Groundwater for Sustainable Development 5 (2017) 235–243

Contents lists available at ScienceDirect

Groundwater for Sustainable Development

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

Controls on groundwater quality and dug-well asphyxiation hazard in Dakoro area of Niger

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ARTICLE INFO

Keywords:
West Africa
Niger
Groundwater chemistry
Hydrogen sulfide

ABSTRACT

In the Dakoro area of Niger, hand-dug wells are commonly used for village water supply. Several cases of asphyxiation during well digging have occurred, but the source and composition of the gas (suspected to be CO_2, H_2S, or CH_4) remain uncertain. In addition, data on water quality in the region are sparse. We sampled ten dug wells and five deeper boreholes for analyses of solute chemistry and core samples from one borehole for sediment chemistry. With respect to inorganic solutes, groundwater quality was generally good, although one dug-well sample exceeded the drinking-water standard for NO_3^-. Solute chemistry tended to vary between dug wells (commonly Ca-HCO_3 or Ca-SO_4 waters, with elevated Si and circumneutral pH) and boreholes (typically Na-HCO_3 waters, with lower Si and alkaline pH). These compositions variously appear to reflect dissolution of calcite, gypsum, and silicates; pyrite oxidation; and cation exchange. Some dug wells and boreholes had high acetate concentrations, low SO_4-S relative to total S, and/or a rotten-egg odor, all of which are consistent with reduction of SO_4^{2-} to H_2S. This reaction is likely in Marine Series shales that are relatively high in S and organic C. Consequently, monitoring for H_2S and other gases during well digging is warranted.

1. Introduction

Like other countries in the Sahel region of West Africa, Niger is characterized by uncertain surface-water availability due to seasonal and annually variable rainfall (Ouedraogo et al., 2014). Consequently, groundwater is the principal domestic water supply in Niger (Rabe, 2011). In the Dakoro area of south-central Niger (Fig. 1), villages commonly use hand-dug wells because of limited access to electricity for pumps. Unfortunately, several deaths have resulted from asphyxiation during digging (Boeckh, 1965; Brodbeck et al., 1987). The latter authors attributed these deaths to the occurrence of a colorless, odorless gas at a depth of 50 m or more below land surface (bls). Possible gases include H_2S from bacterial sulfate reduction; methane (CH_4) from anaerobic decomposition of organic matter; and CO_2 either from oxidation of organic matter and pyrite or from respiration by well diggers. Brodbeck et al. (1987) concluded that asphyxiation by CO_2, which is heavier than air and would thus accumulate at the bottom of excavations, is most probable. Those authors delineated "low-risk" and "high-risk" zones based on the upper surface of Marine Series sedimentary rocks at ~ 50 m bls. At greater depth, aerobic oxidation would be inhibited by the presence of the water table. The boundary between the zones was marked by faults inferred from lineaments on aerial photographs.

Since 1987, there has been no further investigation on the source or nature of the asphyxiating gas in Dakoro-area wells. Kaya village, where three people died during well digging, relies on a dug well 47 m deep (Table 1), which recharges slowly (over a period of several hours) after extensive withdrawals. A borehole was drilled to ~ 180 m depth in 2015, but the pump failed within a week afterward and the well is not currently in use. The present study examines water from wells mostly within the "high-risk" zone and sediments from the Kaya borehole to assess groundwater quality, controls on groundwater chemistry, and the possible origin of gas.

2. Geologic setting

Stratigraphically, the lowermost sediments in the study area lie within the fluviodeltaic Tegama Group (Lower Cenomanian) of the Continental Intercalaire (Fig. 2). This group is represented by the Tegama Series (sandstones, siltstones, and clays) and the overlying Farak Series (finely bedded, massive clays, fine sandstones, and locally micaceous siltstones) (Kogbe, 1981; Alzouma, 1994). The Continental Intercalaire is overlain by the lagoonal-lacustrine Intermediate Series (Lower to Mid-Cenomanian), which consists of alternating fine to

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http://dx.doi.org/10.1016/j.gsd.2017.08.004
Received 31 May 2017; Received in revised form 26 July 2017; Accepted 17 August 2017
2352-801X/

Fig. 1. Map of Africa showing study-area location (black circle) within Niger (modified from http://alabamamaps.ua.edu/, accessed 24 July 2017).

coarse sands, silts and clayey beds with decimeter- to meter-scale cross bedding (Brodbeck et al., 1987). Above the Intermediate Series is the Marine Series (Upper Cenomanian to Mid-Turonian/Senonian), which consists of ~ 10–15 m of gray to black silty shales locally rich in pyrite, lignite, and gypsum, capped with decimeter-scale beds of lumachelles (bioclastic limestones) (Brodbeck et al., 1987). Subsequently, the Upper Cretaceous (Santonian/Campanian?) Lower Sandstone, a regressive marine sequence of alternating fine sandstones, siltstones and clay-rich sediments, was deposited. This is overlain by Quaternary alluvium in the Tarka Valley and by sand dunes up to 20–40 m thick in upland areas (Brodbeck et al., 1987). In part because of the lack of outcrops and sparse subsurface data, there is no detailed geological map of the area at present, apart from the regional map of the whole Iullemeden basin (Greigert, 1979). However, Brodbeck et al. (1987) inferred aquifer lithology based on well data.

Three aquifer systems have been delineated in the study area (Brodbeck et al., 1987). Quaternary alluvial and aeolian sediments locally comprise a discontinuous (perched?) aquifer. The regional unconfined aquifer lies within the Farak Series and Lower Sandstone (Fig. 2). In the eastern part of the area, unconfined groundwater flows within the Farak Series generally westward or toward the Tarka valley to the north. To the west, the water table radiates away from a mound between Makera and Dakoro (Fig. 3). Brodbeck et al. (1987) proposed that recharge occurs via infiltration along faults, which juxtapose the eastern and western flow systems noted above, thus resulting in a complex, multilayered aquifer. The Tegama Series serves as the regional confined aquifer.