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Determining the optimum locations for pumping low-fluoride groundwater to distribute to communities in a fluoridic area in the Upper East Region, Ghana

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ABSTRACT

Groundwater is the primary source of water in the Upper East Region of Ghana, and is generally considered a safe source of drinking water; but there are pockets where the groundwater contains high concentrations of fluoride due to the dissolution of minerals in the local granite. The goal of this study is to evaluate the hydrogeology and hydrogeochemistry of an area where dental fluorosis endemic, in order to identify the optimum locations to pump and distribute low-fluoride groundwater. As expected, the data indicate that the higher elevation recharge areas with outcrops of Bongo granite have elevated concentrations of fluoride in the groundwater (up to 4.6 mg L^{-1}), posing the highest risk of fluorosis in the nearby communities. The lower elevation areas, which are the farthest from the Bongo granitic, have the lowest groundwater fluoride (< 0.5 mg L^{-1}) and the lowest risk of fluorosis. Groundwater flow models suggest that the steady decrease in fluoride is driven by dispersion, with the fluoride concentrations dropping to the World Health Organization's recommended drinking water limit of 1.5 mg L^{-1} at about 400–500 m from the source. The optimum locations to install boreholes (or use existing boreholes) for piping low fluoride groundwater to the higher fluoride areas, would be at or beyond this distance. Although the initial costs of developing such a water system would be substantial, this is a potentially viable option for providing low fluoride water to communities suffering from fluorosis.

1. Introduction

The Upper East Region of Ghana is semi-arid, economically poor, and primarily rural with most residents working as subsistence farmers. The majority of households rely on groundwater collected from drilled boreholes with hand-pumps or hand-dug open wells for their domestic water. Groundwater is generally considered a safe and economical source of drinking water, but there are pockets in the Upper East Region where the groundwater contains concentrations of naturally occurring fluoride well above the World Health Organization (WHO) recommended limit of 1.5 mg L^{-1} (WHO, 2011). The source of groundwater fluoride is Bongo granite (Apambire, 1996; Apambire et al., 1997; Apambire, 2000); and the result of consuming high fluoride groundwater is an increase in cases of dental fluorosis (Apambire, 1996; Apambire et al., 1997; Apambire, 2000), as well as an increased risk of skeletal fluorosis. Due to the health risks of drinking high fluoride water, many drilled boreholes in the region remain closed because the fluoride in these wells exceeds 1.5 mg L^{-1}. Drilling boreholes and then leaving them closed is not just wasteful economically, but it exacerbates the ongoing problem of limited access to safe drinking water in a water stressed region.

The study area of Namoo in northern Ghana has pockets of high fluoride groundwater and correlated cases of dental fluorosis (Craig et al., 2015). The objective of this work is to characterize the hydrogeology, geochemistry, and groundwater chemistry of Namoo to better understand the distribution of groundwater fluoride, and to identify conditions that may influence its concentration. The results are intended to identify areas with low fluoride groundwater, in order to utilize existing boreholes or drill new ones to be tapped as safe drinking water sources. The water from these boreholes could then be distributed to nearby communities that lack a safe drinking water source. This approach would save money on drilling costs and provide more options for sources of low fluoride drinking water in an economically poor, water stressed region.

2. Materials and methods

2.1. Study area characterization: hydrogeology and climate

The study area of Namoo is located in the Bongo District, Upper East Region, Ghana (Fig. 1). To map the location and elevation of wells in

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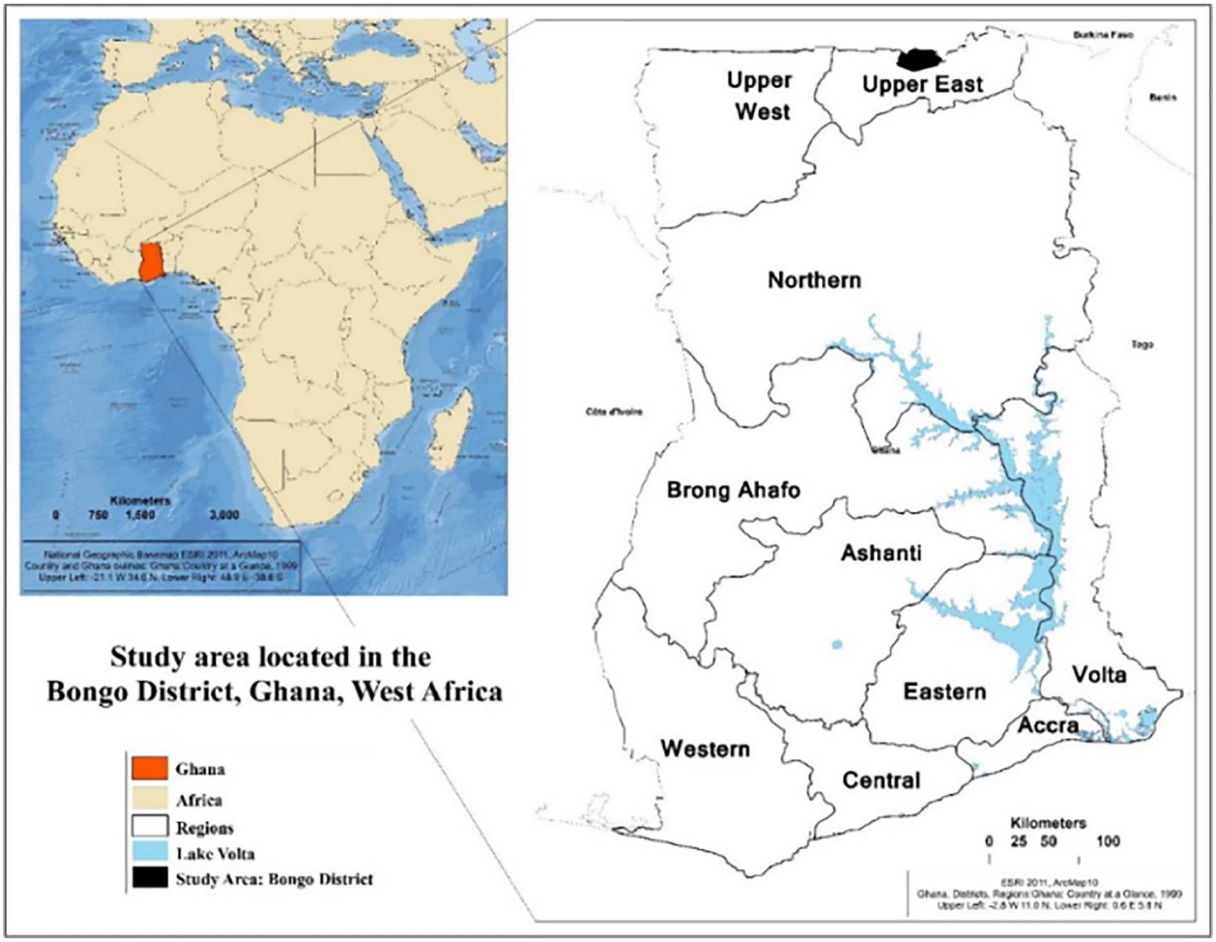

Fig. 1. The location of the Bongo District in the Upper East Region of Ghana. The community of Namoo is an electoral area within the Bongo District.

Namoo, hand-dug open wells (open wells) and drilled borehole hand-pump wells (boreholes) were identified and marked with a Garmin eTrex Vista global positioning system (GPS). Obtaining accurate elevation measurements from hand-held GPS devices is difficult, so to minimize the relative error, all of the elevation readings were recorded in a single day with a clear sky and maximum satellite strength, with all elevations presented as meters above sea level. Water level in the open wells was measured once manually during each the late wet (September 2012) and dry (April 2013) season with a Solinst water level meter. Depth to the bottom of open wells was determined by lowering a weighted rope to the bottom of each well. Manual measurements were also taken from the closed boreholes (not in use = no hand-pumps). To continuously monitor changes in groundwater levels, Schlumberger Diver water level-loggers were installed in two closed boreholes with a barometric pressure logger also located in the study area. Each Schlumberger Diver recorded pressure every 30 min: one from April–October and the other from April–December 2013. Beginning in late July 2012, seasonal variation in air temperature and precipitation was monitored by installing a Decagon weather station to record air temperature and precipitation every 30 min. Pumping rates were also collected for 13 boreholes in the Bongo District.

2.2. Groundwater chemistry

Water samples were collected from 40 open wells and 17 boreholes during the late wet (September), late dry (April), and shoulder (October–November) seasons and analyzed for fluoride concentrations. Boreholes with hand-pumps were pumped for several minutes before collecting samples and were also usually in use by community members which further purges the well. As a result, the samples collected from these boreholes provide a consistently accurate representation of the groundwater chemistry. Most open wells were used regularly with those samples also providing an accurate representation of the chemistry of the water being consumed. However the few infrequently used open well samples may provide less accurate representations of the local groundwater, because flushing the wide diameter wells before sample collection was not possible. Samples collected from closed boreholes are also less reliable because they were not well flushed before collecting a sample.

2.2.1. Field analyses: fluoride, conductivity, temperature, pH, alkalinity, dissolved oxygen

The water samples were collected in Nalgene polypropylene copolymer centrifuge tubes. They were analyzed the same day for fluoride using an Orion 4-star meter and fluoride ion selective electrode, with TISAB III added to the sample just before analysis (APHA, 1998). The fluoride ion selective electrode was calibrated by creating calibration curves using 1 and 10 mg F^{-} L^{-1} standards or 0.1 and 1 mg F^{-} L^{-1} standards, depending upon the concentration of the sample, with the electrode calibrated every eight to ten samples to maintain an accuracy within 5%. The accuracy of the calibration curve was also checked with 5 mg F^{-} L^{-1} standard for the higher range calibration curve, and 0.5 mg F^{-} L^{-1} for the lower range calibration curve. The majority of samples, including those from all boreholes and open wells with fluoride concentrations above 2.5 mg L^{-1}, were analyzed again at the Desert Research Institute in Reno, Nevada using a new fluoride ion selective electrode. The repeat analysis was done to confirm accuracy within 5%. The pH was measured immediately upon collection using a