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Faecal contamination of household drinking water in Rwanda: A national cross-sectional study

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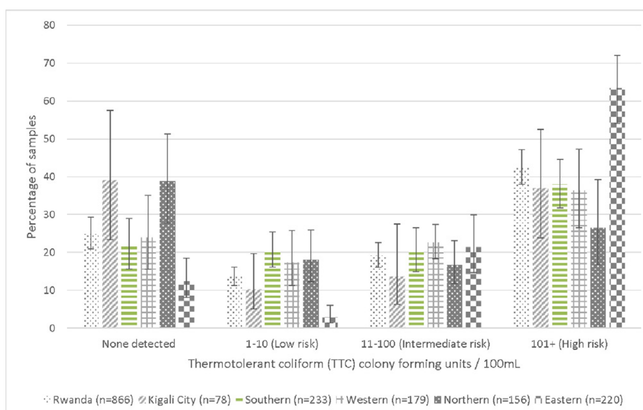
HIGHLIGHTS

- Nationally representative study of household drinking water quality in Rwanda
- More than 75% of houses had detectable TTC contamination in their drinking water
- Houses using surface compared to other sources had highest odds of TTC contamination
- Houses not using piped or rain/bottle sources had increased odds of TTC contamination
- Extreme rain, elevation and open waste dumping were risk factors of TTC contamination

GRAPHICAL ABSTRACT



Household drinking water quality (thermotolerant coliform colony forming units/100 mL) nationally and by province with 95% confidence intervals.

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ABSTRACT

Unsafe drinking water is a leading cause of morbidity and mortality, especially among young children in low-income settings. We conducted a national survey in Rwanda to determine the level of faecal contamination of household drinking water and risk factors associated therewith. Drinking water samples were collected from a nationally representative sample of 870 households and assessed for thermotolerant coliforms (TTC), a World Health Organization (WHO)-approved indicator of faecal contamination. Potential household and community-level determinants of household drinking water quality derived from household surveys, the 2012 Rwanda Population and Housing Census, and a precipitation dataset were assessed using multivariate logistic regression. Widespread faecal contamination was present, and only 24.9% (95% CI 20.9–29.4%, $n = 217$) of household samples met WHO Guidelines of having no detectable TTC contamination, while 42.5% (95% CI 38.0–47.1%, $n = 361$) of samples had >100 TTC/100 mL and considered high risk. Sub-national differences were observed, with poorer water quality in rural areas and Eastern province. In multivariate analyses, there was evidence for an association between detectable contamination and increased open waste disposal in a sector, lower elevation, and water sources other than piped to household or rainwater/bottled. Risk factors for intermediate/high risk

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contamination (>10 TTC/100 mL) included low population density, increased open waste disposal, lower elevation, water sources other than piped to household or rainwater/bottled, and occurrence of an extreme rain event the previous day. Modelling suggests non-household-based risk factors are determinants of water quality in this setting, and these results suggest a substantial proportion of Rwanda's population are exposed to faecal contamination through drinking water.

1. Introduction

Globally, an estimated 1.25 million deaths and 75 million disability-adjusted life years (DALYs) are attributable annually to obtaining water from unsafe sources (Forouzanfar et al., 2015). Most of the deaths are from diarrhoea, especially among young children exposed to faecal contamination in drinking water (Prüss-Ustün et al., 2014). In Rwanda, unsafe water is currently ranked third as a risk-factor for disease (Forouzanfar et al., 2015), and diarrhoea is a leading cause of mortality in children under 5, accounting for an estimated 9% of overall deaths (Liu et al., 2014).

While the UN celebrated the achievement of the Millennium Development Goal (MDG) for water in 2012, unsafe drinking water is still the eighth leading risk factor for disease globally (Forouzanfar et al., 2015). An estimated 663 million people do not have access to an improved drinking water source (defined to include piped water to the dwelling, plot or yard, as well as public taps/standpipes, tubewells or boreholes, protected dug wells, protected springs, and rainwater collection) (WHO/UNICEF, 2015a). However, water from improved water sources is not necessarily free of faecal contamination (Bain et al., 2014b; Shaheed et al., 2014), with an estimated 1.8 billion people using a source that has faecal contamination, particularly in Africa (Bain et al., 2014a). Moreover, in these hygiene-challenged environments, even water that is safe at the source frequently becomes contaminated from faecal pathogens during collection, transport and storage in the home (Trevett et al., 2005; Wright et al., 2004).

Furthermore, safe water source coverage is not always equitable. Subnational inequalities, including urban and rural differences and differential access to types of improved water sources such as piped water are commonplace (Bain et al., 2014c; Fuller et al., 2015; Luh et al., 2013; Pullan et al., 2014; Yu et al., 2014). In Rwanda, 76% of the population has access to an improved drinking water source, with 9% having access to piped water onto premises. However, while 85% of the urban population has access to improved drinking water sources including 28% having access to water piped onto premises, access for the rural population is only 57% and 2% respectively ((NISR) and (MINECOFIN), 2014).

With the adoption of the Sustainable Development Goals and specifically Target 6.1 of achieving universal and equitable access to safe and affordable drinking water for all by 2030, there is a need to incorporate water quality testing at sources and households (WHO/UNICEF, 2015b). In cooperation with the Rwanda Ministry of Health and DelAgua Health Rwanda—a private company distributing water filters and cookstoves financed by carbon credits (Barstow et al., 2014)—we conducted a national cross-sectional study to assess the faecal contamination of drinking water at the household level. In addition to testing water quality, potential risk factors for water quality were assessed at a household level and analyzed along with potential community-level determinants.

2. Materials and methods

2.1. Study setting

The study was conducted in all five provinces and 30 districts of Rwanda from 22 February to 4 April 2015, which included dry and rainy periods. In general, Eastern and Southern provinces are relatively drier and warmer compared to Northern and Western provinces, with increasing elevation and hilly terrain moving east to west. While most of the country is rural, Kigali City province is predominantly urban.

2.2. Sample size calculation

The primary outcome of interest was a national estimate of faecal contamination of drinking water at the household level. For this purpose, we used thermotolerant coliforms (TTC), a WHO-approved indicator of faecal contamination (WHO, 2011). We used a Monte Carlo simulation in order to generate within-village variance and between-village variance estimates necessary for sample size calculations (Chakraborty et al., 2009). Based on previously collected water quality data from Rwanda (Rosa et al., 2014b), we estimated an average within-village proportion of households with TTC-free drinking water of 40%, with a range of 0% to 100% as parameters for the simulation, as well as average size of a village and variation in size of villages based on a national database (Rwanda Ministry of Local Government, 2011). The variance components and intra-cluster correlation (ICC) were averaged across 1000 simulation runs to yield an ICC of 0.248, a within-village variance of 0.173 and a between-village variance of 0.057. Using the within-village and between village variance outputs from the simulation, we then calculated sample size. Setting a constant of 6 households to be sampled per village due to logistical considerations, we estimated a total of 144 villages ($n = 864$ households) would be required to generate a national-level estimate of faecal contamination in household water quality with 90% confidence with a 10% relative precision. One additional village was added to buffer against potential sample loss.

2.3. Sample selection

To construct a nationally representative sample of households, a stratified two-stage cluster sample design was developed. Prior to sample selection, the population was stratified by geographic district ($n =$ 30 districts) and urban/rural status. Within each district, households were designated as urban or rural according to the village's urban or rural classification by the Rwanda Housing Authority Urban Status Final Report (RHA, 2012). As the intention was to have a binary indicator of urban status, peri-urban households were classified as urban households in the sample allocation. Proportional allocation was used to determine a stratum-specific sample size based on the number of urban and rural households in each district derived from the 2012 national *ubudehe* database, which includes head of household names for each village (Rwanda Ministry of Local Government, 2011). In the first sampling stage, villages were randomly sampled from each stratum with probability proportional to estimated size (number of households). In the second stage, 6 primary households were randomly selected per village. Backup households were randomly pre-selected prior to data collection in case enumerators were unable to locate a primary household or the household member declined to participate. Community health workers were consulted prior to initiating surveys within a village in order to confirm the residency status and location of randomly selected households.