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IJHEH-13092; No. of Pages 10
ARTICLE IN PRESS
International Journal of Hygiene and Environmental Health xxx (2017) xxx–xxx
Contents lists available at ScienceDirect
International Journal of Hygiene and Environmental Health
journal homepage: www.elsevier.com/locate/ijheh

Use, microbiological effectiveness and health impact of a household water filter intervention in rural Rwanda—A matched cohort study

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ARTICLE INFO

Article history:
Received 28 February 2017
Received in revised form 29 May 2017
Accepted 29 May 2017

Keywords:
Household water treatment
Water quality
Faecal contamination
Rwanda

ABSTRACT

Unsafe drinking water is a substantial health risk contributing to child diarrhoea. We investigated impacts of a program that provided a water filter to households in rural Rwandan villages. We assessed drinking water quality and reported diarrhoea 12–24 months after intervention delivery among 269 households in the poorest tertile with a child under 5 from 9 intervention villages and 9 matched control villages. We also documented filter coverage and use. In Round 1 (12–18 months after delivery), 97.4% of intervention households reported receiving the filter, 84.5% were working, and 86.0% of working filters contained water. Sensors confirmed half of households with working filters filled them at least once every other day on average. Coverage and usage was similar in Round 2 (19–24 months after delivery). The odds of detecting faecal indicator bacteria in drinking water were 78% lower in the intervention arm than the control arm (odds ratio (OR) 0.22, 95% credible interval (CrI) 0.10–0.39, $p < 0.001$). The intervention arm also had 50% lower odds of reported diarrhoea among children <5 than the control arm (OR = 0.50, 95% CrI 0.23–0.90, $p = 0.03$). The protective effect of the filter is also suggested by reduced odds of reported diarrhoea-related visits to community health workers or clinics, although these did not reach statistical significance.

1. Introduction

Unsafe drinking water and household air pollution are two significant environmental health risks and contribute to diarrhoea and pneumonia, two major causes of death for children under 5 years of age (GBD 2015 Risk Factors Collaborators, 2016; Liu et al., 2014; Prüss-Ustün et al., 2014). In 2011, an estimated 700,000 deaths among children under 5 were due to diarrhoea (Fischer Walker et al., 2013b). In Rwanda, diarrhoea is a leading contributor to mortality in children under 5 years and is second after pneumonia, accounting for 9% of deaths in this age group (Liu et al., 2014), and unsafe water is estimated to be the third leading risk factor for overall disease (GBD 2015 Risk Factors Collaborators, 2016).

The 2014–2015 Rwanda Demographic and Health Survey estimated 27.6% of the population use unimproved drinking water sources, with the majority residing in rural areas (National Institute of Statistics of Rwanda (NISR) et al., 2015). Access to improved water sources does not necessarily result in consumption of safe drinking water since not all improved sources are free of microbiological contamination (Bain et al., 2014). Moreover, since water is often collected and stored within the household after collection, additional contamination can occur during transit and storage (Wright et al., 2004). A recent nationally representative study in Rwanda found that more than 75% of households had drinking water with detectable thermotolerant coliforms (TTC), exceeding World Health Organization (WHO) guidelines for drinking water (Kirby et al., 2016; WHO, 2011).

There is increasing evidence that household drinking water quality is a determinant of diarrhoea (Hodge et al., 2016; Luby et al., 2015), and efforts to improve drinking water quality, such as by using filters, may reduce diarrhoea (Clasen et al., 2015; Wolf et al., 2014). Household water treatment is recommended by the WHO as an intermediate step towards ensuring safe drinking water supply and is part of a 7-point plan for comprehensive diarrhoea control (UNICEF/WHO, 2009; WHO, 2007). However, most of the studies to date have been short-term studies and use of interventions

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http://dx.doi.org/10.1016/j.ijheh.2017.05.013
1438-4639/

Please cite this article in press as: Kirby, M.A., et al., Use, microbiological effectiveness and health impact of a household water filter intervention in rural Rwanda—A matched cohort study. Int. J. Hyg. Environ. Health (2017), http://dx.doi.org/10.1016/j.ijheh.2017.05.013

can change over time (Hunter, 2009). A recent systematic review and meta-analysis found that while shorter-term (<12 months) trials yielded protective effects from household water treatment interventions, none of the four trials with follow-up exceeding 12 months reported an effect on diarrhoea (Clasen et al., 2015). This could be due to a combination of declining usage over time, as well as non-exclusive use of the filter for consumption of drinking water. Moreover the health impact among non-blinded trials may be exaggerated due to reporting bias (Clasen et al., 2015). There is a lack of evidence regarding the long-term effectiveness of these technologies, particularly within a programmatic, scalable context.

In October 2012, a public-private partnership between the Rwanda Ministry of Health and DelAgua Health provided portable biomass-burning "rocket" cookstoves and household water filters to all households (1943) in 15 villages located in 11 of Rwanda's 30 districts. The intervention was distributed at a central location within each village and accompanied by behaviour change messaging and monitoring conducted by trained community health workers (CHWs) through quarterly-biannual visits (Barstow et al., 2014). A 5-month household randomized controlled trial (RCT) was conducted in three of the villages to assess the intervention's impact on household drinking water quality and household air pollution. The trial showed high uptake of the filter and was associated with a 97.5% reduction in TTC in drinking water despite non-exclusive use (Rosa et al., 2014b; Thomas et al., 2013a). However, the study did not assess health impact, and evidence for the sustained uptake and effectiveness of the intervention outside of a short-term intensive trial remains unclear.

We undertook a matched-cohort study to assess medium-term uptake of the filter 12–24 months after intervention receipt in order to determine its impact on faecal contamination of drinking water in the home and child diarrhoea. We used a matched cohort design since the intervention was pre-existing and was not randomly allocated to households or villages. The matched cohort design seeks to minimise the risk of unmeasured confounders by matching on characteristics likely to impact outcomes of interest (Austin, 2011; Stuart, 2010). This design has been used in other studies of pre-existing interventions where randomization is not possible (Arnold et al., 2009, 2010; Ercumen et al., 2015a).

2. Materials and methods

2.1. Village selection and matching

This study was based in the Southern and Western provinces of Rwanda, where most of the study population are engaged in agriculture. The setting is primarily rural, with study villages ranging from 1400 to 2500 m in elevation. The area experiences two rainy seasons, with the "short rains" typically in September, October, November and December, and the "long rains" typically in March, April and May (Rwanda Meteorology Agency, 2016). Of the 15 villages that received the intervention in October 2012, nine were purposely selected for follow-up in this study. Three of the original 15 villages were excluded due to the previous RCT (Rosa et al., 2014b), and 3 were excluded due to low number of estimated eligible households and programmatic development activities.

Village-level matching was performed using a combination of restriction, propensity score matching, and rapid assessment (Arnold et al., 2009, 2010). Intervention villages were first exact matched to non-bordering potential control villages within the same health centre catchment area (sub-district). A post-intervention structured phone survey was then conducted in July 2013 and administered to one CHW from all intervention and potential control villages. The phone survey contained categorical questions on cooking and drinking water practices within the village, including drinking water sources and household water treatment methods, which the CHW answered as percentages by estimation. Additionally, pre-intervention household survey data from the nine intervention villages, originally collected by village CHWs for programmatic purposes in October 2012, were aggregated by village for additional matching to the indicators collected by the phone survey. Finally, the 2012 National *Ubudehe* Database was accessed to obtain the proportion of households and average household size by *ubudehe* category for each village (Rwanda Ministry of Local Government, 2011). *Ubudehe* categories are based on socioeconomic designations for each household by the Rwanda government in collaboration with community members. There are six *ubudehe* categories, with *ubudehe* 1 and 2 households comprising approximately the poorest 30% of the population.

Village-level data were thus combined from the above three sources. For intervention village-level data, characteristics likely to change due to the intervention, such as water treatment and cooking practices, were derived from the DelAgua household survey since it assessed these practices prior to receipt of the intervention. All other village-level characteristics were derived for intervention and control villages from the CHW phone survey and National *Ubudehe* Database. Potential control villages were restricted based on the implementer's original intervention village selection criteria which was intended to represent a typical rural village's water service and energy use (Barstow et al., 2014). Villages were restricted if more than 20% of households had piped water, more than 60% used water treatment other than boiling, more than 20% used cooking fuel other than biomass or charcoal, or more than 20% used a non-traditional stove (Barstow et al., 2014). After restriction, the pool of potential control villages for each intervention village ranged from 6 to 61 (mean = 23 villages).

Propensity score matching using probit regression was then conducted using different combinations of the village-level covariates described above, given their potential relationship to drinking water quality and household air pollution which were the primary outcomes of interest (Brookhart et al., 2006). The mean bias of each fitted model was examined in an iterative process across the range of potential matching variables in order to obtain optimal covariate balance for all available covariates between arms (Imbens and Rubin, 2015). Using the propensity score from the optimal model, each intervention village was then matched to a control village within the same health centre catchment area using the nearest neighbour method (Austin, 2009; Rosenbaum and Rubin, 1985). Propensity score matching was performed using the Stata add-on package PSMATCH2 (Leuven and Sianesi, 2003).

Lastly, a rapid assessment was conducted in each of the selected control villages after visiting its respective intervention village. The rapid assessment consisted of a transect to qualitatively observe similarity to its paired village, and an in-person meeting between the staff supervisor and village's chief and CHWs. During the in-person meeting, the supervisor confirmed key variables used in the matching, including estimated total number of households, children under 5 years of age, percent of households using improved water supply, primary household fuel type, primary household stove type, household cook times, and water treatment practices. Additionally, the chief and CHWs were asked to describe any changes in the village since October 2012 that could affect the primary and secondary outcomes.

2.2. Enrolment and eligibility

Households were enrolled and visited once between November 2013 and May 2014 (Round 1) and visited a second time between May 2014 and November 2014 (Round 2). The first household visit attempt at each round was unannounced. In each village, we enrolled all consenting households with a child under 5 years of