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Review

Seasonal variation of fecal contamination in drinking water sources in developing countries: A systematic review

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HIGHLIGHTS

- A significant seasonal trend of greater contamination occurs during the wet season.
- The trend was found across source types, climate zones, and population settings.
- Sampling guidelines can improve estimates of global access to safe drinking water.

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ABSTRACT

Accounting for fecal contamination of drinking water sources is an important step in improving monitoring of global access to safe drinking water. Fecal contamination varies with time while its monitoring is often infrequent. We sought to understand seasonal trends in fecal contamination to guide best practices to capture seasonal variation and ascertain the extent to which the results of a single sample may overestimate compliance with health guidelines. The findings from 22 studies from developing countries written in English and identified through a systematic review were analyzed. Fecal contamination in improved drinking water sources was shown to follow a statistically significant seasonal trend of greater contamination during the wet season ($p < 0.001$). This trend was consistent across fecal indicator bacteria, five source types, twelve Köppen–Geiger climate zones, and across both rural and urban areas. Guidance on seasonally representative water quality monitoring by the World Health Organization and national water quality agencies could lead to improved assessments of access to safe drinking water.

Contents

Abbreviations: BME, Bayesian Maximum Entropy; DHS, Demographic and Health Survey; JMP, Joint Monitoring Programme for Water Supply and Sanitation; MDG, Millennium Development Goal; UN, United Nations; UNICEF, The United Nations Children's Fund; WHO, the World Health Organization

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1. Introduction

Global access to safe drinking water is tracked by the Joint Monitoring Programme for Water Supply and Sanitation (JMP) of the WHO and UNICEF as the proportion of the population using an improved drinking water source. An improved source is one that, "by nature of its construction, adequately protects the source from outside contamination, particularly fecal matter" (WHO/UNICEF, 2013) (Table 1). This indicator is a proxy for safety and does not account for actual contamination. This is a notable shortcoming as 'safe drinking water' is defined by the WHO as water "which does not represent any significant risk to health over a lifetime of consumption" (WHO, 2011), and fecal contamination is considered to be the main threat to public health (WHO/UNICEF, 2010). A systematic review found that 38% of water quality studies of improved sources in low-income regions report at least a quarter of water samples to contain fecal contamination (Bain et al., 2014a). When accounting for fecal contamination, estimates suggest that more than 1.8 billion people consume drinking water from a contaminated source (Bain et al., 2014b; Wolf et al., 2013; Onda et al., 2012). As such, monitoring of fecal contamination is considered by the JMP to be one of the next steps in improving global monitoring of access to safe drinking water (WHO/UNICEF, 2010).

Fecal contamination of drinking water is monitored using fecal indicator bacteria (FIB) (WHO, 2011). *Escherichia coli* (*E. coli*) is currently recognized by the WHO and the JMP as the best FIB for monitoring fecal contamination of drinking water and thermotolerant coliforms (TTC) are suggested as an acceptable alternative (WHO, 2011; WHO/UNICEF, 2010). The WHO guideline value for *E. coli* in drinking water is "none detectable in any 100-ml sample" (WHO, 2011). In the United States, the Safe Drinking Water Act requires drinking water systems to be analyzed for total coliforms between once a month for the smallest systems and 480 times per month for the largest. All positive samples must then be tested for the presence of *E. coli* or TTC (Federal Register, 1989). Due to limited resources, especially affecting developing countries, this level of sampling is not always achievable. Instead FIB monitoring is often conducted using one-off or infrequent sampling, with up to a few samples each year (WHO/UNICEF, 2010). Unrepresentative sampling timing could impair the accuracy of fecal contamination estimates in these areas, as it is possible for FIB to be present only during occasional contamination events since microbial contamination varies with time and FIB generally do not survive longer than four to twelve weeks (Edberg et al., 2000).

Of particular concern is sampling during only one season. 'Season' can refer to either astronomical divisions of the year (winter, spring, summer, autumn) or to divisions based on climatic periods (e.g., wet season(s), dry season). Within the context of this review 'season' refers to wet and dry seasons. Seasonal variation of fecal contamination is an issue because although water quality is thought to usually be worse during the wet season (WHO/UNICEF, 2010) drinking water surveys, like household surveys (Wright et al., 2012), are often conducted in the dry season for logistical reasons such as accessibility of areas with unpaved roads. An understanding of seasonal trends in fecal contamination could help shape guidelines for sampling plans to decrease the chance of inaccurate and misleading fecal contamination data and enhance interpretation of available data. A known effect size in any trends (i.e., by how much does the contamination vary) could be used to assess the representative nature of past data if the sampling periods of that data are also known. While previous studies have shown that water quality parameters in surface waters (Ouyang et al., 2006) as well as some unimproved drinking water sources in developing countries (Wright, 1986) follow seasonal patterns, no review has been conducted on the general seasonal trend of fecal contamination in improved drinking water source types in developing countries.

The aim of this study is to systematically review studies on seasonal variation in fecal contamination of improved sources of drinking water in developing countries with a view to better understanding the prevailing (seasonal) trends.

Table 1
Classification of drinking water source types according to the WHO/UNICEF Joint Monitoring Programme (WHO/UNICEF, 2014).

Improved drinking water sources	• Piped water into dwelling, yard or plot • Public tap or standpipe • Tubewell or borehole • Protected dug well • Protected spring • Rainwater collection
Unimproved drinking water sources	• Unprotected dug well • Unprotected spring • Cart with small tank or drum • Tanker truck • Surface water (river, dam, lake pond, stream, canal, irrigation channel) • Bottled water[a]

[a] Bottled water is considered unimproved if the household does not use drinking-water from an improved source for cooking and personal hygiene (WHO/UNICEF, 2014).

2. Methods

This analysis of studies reporting seasonal variation (e.g., rainfall season) in fecal contamination of improved drinking water sources in developing countries was based on a systematic review published elsewhere (Bain et al., 2014a). This systematic review was conducted in adherence with Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA), a set of guidelines designed to improve reporting of systematic reviews and meta-analyses (Moher et al., 2009).

2.1. Data sources

Studies relevant to the topic of seasonal variation in contamination were retrieved from Bain et al. (2014a), which examined fecal contamination (TTC and *E. coli*) of drinking water at the point of collection (i.e., water sampled directly at the water source) in developing countries and created a drinking water quality database of 319 studies. The search method and inclusion criteria for the study are published elsewhere (Bain et al., 2014a).

Studies were included in this review provided they: were written in English; separately reported on sources that could be classified as