Journal of African Earth Sciences 121 (2016) 180–199

Contents lists available at ScienceDirect

Journal of African Earth Sciences

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

Poor understanding of the hydrogeological structure is a main cause of hand-dug wells failure in developing countries: A case study of a Precambrian basement aquifer in Bugesera region (Burundi)

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ARTICLE INFO

Article history:
Received 17 December 2015
Received in revised form
25 May 2016
Accepted 26 May 2016
Available online 27 May 2016

Keywords:
Hydrogeology
Groundwater potential
Vertical electrical sounding (VES)
Geoelectrical structure
Precambrian crystalline basement
Saprolite
Weathered overburden
Productivity of hand-dug wells

ABSTRACT

This study investigates a Precambrian basement aquifer in Bugesera region, a typical African rural area in northeastern Burundi. Domestic water supply relies on groundwater which is tapped through hand-dug wells. Despite several attempts to increase the number of water points in the area, the water demand is still far from being met as a result of the high rate of well failure. This paper seeks to understand whether the hydrogeological structure and the spatial distribution of hydraulic parameters can explain the low productivity and the high failure rate of hand-dug wells. The hydrogeological structure inferred from the interpretation of a large number of vertical electrical soundings (VES) reveals a typical sequence of geoelectrical layers, which is characterized by an overall upwards fining from the fresh basement, over the fractured/weathered basement, to the overburden or saprolite with a clay-rich layer on top. Whereas the overall aquifer potential mainly depends on the thickness of the weathered overburden, the aquifer potential for shallow hand-dug wells is determined by the hydraulic conductivity of the upper few meters of the saturated zone. This upper zone was investigated in the pumping tests. The spatial distribution of the specific capacity reveals a wide variation of hydraulic parameters, depending on the well's position in the depth profile of the aquifer's hydraulic conductivity. The thickness of the potential aquifer is highest in the central part of the study area (pegmatitic and granitic intrusions) which has the highest overall aquifer potential compared to the surrounding metasedimentary formations. However, a thick weathered overburden will increase the groundwater potential of an aquifer for deep boreholes, whereas for hand-dug wells, the productivity can only be high if the thickness of the weathered overburden is small enough, or the water table is deep enough, to allow to tap the coarse part at the base of the overburden and/or part of the weathered/fractured basement. This study reveals that the main cause of low productivity and failure of many hand-dug wells in Bugesera region is not to be linked to poor groundwater resource potential but rather stems from the inappropriate random siting of wells and from poor well construction expertise which does not take into account the hydrogeological conditions. The results of the investigation indicate that in the typical weathering profile of the Precambrian basement in Sub-saharan Africa, the coarse lower part of the weathered overburden and the fractured/weathered basement offer good prospects for water resource. Depending on the depth at which this layer is encountered, either shallow hand-dug wells or deep drilled wells are most appropriate.

1. Introduction

The hydrogeological structure is the sesame key for a sound understanding of the hydrodynamics and hydrogeochemistry of groundwater. A good knowledge of the lithological setting of a groundwater reservoir enables to characterize the typology of the

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http://dx.doi.org/10.1016/j.jafrearsci.2016.05.025
1464-343X/

aquifer and therefore to determine the appropriate interpretative model. Precambrian and Archean crystalline basement rocks and associated aquifers occur in extensive areas of Sub-Saharan Africa where they cover more than 40% of the surface area. They comprise magmatic rocks and metamorphic rocks of various metamorphic grades (Chilton and Foster, 1995). Crystalline basement aquifers are generally believed to have a low groundwater potential but their extensive occurrence is suitable for water supply to the sparse pattern of human settlements and the small to medium size of most of the cities in Sub-Saharan Africa. In Burundi, Precambrian basement rocks occupy more than 90% of the land surface and thus constitute an invaluable potential supply source of water, mainly in rural areas and small cities where gravity-driven water distribution systems and surface water treatment facilities do not exist.

In the past, the study of Precambrian basement aquifers has not received enough attention due to their presumed low groundwater potential. However, the tremendous increase of the global population together with increase in water demand in the late 20th century have fostered substantial advances towards the understanding of Precambrian basement aquifers (Nyagwambo, 2006). Nowadays, several studies conducted in Precambrian rock environments converge to a commonly accepted hydrogeological structure consisting of two stratiform but hydraulically communicating aquifers; namely the saprolite and the fractured/weathered part of the substratum (Chilton and Smith-Carington, 1984; Acworth, 1987; Wright, 1992; Chilton and Foster, 1995; Taylor and Howard, 2000; Wyns et al., 2004; Dewandel et al., 2006; Chandra et al., 2008**).** According to Dewandel et al. (2006), when the weathering profile is not truncated by erosion, the saprolite and the weathered/fractured basement form a composite aquifer. The saprolite layer has mainly a storage function, whereas the fractured/weathered substratum may play a transmissive role for deep and well developed boreholes. The saprolite is a clay-rich layer resulting from the prolonged in-situ weathering of the bedrock. Due to its relatively high clay content, the saprolite has a high porosity but a low hydraulic conductivity. The fractured/weathered substratum is the upper part of the basement which is characterized by a network of fractures and fissures resulting from weathering processes, lithostatic decompression, cooling stresses or tectonic activity (Wright, 1992; Chilton and Foster, 1995). It is this part of the bedrock which is exposed to the weathering front and thus features the first stages of the weathering process in which the fabric and structural characteristics of the fresh basement are still recognisable. The weathered/fractured basement tends to have a high hydraulic conductivity compared to the saprolite although the storage capacity of the fractures is low. .

The development of such a hydrogeological structure results from a combination of processes of deep weathering and stripping through colluvial and fluvial erosion (Taylor and Howard, 2000). Factors governing the weathering process comprise the characteristics of the basement rocks, climatic conditions, tectonic activity, topography and time. Basement aquifers are generally characterized by a discontinuous response to abstraction due mainly to the spatial variability of lithologies, structural features and tectonic history of basement rocks (Wright, 1992; Diop and Tijani, 2008). They generally feature low but highly variable hydraulic parameters. The typology of basement aquifers is complex. They are generally considered as unconfined but may respond in a leaky fashion when the groundwater table rests in the uppermost clayey layer of the weathering profile (Wright, 1992; Diop and Tijani, 2008).

Hand-dug wells are still widely used in the developing world in general and particularly in Sub-Saharan Africa where due to limited investments and insufficiency of energy, the feasibility of drilling deep boreholes is strongly limited. Hence, in such conditions, hand-dug wells may offer the only means of groundwater exploitation, and also the only possibility to evaluate the hydraulic parameters of aquifers.

This study investigates the Burundian portion of a transboundary aquifer which stretches over northeastern Burundi and southeastern Rwanda, i.e. Bugesera region (Bakundukize, 2012). While overall Burundi enjoys a humid tropical climate with abundant rainfall and numerous springs, which cover more than 90% of the domestic water demand, Bugesera depression, like a desertic island within an ocean, is marked by the lack of natural springs, which makes it one of the most water-scarce areas in Burundi. The only source of potable water is groundwater which is tapped through shallow hand-dugs wells with a diameter of around 1 m, equipped with hand- or foot-operated pumps. However, most of these wells are characterized by a low yield or often operate intermittently, so that overall the local domestic water demand is still unmet. Local populations who are facing a severe lack of clean water and the consequent water-borne diseases, since long believe that their region is struck with a curse. Yet the estimation of the long term average groundwater recharge performed by Bakundukize et al. (2011) using the soil moisture balance method, indicates that the Precambrian basement aquifer is relatively well replenished by the relatively abundant rainfall (1059 mm/year). Therefore, our study in the area aims to understand whether the hydrogeological setting can give tangible explanatory clues as to why the low yield or the failure of most of the hand-dugs wells occur, and the feasibility of alternative solutions. The study is based on the interpretation of geophysical data constrained by lithological information from auger soundings and lithological descriptions of recently constructed wells. The specific well capacities are derived from the analysis of 41 constant rate pumping tests conducted across the study area.

2. Study area

2.1. Location, physiographic features, land use and climate

The study area is located in northeastern Burundi and stretches between longitudes 29°56′36.2″E to 30°23′38.9″E and latitudes 2°19′45.2″S to 2°41′37.4″S, with a surface area of approximately 1050 km^2 of which 153 km^2 are occupied by small lakes (Fig. 1). The study area features two distinct geomorphologic entities: the northern part centred around the so-called "*Lacs du Nord*" (northern lakes) which is a depression with altitudes ranging between 1320 m and 1600 m; and the southern part which displays a more rugged landscape where dissected crests culminate up to more than 1800 m. The whole Bugesera region covers important parts of northeastern Burundi and southeastern Rwanda. In Burundi, Bugesera region forms one of the 11 natural regions. One of the most striking physiographic features in this region is the existence of a perennial complex of interconnected swamps and several small lakes which form the head waters for the Kagera River. But yet, according to local saying, this region is called "*mu Bugesera*" which literally means, "*a damned*", "*a cursed*" area, due to the generalized scarcity of clean water. During periods of high river stage, which occur generally in April-May, water from the Kagera river system overflows to the complex of marshland and lakes where important volumes of water are stored. This water is progressively released to sustain river discharge during the dry season.

The land use is dominated by agricultural land (69%) with sparse forest plantations and some relicts of natural vegetation. Human settlement is characterized by a dispersed pattern which is typical of most of the developing countries. The only urban settlement is the small city of Kirundo.

The main climatic feature of the study area is the bimodal