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Prevalence of microbiological contaminants in groundwater sources and risk factor assessment in Juba, South Sudan

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HIGHLIGHTS

- Of 147 water sources, 66%, including 95 boreholes, contained thermotolerant coliforms.
- Statistically, fecal pollution was associated with cumulative long-term rainfall.
- It was also linked to topography and on-site hygiene, however less significantly.
- The results indicated that the contributing groundwater was contaminated.
- The near presence of latrines was not associated with fecal contamination.

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ABSTRACT

In low-income regions, drinking water is often derived from groundwater sources, which might spread diarrheal disease if they are microbiologically polluted. This study aimed to investigate the occurrence of fecal contamination in 147 improved groundwater sources in Juba, South Sudan and to assess potential contributing risk factors, based on bivariate statistical analysis. Thermotolerant coliforms (TTCs) were detected in 66% of the investigated sources, including 95 boreholes, breaching the health-based recommendations for drinking water. A significant association ($p < 0.05$) was determined between the presence of TTCs and the depth of cumulative, long-term prior precipitation (both within the previous five days and within the past month). No such link was found to short-term rainfall, the presence of latrines or damages in the borehole apron. However, the risk factor analysis further suggested, to a lesser degree, that the local topography and on-site hygiene were additionally significant. In summary, the analysis indicated that an important contamination mechanism was fecal pollution of the contributing groundwater, which was unlikely due to the presence of latrines; instead, infiltration from contaminated surface water was more probable. The reduction in fecal sources in the environment in Juba is thus recommended, for example, through constructing latrines or designating protection areas near water sources. The study results contribute to the understanding of microbiological contamination of groundwater sources in areas with low incomes and high population densities, tropical climates and weathered basement complex environments, which are common in urban sub-Saharan Africa.

1. Introduction

Improving water supply, sanitation, hygiene and management of water resources could prevent almost one-tenth of the global disease burden (Prüss-Üstün et al., 2008). In low-income countries, it has been estimated that 80% of all illness is related to water (Tebbutt, 1998). The primary cause of waterborne disease is microbiological contamination (Villanueva et al., 2014), and the most important microbial risks are associated with ingestion of fecally contaminated water, according to the World Health Organization (WHO) (2011). The United Nations (UN) has set a target of increasing access to safe drinking water, drawn from improved sources, and in low-income regions improved sources often derive from groundwater, such as protected wells and boreholes (Graham and Polizzotto, 2013). Pedley and Howard (1997) estimated that 80% of the residents of rural and peri-urban areas in developing countries rely on groundwater sources for drinking-water. However, the use of groundwater-fed sources has

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been linked to outbreaks of fatal diarrheal disease (Beller et al., 1997; Dalu et al., 2011; Howard et al., 2002; Nasinyama et al., 2000). Graham and Polizzotto (2013) argued that the ability to make informed decisions about water and sanitation is largely limited by a scarcity of data, especially regarding the effects of environmental conditions on contamination. It is thus imperative to better investigate the incidence and causes of microbial contamination of groundwater sources.

Previous studies have assessed groundwater sources located in rural regions in the Sahelian region of Burkina Faso (Guillemin et al., 1991); two districts of Conakry, Guinea (Gélinas et al., 1996); peri-urban areas in Kampala, Uganda (Howard et al., 2003) and Harare, Zimbabwe (Dalu et al., 2011); and rural, northern Malawi (Kanyerere et al., 2012). All of these studies reported that fecal coliforms were present in at least one of the investigated sources. However, in most parts of sub-Saharan Africa there is still a knowledge gap regarding the processes that affect the transport and occurrence of fecal pollution in the aquifers (Nyenje et al., 2013). The relative importance of different contamination mechanisms in various socioeconomic and hydrogeological environments must be better specified.

In Sudan, incidences of acute watery diarrhea occur in thousands every year, and outbreaks of cholera, specifically, took place yearly from 2006 to 2009 and in 2014, as reported by the WHO (2014). In South Sudan, an independent country since 2011, the background risk for diarrhea is remarkably high, especially for small children, according to the WHO (2014). The Southern Sudan Household Health Survey (2006) reported that 42.9% of children under five years of age in the country had been afflicted with diarrhea during the two weeks preceding the survey. There is currently (as of 1 September 2014) a cholera outbreak in South Sudan, ongoing since May 2014, when it was declared an outbreak by the Ministry of Health, Republic of South Sudan, and the National Bureau of Statistics (2010). As of 24 August 2014, a total of 5981 cases (including 132 deaths) have been reported in the country, as communicated by the United Nations Office for the Coordination of Humanitarian Affairs (UNOCHA) (2014). Evaluating the cholera outbreak in 2005–2006, Karsany et al. (2012) argued that cholera remains a threat to Sudan. They recommended that water supplies, both official and unofficial, be tested continuously to detect pathogens. The spreading of water-related infectious diseases has been linked to the ingestion of unsafe water, among other factors (Batterman et al., 2009).

Juba, the capital of South Sudan, suffers from segregation and high-density, low-income populations that lack access to appropriate infrastructure, clean water and sanitation, as reported by the United States Agency for International Development (USAID) (2005). Juba has recently experienced rapid population growth, related mainly to the conflict between the Sudanese Armed Forces and the Sudan Peoples' Liberation Army, and the subsequent arrival of large numbers of internal refugees: its population more than tripled in 15 years, from 115,000 in 1993 to 372,000 in 2008, based on data from USAID (2005, 2010). USAID (2005) estimated that more than a third of the population (86,000 of 250,000) occupied squatter housing in 2005. Only 2.1% of South Sudanese households had water on the premises in 2010, as reported by the South Sudan Household Health Survey (2010). The Japan International Cooperation Agency (JICA) (2009a) stated that most of the population in Juba relies on public wells or water tankers, the latter of which often distribute raw river water which is not considered suitable for human consumption.

In 2010, the humanitarian aid organization Médecins Sans Frontières (MSF) evaluated the microbiological water quality of 153 groundwater-fed drinking water sources in Juba. The sources comprised boreholes and protected, hand dug wells and were thus considered improved. The study focused on the incidence of thermotolerant coliforms (TTCs), which are considered acceptable indicators of fecal pollution by WHO (2011). According to WHO (2011), TTC populations are composed predominantly of the recommended fecal indicator *Escherichia coli* (*E. coli*) in most environments. The results from the study conducted by MSF are presented and analyzed in this paper. The objective is to map the prevalence of fecal contamination and to assess possible contributing risk factors, including source-site characteristics and precipitation prior to sampling. This study will contribute to the development of guidelines relating to the reduction of water quality vulnerability to fecal contamination in the type of hydrogeological and socioeconomic environments found in Juba. The study will provide a basis for a discussion around possible mitigation measures, contingency planning and siting of future water sources.

2. Methods

2.1. Study area

South Sudan is located in sub-Saharan Africa, close to the Equator. It borders Ethiopia to the east, Kenya, Uganda and the Democratic Republic of the Congo to the south, Sudan to the north and the Central African Republic to the west. The climate is tropical with a drier season from around November to March, followed by a rainy season from around April to October. Juba is situated in an alluvial plain that slopes in the southwest-to-northeast direction, from the foothills of Mount Jebel Kujur in the west, towards the river Bahr-el-Jebel (White Nile) in the east. The study focused on the least-developed parts of Juba, the investigated sources being scattered mainly over the municipal subdivisions Juba Town, Munuki, Kator and Lologo.

2.2. Water sampling

Water was sampled from 153 improved water sources, including 151 boreholes and two protected hand-dug wells, amounting to approximately one third of the city's hand pumps. They were primarily located based on a list from the Directorate of Rural Water and Sanitation Development in South Sudan. Sampling was conducted during the rainy season, from April 6th to October 29th 2010, a period covering nearly seven months. The project aimed at investigating 150 sources twice each, with three months between the samples; however, due to logistical and equipment constraints some of them could only be visited once (23). Two samples of water were collected on every visit (a particular source and date). Additional visits were made if the results of the two visits deviated or if there were uncertainties regarding the identity of the investigated borehole. A maximum of eight boreholes were sampled per day. A total of 359 visits were conducted on 77 unique dates.

Each sample was collected from the hand pump taps into a sterile sample sachet. Before sampling, the mouth of the tap was disinfected by heating it with a lighter. To wash out deposits in the pipe, the water was run for at least one minute before sampling. The sachets were placed in a cold chain and transported to a laboratory within six hours, where the testing process started instantly. Most samples contained 100 ml of water; in the remaining cases the turbidity would have prevented accurate colony counting and the volumes were reduced, though they remained at levels $\geq$10 ml.

2.3. Source site inspections

The following site-specific characteristics were recorded at the time of the sampling: the drainage efficiency, the on-site hygiene, the presence of latrines and the local topography (Table 1). The drainage efficiency reflected damages in the borehole apron or drainage channel, whereas the on-site hygiene represented the cleanliness around the borehole, indicating the presence of littering, ponding or rearing animals. The drainage efficiency and the local topography thus accounted for microbiological transport pathways, either at the manufactured water source or from hydrogeological transport processes in its vicinity. On-site hygiene and latrine presence are related to the possible effects of local sources of contamination.