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Trace elements geochemistry of fractured basement aquifer in southern Malawi: A case of Blantyre rural

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ABSTRACT

In this study, twenty one (21) trace elements in the basement complex groundwater of Blantyre district, Malawi were analyzed. The majority of the analyzed trace elements in the water were within the standards set by World Health Organization (WHO) and Malawi Standards Board (MSB). But, iron (Fe) (BH16 and 21), manganese (Mn) (BH01) and selenium (Se) (BH02, 13, 18, 19 and 20) were higher than the WHO and MSB standards. Factor analysis (FA) revealed up to five significant factors which accounted for 87.4% of the variance. Factor 1, 2 and 3 suggest evaporite dissolution and silicate weathering processes while the fourth factor may explain carbonate dissolution and pH influence on trace element geochemistry of the studied groundwater samples. According to PHREEQC computed saturation indices, dissolution, precipitation and rock-water-interaction control the levels of trace elements in this aquifer. Elevated concentrations of Fe, Mn and Se in certain boreholes are due to the geology of the aquifer and probable redox status of groundwater. From PHREEQC speciation results, variations in trace element species were observed. Based on this study, boreholes need constant monitoring and assessment for human consumption to avoid health related issues.

1. Introduction

Groundwater is the main domestic water source in developing countries. It is reliable, convenient and cleaner compared to surface water. Since most communities in rural areas have easy and direct access to groundwater, they use it with little or no treatment. This fact makes it hazardous in cases of high loading of undesirable elements. Most of such elements exist entirely from the geochemical activities since water is a profound chemical reaction media and solution. As such, it is very likely that any element existing in the aquifer can dissolve and react under special circumstances such as oxidation/reduction conditions (redox), pH variations and optimal temperature. Some elements may mobilize under reducing conditions while others are more prevalent under oxidizing conditions. Besides, chemical reactions and speciation may influence the potency of certain elements. For instance, ionic barium and its soluble compounds are toxic to humans while the insoluble barium sulfate ($BaSO_4$) is harmless (Nogueira et al., 2010). Mobile elements are more hazardous than precipitated elements. As such, the extent to which elements affect humans and living organisms depends on the chemical characteristics/species, concentration, exposure duration and bioaccumulation potential of the element.

Complex processes control the distribution of trace elements in groundwater, which has a large range of chemical composition (Chen et al., 2007). Trace elements composition of, and their associated elevations in groundwater, depends on various natural factors (Chen et al., 2007; Helena et al., 2000). As well, human activities can change groundwater composition, either by polluting it or by changing the hydrological cycle (Helena et al., 2000).

To find out the quality of groundwater for rural communities, the analytical and field data was assessed using World Health Organization (WHO, 2011) and Malawian standards (MSB, 2005) maximum permissible levels (MPL). The trace elements geochemistry was evaluated using statistical techniques especially multivariate's factor analysis. Furthermore, trace element speciation studies were done using PHREEQC geochemical modeling.

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Therefore, this paper discusses the hydrochemistry of trace elements in basement complex aquifers of southern Malawi. There are very limited studies so far on trace elements in the groundwaters of the Blantyre district (Mapoma and Xie, 2014). The field sampling and analytical work were done in the months of September and October, 2013.

2. Geological setting of the study area

Blantyre district is located within latitudes 15.350–16.015° S and longitudes 34.725–35.125° E. The district covers an area of 1792 km^2 with undulating topography ranging from an elevation of about 780–1612 m above sea level. Blantyre district is underlain by an extensive Precambrian crystalline basement complex made up of metamorphic and igneous rocks that include syenitic granites, charnokites and ultra-basic gneisses, schists, granulites and quartzites (Mkandawire, 2004). The main lithofacies within the bounds of the Blantyre district are dark grey gneisses enriched in amphibole and pyroxene.

3. Materials and method

3.1. Field sampling and field parameter measurement

Twenty-one community boreholes within Machinjiri area in Blantyre (Fig. 1) were selected for study. Preliminary analyses included immediate in situ measurements of pH (Wagtech pH meter, S/N 297046), dissolved oxygen (HANNA, Model HI9743), temperature, electric conductivity (EC) and total dissolved solids (TDS) (Wagtech EC/TDS/°C meter, S/N 303178) and turbidity (Wagtech Turbidity meter, Model No. WT3020) while ALPHA titration technique was used to determine bicarbonate (HCO_3) in the Department of Physics and Biochemical Sciences chemistry laboratory of the University of Malawi. A portable hand held GPS (Global positioning system) was used to record borehole collar elevation and location coordinates. Furthermore, water samples for laboratory analysis were collected in two sets of 21 samples. During collection, the water samples were filtered through a 0.45 μm millipore filter into 100 mL high density polyethylene (HDPE) bottles washed with distilled water. The pH for twenty one samples intended for cation (major and trace elements) analysis was controlled to pH < 2 using 6 M HNO_3. The samples for laboratory analysis were kept in refrigerator for preservation.

3.2. Analytical techniques

The laboratory analysis was done at State Key Laboratory of Biogeology and Environmental Geology of China University of Geosciences (Wuhan) within one week of sampling. Unacidified aliquots were analyzed for fluorides (F), chlorides (Cl), nitrates (NO_3), nitrites (NO_2), sulfates (SO_4) and bromine (Br) by Ion Chromatography model DX-1100 (Dionex). Major water quality cations and trace elements were analyzed using inductively coupled plasma optical emission spectrometry (ICP-OES) (ICAP6300). The major and trace elements analyzed were calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), silica (Si), silver (Ag), arsenic (As), aluminium (Al), gold (Au), boron (B), barium (Ba), beryllium (Be), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), lithium (Li), manganese (Mn), nickel (Ni), lead (Pb), selenium (Se), tin (Sn), strontium (Sr), vanadium (V) and zinc (Zn). The average analytical error for major and trace chemical constituents using ICP-OES is less than ±5%.

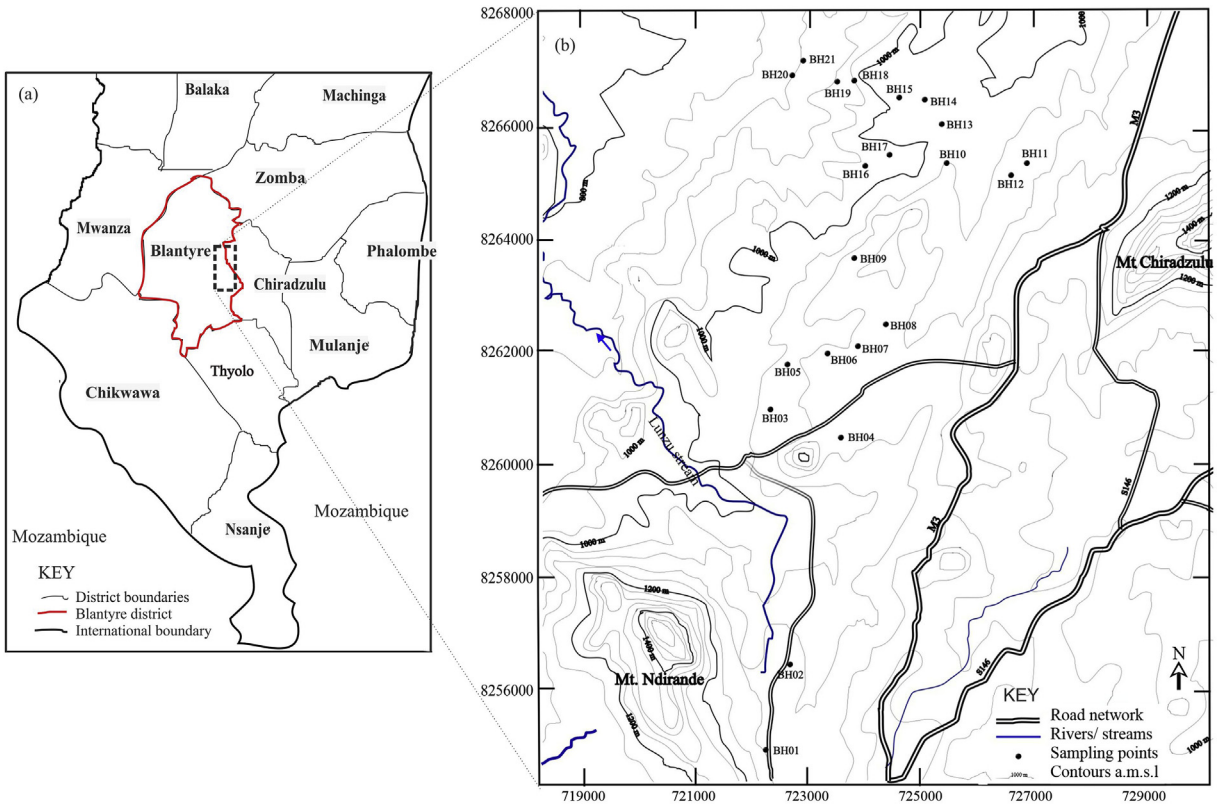

Fig. 1. Map showing the location of Blantyre district in southern Malawi (a) and the specific study area within the district (b) including sampling points and contours representing average mean sea level elevation (a.m.s.l).