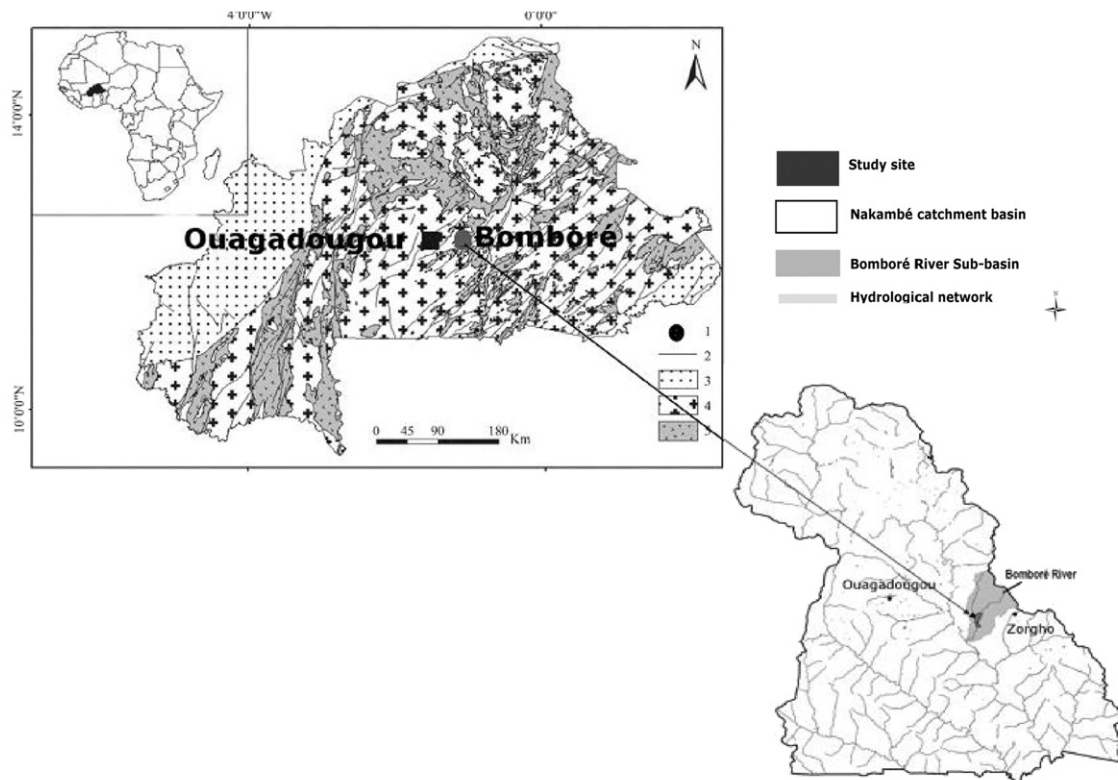


Fig. 1. Simplified geological map of Burkina Faso (modified from Castaing et al., 2003) and the Bomboré Sub-basin within the Nakambé River basin. 1) Bomboré gold mineralization area; 2) fault; 3) Neoproterozoic to Paleozoic sedimentary basin; 4) Eburnean granitic rock; 5) Birimien volcanosedimentary rock.

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