Journal of African Earth Sciences 114 (2016) 192–202

Contents lists available at ScienceDirect

Journal of African Earth Sciences

journal homepage: www.elsevier.com/locate/jafrearsci

Hydrochemical characteristics of rural community groundwater supply in Blantyre, southern Malawi

Harold Wilson Tumwitike Mapoma [a, b, *], Xianjun Xie [a, **], Liping Zhang [a], Mathews Tananga Nyirenda [a], Albert Maliro [b], Darlington Chimutu [b]

[a] School of Environmental Studies, China University of Geosciences (Wuhan), Lumo Road 388, Wuhan 430074, Hubei, China
[b] Department of Physics and Biochemical Sciences, University of Malawi, The Polytechnic, P/ Bag 303, Blantyre 3, Malawi

ARTICLE INFO

Article history:
Received 20 January 2014
Received in revised form
20 October 2015
Accepted 26 November 2015
Available online 1 December 2015

Keywords:
Factor analysis
Fractured basement
Groundwater
Irrigation
Borehole
Blantyre

ABSTRACT

The purpose of this research was to characterize the quality of groundwater for drinking and irrigation in Blantyre, Malawi as well as identify some geochemical processes governing mineralization of major and some minor elements. The aquifer studied is part of the extensive crystalline basement complex. The suitability and classification involved confirmatory analysis of the results with World Health Organization and Malawi Standards Board groundwater guideline values. The water samples were analyzed for major descriptors (pH, Temperature, turbidity, major ions, total dissolved solids and electrical conductivity (EC), using standard methods. Besides, arsenic, iron and fluoride were analyzed as well. Multivariate statistics (especially Hierarchical Cluster Analysis and Factor Analysis), hydrographical methods (i.e. Piper diagram) and geochemical modeling programs (AquaChem and PHREEQC) were used to characterize the quality and explain the sources and evolution of groundwater. Suitability of groundwater for irrigation was assessed using Wilcox method which identified BH01, BH16 and BH21 as high salinity areas. Incidentally, the three boreholes had relatively higher sulfate and nitrate concentrations than the rest. Nevertheless, the groundwater was found to be within acceptable limits for drinking quality except elevated concentrations of nitrate, fluoride and iron in some boreholes compared with WHO standards, despite meeting the national standards. Borehole BH01, BH02, BH07, BH13 and BH18 exhibited nitrate concentrations greater than national standards (45 mg/L) an indication of groundwater contamination. Furthermore, the groundwater is slightly acidic to slightly above neutral with total dissolved solids less than 500 mg/l. Generally, groundwater was undersaturated with respect to both calcite and dolomite while oversaturated with respect to halite, goethite and hematite. Silicate and carbonate weathering were identified as main mineral sources for major ions in groundwater. There is a dire need for more studies and monitoring of the groundwater in this area to safeguard the resource and human health.

1. Introduction

Groundwater quality has recently gained significant attention in rural water supply due to its reliability and dependable nature. Even though groundwater contributes only 0.6% of the total water resources world over (Meenakshi and Mehshwari, 2006), rural communities largely depend on it due to intermittent and inadequate piped water supply. Groundwater provides a relatively clean, reliable and cost effective resource (Bovolo et al., 2009) with good natural quality that is adequate enough for potable supplies while demanding minimal treatment attention (Yidana, 2010). However, natural factors and anthropogenic activities degrade some of the aquifers rendering them unfit for human consumption (Epule et al., 2011).

Globally, about 25–40% of the drinking water is derived from groundwater (Morris et al., 2003). While the quantity of freshwater has dwindled appreciably (Pritchard et al., 2008), groundwater quality is threatened from liquid waste (von der Heyden and New, 2004) and fertilizer application. Thus, the current generation faces the challenge to conserve water resources in the wake of global

* Corresponding author. School of Environmental Studies, China University of Geosciences (Wuhan), Lumo Road 388, Wuhan 430074, Hubei, China.
** Corresponding author.
E-mail addresses: hmapoma@poly.ac.mw (H.W.T. Mapoma), xianjun.xie@gmail.com (X. Xie).

http://dx.doi.org/10.1016/j.jafrearsci.2015.11.023
1464-343X/

change.

Developing countries are currently facing major challenges in terms of inadequate and safe drinking water supply (DeGabriele, 2002) aggravated by high population growth. It is postulated that at least 44% of the population in sub-Saharan Africa does not have access to clean and reliable water supply (Dungumaro, 2007). This condition threatens human health and plant growth (Olajire and Imeokparia, 2001), thereby adversely affecting economic development and social prosperity (Milovanovic, 2007). Therefore it is of noble cause to assess the groundwater quality and ascertain its suitability for drinking and irrigation purposes.

In Malawi, 85% of rural people have some form of access to safe drinking water (World Bank, 2013 data, http://data.worldbank.org/indicator/SH.H2O.SAFE.RU.ZS) of which about 37% use boreholes as their main source (Staines, 2002) and consumed without any form of treatment (Pritchard et al., 2007, 2008). According to Environmental Affairs Department (EAD, 2004), about 46% of people in the rural area of Malawi have access to potable water in the form of tap (10%), borehole (29%) and protected wells (7%). The rest of the population in the rural areas draw from hand dug wells (Pritchard et al., 2008), providing raw water supplies which contributes to high water borne disease incidences. School children are vulnerable to contaminated drinking water since they are not easily monitored when taking water in rural areas.

In the wake of such worries, scientists locally and elsewhere have studied and assessed the quality of groundwater in the aquifers. Various elements ranging from essential to health threatening have been determined. Variations have been attributed to mainly the geologic input of the aquifer strata (Mapoma et al., 2014). However, in some instances human activities, such as agriculture and irrigation, have contributed significantly to increased loads of minerals as well as their mobilization such as heavy metals, fluoride and arsenic. The health implications of such loading are numerous, especially on human health, such as fluorosis, arsenicosis, cancer and many more.

Guidelines based on health implications offer assurance to communities using groundwater. Various studies on aquifers in specific areas present facts on the quality of groundwater assuring communities of its quality. In some instances results from adjacent aquifers are used as standards to certify safety of groundwater to be abstracted. However, analysis of groundwater on the site to be exploited is the best assurance a community can get. In Blantyre, Malawi, a study done in Lunzu Area (adjacent to Machinjiri) indicated that the water quality of the aquifer is good (Palamuleni, 2002). However, it is expected that groundwater quality can vary in such aquifers within meters of each sampling point. As such, this study was carried out to assess the groundwater suitability for domestic and irrigation in Machinjiri based on both WHO and Malawi Standards. Furthermore, a multivariate analysis was perfumed to evaluate the sources and geochemical controls. The results of the study will provide baseline data on groundwater geochemistry in the area as well as incite on groundwater management and monitoring. Above all, the paper will assist in understanding of the geochemical processes governing groundwater as a starting point of future research in the area.

2. Geomorphology and hydrology of the study area

Machinjiri is a rural setting consisting of various villages within Blantyre District. Blantyre District hosts the largest commercial and industrial city of Malawi. It is the geopolitical capital of Southern Region of the country located in the Shire Highlands at 15° 42″S and 35°E coordinates (Fig. 1). The district is 1792 km^2 in area with undulating topography ranging from an elevation of about 780 to 1612 m above sea level comprising of hills, plateau and ridges and the natural drainage system (Geohive, http://www.geohive.com/cntry/malawi.aspx). In terms of geology, the district is part of the crystalline basement complex that formed during the late Precambrian and lower Paleozoic age. Carter and Bennett (1973); Chilton and Smith-Carington (1984) have both described the geology of Malawi as mainly underlain by the basement complex that is divided into weathered (comprising of plains and plateau areas) and fractured basement (mainly occupying the highlands and hilly places). Machinjiri area thus belongs mainly to the fractured basement system whose extensive rock formation consists of impenetrable pyroxene granulite and syenitic gneiss. Luckily, since Blantyre is on the eastern edge of the southern branch of the East African Rift Valley where prominent faults occur, the basement is fractured enough for potential aquifers to exist for groundwater exploitation (Mapoma and Xie, 2014; Mapoma et al., 2014).

3. Materials and methods

3.1. Sampling and sample analysis

In this study, groundwater was sampled from 21 running hand pumped boreholes (coded as BH01 − BH21) within Machinjiri Traditional Authority. The sampling and subsequent analysis took place in September, 2013. The water samples were filtered on site using 0.45 μm membrane filters. Twenty one samples for cation analyses were stored in 100 ml polypropylene bottles and acidified to pH ≤ 2 using HNO_3. The other set of 21 samples for anion analysis were not acidified. The samples were immediately stored in a refrigerator at the Department of Physics and Biochemical Sciences of University of Malawi, The Polytechnic. Preliminary analyses included immediate in situ measurements of pH (Wagtech pH meter), temperature, electric conductivity (EC) and total dissolved solids (TDS) (Wagtech EC/TDS/°C meter) and turbidity (Wagtech Turbidity meter). Bicarbonate (HCO_3) was analyzed in the Department of Physics and Biochemical Sciences' chemistry laboratory via APHA titration technique. Borehole site elevation and coordinates were measured using a portable hand held global positioning system (GPS).

3.2. Laboratory analysis

Chemical analysis of the samples was done at State Key Laboratory of Biogeology and Environmental Geology of China University of Geosciences (Wuhan) within one week of sampling. All cations, namely Arsenic (As) calcium (Ca), magnesium (Mg), potassium (K) and sodium (Na), were analyzed by Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) (ICAP6300). The average analytical error for major and trace chemical constituents using ICP-OES is less than ±5%. In contrast, major anions (chlorine, Cl and sulfate, SO_4) as well as fluorides (F), nitrates (NO_3) and nitrites (NO_2) were determined by ion chromatography (IC) (Dionex ICS 1100) with a detection limit of 0.01 mg/L. Total hardness of water was determined using empirical method (EPA, http://www.epa.ohio.gov/portals/35/permits/IndustrialStormWater_Final_GP_AppJ_dec11.pdf) (Equation (1)).

$$TH(\text{mg CaCO}_3/\text{l}) = 2.497[\text{Ca}] + 4.118[\text{Mg}] \tag{1}$$

3.3. Data analysis and interpretation

The data obtained from laboratory analysis was used to analyze the quality of groundwater for both domestic (mainly drinking) and irrigation purposes. This was achieved through multi-comparison