Groundwater for Sustainable Development 5 (2017) 66–74

Contents lists available at ScienceDirect

Groundwater for Sustainable Development

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

Analysis of crystalline bedrock aquifer productivity: Case of central region in Cameroon

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ARTICLE INFO

Keywords:
Bedrock aquifer
Crystalline bedrock
Productivity
Transmissivity
Central Cameroon

ABSTRACT

Hydrogeology in the central region of Cameroon is marked by the presence of two types of aquifers: one of them in the weathered rocks and another in the fractured crystalline bedrock. This study focuses on the fractured bedrock aquifer through the examination of records from 67 boreholes drilled in the area. An analysis of the productivity of this aquifer system has been done to enhance the water supply, in view of the drilling data of the region. Boreholes have been grouped according to the depth, weathering depth, rock type, topography, and proximity to lineaments. The results show transmissivity values ranging between 0.1 and 131 m^2 / day with an average and a median of 4.7 and 0.7 m^2 / day, respectively. No correlation between productivity and borehole depth or weathering depth was found. However, beyond 70 m depth, the values of transmissivity tend to fall. In addition, weathering depths between 5 and 35 m appear to provide the highest transmissivity. In terms of topography, the boreholes located in the valleys are more productive than those located in the upland. Schist appears to be more productive than gneisses and quartzites. Wells within 150 m of lineaments are more productive than those located further. Moreover, wells along NW-SE lineaments (120–150°) seem to be more productive. All these factors play an important role in the productivity of wells in the central region of Cameroon. This study thus provides a basis for rural water-supply development programs.

1. Introduction

Water resource management is one of the major challenges facing humanity, with water being a key factor for social and economic development. The UN in its seventh Millennium Development Goals (MDGs) required States in its 7 C target to reduce by 2015 the proportion of people without access to safe drinking water and sanitation (UN, 2014). It is in this context that numerous hydraulic programs have been undertaken worldwide. Through these programs, numerous boreholes have been drilled into fractured crystalline bedrock. They were formed during various tectonic events that resulted in networks of more or less connected fractures. These fracture networks are responsible for the formation of groundwater in fractured bedrock areas (Savané and Biémi, 1999; lasm et al., 2004; Jourda et al., 2006; lasm et al., 2008; Sorokoby et al., 2010). These aquifers, under variably-thick regolith are generally immune to seasonal fluctuations and pollution (Biémi, 1992). For these reasons, water supply is increasingly oriented towards deep groundwater with quality generally meeting WHO (World Health Organisation) standards (Biémi, 1992).

The use of the crystalline bedrock aquifers for water supply is complex because groundwater resources are spatially variable in this system (Wright, 1992; Chilton and Foster, 1995; Mabee, 1999; Banks and Robins, 2002). Consequently, the productivity of wells drilled in crystalline bedrock is spatially variable and even within the same rock. Several authors have tried to explain these variations by examining the factors that influence the movement and storage of water in the bedrock (Cushman et al., 1953; Legrand, 1954; Lamoreaux and Powell, 1963; Cline, 1968; Siddiqui, 1969; Siddiqui and Parizek, 1971; Daniel, 1989; Dine et al., 1995; Henriksen, 1995; Mabee, 1999; Drew et al., 2001; Marechal et al., 2004; Boutt et al., 2010; Holland and Witthüser, 2011). All these studies had a common goal to research the single factor or combination of factors that most influence the productivity and thus use these data to select areas of high potential productivity. Due to low intrinsic permeability and low porosity observed in the crystalline bedrock, aquifers of these environments differ widely from those of sedimentary environments and thus require specific knowledge and techniques for prospecting groundwater. In the 1960s and 1970s, the analysis of lineaments emerged as a technique for locating potential high-productivity zones in fractured bedrock (Lattman and Parizek, 1964; Siddiqui and Parizek, 1971; Parizek, 1976). According to Deslandes and Qwyn (1991), lineament is any structure having a rectilinear or curvilinear path of a geological significance. The analysis

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http://dx.doi.org/10.1016/j.gsd.2017.05.003
Received 10 October 2016; Received in revised form 11 May 2017; Accepted 20 May 2017
Available online 23 May 2017
2352-801X/ © 2017 Published by Elsevier B.V.

of lineaments has grown because it saves a lot of time especially when the study area is very large.

Research on the factors that influence borehole in crystalline bedrock has been focused on the influence of topography, rock type, structure of the bedrock, type of overburden and borehole depth (Ellis, 1909; Stuckey, 1929; Frucron, 1939; Legrand, 1949; Cushman et al., 1953; Legrand, 1954; Dingman and Meyer, 1954). All these independent and interrelated factors play an important role in the occurrence of groundwater through the control of the nature and depth of the regolith, the development of fractures in the fault zone and the presence of high porosity material (Holland and Witthüser, 2011). Numerous studies have sought the main parameter that controls the productivity of crystalline bedrock aquifers in order to identify areas with high productivities. According to Long and Witherspoon (1985), Berkowitz (1995) and Odling (1997), the productivity of crystalline bedrock aquifers is mainly controlled by fracturing through the opening, length, spatial distribution and connectivity of bedrock fractures. Cline (1968), McFarlane et al. (1992), Henriksen (1995) and Mabee (1999) showed the influence of topography on borehole yield. For Gustafson and Krasny (1994) and Neves and Morales (2007), the productivity of boreholes is more influenced by the rock type in which they are dug. The recent work of Holland and Whitthüser (2011) have shown that borehole yields in crystalline bedrock are linked to a number of factors such as bedrock type (pegmatite, gneiss ….), lithologic settings (aureole of granitoids), proximity and orientation of dykes, proximity and orientation of lineaments and topographic setting (slope, valleys …) and proximity to surface water.

Despite the number of studies completed across the world, there is not in our knowledge a study of crystalline bedrock aquifers of the central region of Cameroon, where the water supply projects are generally oriented toward bedrock groundwater. This paper aims to evaluate the factors that influence the productivity of crystalline bedrock aquifers and compare the results with those of other studies worldwide. The following factors will be considered: the type of rock, topographic setting, weathering thickness, borehole depth, and proximity to lineaments.

2. Study setting and geological context

The study area lies between 3.0817 and 4.9691° north latitude and between 10.6877 and 13.0258° east longitude (Fig. 1). This area is subject to a "Guinean forest, high Cameroonian type sub-equatorial climate" (Vallerie, 1973). From the geological point of view, the area has a substratum essentially made of metamorphic and plutonic rocks belonging to the Precambrian basement complex (Nedelec and Nsifa, 1987; Nzenti et al., 1988; Nedelec et al., 1990; Toteu et al., 1994; Shang, 2001; Shang et al., 2004). This bedrock is divided into two large groups: Nyong and Yaounde Group (Toteu et al., 2008) (Fig. 2).

Cameroon crystalline bedrocks are essentially made up of two superposed aquifers: an upper aquifer located in the granular weathered bedrock and a deeper discontinuous aquifer associated with large fractures (Djeuda Tchapnga, 2001). The upper aquifer is between 8 and 20 m deep and is almost isotropic. The lower aquifer where water is encountered beyond 20 m depth is anisotropic (Mfoutou, 1996, unpublished work; Djeuda Tchapnga, 1987; Bosso Bosso, 2000, unpublished work). The hydrodynamic behavior of these aquifers is different. The work of Bosso Bosso (2000) in the Yaounde region reveals that deep aquifers are discontinuous and fractured; high productivity fractures (20–35 m^3 / h) and almost dry fractures ($Q < 5\ m^3$ / h) are present; maximum water inflow is between 30 and 60 m deep; transmissivity and storativity are linearly related to the flow rate.

3. Methods

3.1. Database

The data used in this study come from 67 boreholes obtained through the rural water supply programs in Cameroon. The main difficulty is the presence in data sheets of many gaps that limit some interpretations. The parameters taken into account are: well yield Q (m^3 / h); borehole depth (BD in m); weathering depth (WD in m); water level in the borehole after equipment (WL in m); water strike (WS in m); and transmissivity (T) in m^2 / day, which are determined from the interpretation of pumping tests (Table 1).

Only data from pumping tests of 67 wells are available as part of this study. The pumping time was short (5 h) and measurements were made directly in the pumping borehole; this is because constructing an observation piezometer would roughly financially cost the same price drilling. So, instead of drilling an observation piezometer, the state preferred to drill a water-supply borehole at another locality. The absence of a true observation of drawdown and recovery along with a short pumping time leads us to say that the transmissivity data obtained are approximate. However, they can provide a useful estimate of the relative characteristics of bedrock aquifers. Although determining the parameters of aquifers was not the first goal of the design department mentioned above, pumping tests of the 67 boreholes were determined using the classic Theis (1935) method and Jacob approximation (1947). Using these data the transmissivity was evaluated mostly using recovery data as recommended by Lasm (2000). However, in some cases, the drawdown data were used due to insufficient recovery data. Transmissivity is calculated by the slope of the line. The slope is determined by increased drawdowns or depths of water levels on a semi-logarithmic graph (Fig. 3). From the latter the transmissivity was determined by the Eq. (1) (Castany, 1998):

$$T = \frac{0.183Q}{c}, \tag{1}$$

where, Q = borehole yield in m^3/h, c = slope of the straight on the semi-logarithmic graph and, T = transmissivity in m^2/h.

3.2. Data analysis

The approach used in this study is classic through the consolidation of the transmissivity according to the depth of drilling, the thickness of alteration, topography, rock type and proximity of lineaments. It includes Landsat satellite ETM+ imagery (P1845056 recorded 31 January 2008 during the dry season) and 1:200,000 geological maps and 1:50,000 topographic maps. All these images have enabled us to extract data for boreholes such as location, proximity to the lineaments, geology and topography. Parameters such as rock type (granite, gneiss, and quartzite), the thickness of alteration and the depth of borehole were derived from technical data of the 67 boreholes from the detailed logs. Boreholes have been grouped according to the above mentioned parameters and the transmissivity mean and median were calculated.

3.3. Analysis of lineaments

Lineaments mapping (Fig. 4) can be done by analysis of topographic maps, hydrographic networks or air-photography interpretation (Ousmane, 1988; Yameogo, 2008). Hydrogeologists increasingly use digital media such as DTM (Bonnet and Colbeaux, 1999; Durand, 2005) and satellite imagery (Savadogo, 1984; Biémi, 1992; Savane, 1997; Rana, 1998; Jourda, 2005) for the extraction of lineaments. Here, we used satellite images for the extraction of lineaments in the central region. These satellite images are coupled with 1:200,000 Geotiff topographical maps. Software such as Erdas and ArcGIS allowed digital treatment of images. This software has been useful for the enhancement of linear structures and finalizing the map. The statement of lineaments

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