Short Communication

Does the source of water for piped supplies affect child health? Evidence from rural Vanuatu

Tim Foster, Emily Rand, Erie Sami, Brieana Dance, Jeremy Kohlitz and Juliet Willetts

ABSTRACT

Piped water systems are considered to provide the highest service level for drinking water supplies; however, global monitoring of safe water access pays little attention to the type of water source that piped systems draw upon, even if the water is not treated prior to distribution. This study sought to understand whether the source of water for untreated piped supplies influences the prevalence of diarrhoea among children in rural Vanuatu. The analysis was based on a dataset integrating a Demographic and Health Survey and a nationwide water supply inventory. After adjusting for a range of potential confounders, the results revealed a significant association between diarrhoea and the type of water source supplying a piped system. Compared with borehole-supplied piped systems, spring-fed piped systems were significantly associated with increased odds of diarrhoea (adjusted odds ratio [AOR] 5.8, 95% confidence interval [CI] 1.1–31, $p = 0.040$). No significant association between diarrhoea and piped systems drawing on surface water was observed. Increased odds of diarrhoea were significantly associated with water supply systems constructed prior to the year 2000 (AOR 4.9, 95% CI 1.9–13, $p = 0.001$). The results highlight the need for improvements in spring protection as well as ongoing maintenance and periodic renewal of water supply infrastructure.

Key words | child health, diarrhoeal disease, rural water supply, Sustainable Development Goals, Vanuatu, water quality

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INTRODUCTION

Piped water systems are considered to provide the highest service level for drinking water supplies. This is reflected in monitoring frameworks and national policy objectives, and is implicitly supported by the safely managed water service indicator under Sustainable Development Goal (SDG) target 6.1, which is predicated on water being available on the premises. There is strong evidence that access to piped water is associated with improved health, particularly a reduced risk of diarrhoeal disease (Overbo *et al.* 2016; Wolf *et al.* 2018). However, neither research nor global monitoring has typically distinguished between piped services based on the water source from which they draw. This may matter little for piped water systems with treatment prior to distribution; however, it may have major implications for piped systems supplying raw (untreated) water, as is often the case in rural areas of low- and middle-income countries. To illustrate the point, a piped water supply drawing on surface water might formally be classified as a high service level, even if the raw water it provides is from the same source that is presumed to be highly

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unsafe when collected manually. The importance of this issue is underscored by findings from a systematic review that observed higher rates of contamination when piped systems lacked treatment (Bain *et al.* 2014).

This study sought to understand whether the source of water for untreated piped supplies influences diarrhoeal disease among children. The assessment focussed on rural areas of Vanuatu, a middle-income country in the South Pacific where diarrhoeal disease accounts for around 6% of child deaths (Carter *et al.* 2016). Small-scale piped schemes that supply untreated water are common in rural areas of Vanuatu. Forty percent of rural households obtain drinking water from piped systems, either from a private connection or public tap (VNSO 2017). As with many other countries, Vanuatu's safe water access estimates are derived from censuses and nationally representative household surveys that do not establish the source of this piped water. In contrast, Vanuatu's national inventory of rural water supply infrastructure does comprise information on the type of water source that piped systems draw upon. Of the almost 500 rural piped water systems, 32% are supplied from surface water, 54% from springs and 14% from groundwater via boreholes or dug wells.

METHODS

This investigation assessed the association between the source of piped water and diarrhoea among children in rural Vanuatu by integrating a nationally representative Demographic and Health Survey (DHS) from 2013 with data from the country's rural water supply inventory collected in 2014–2016. The DHS was a joint effort between Vanuatu's National Statistics office, Ministry of Health, and the Secretariat of the Pacific Community. DHS procedures and questionnaires are reviewed and approved by the ICF Institutional Review Board. Data collection for the national water supply inventory was overseen by the Department of Geology, Mines & Water Resources (DGMWR) of Vanuatu in partnership with UNICEF. Further details on the data collection methodology for both the DHS and the national water supply inventory can be found elsewhere (VNSO & SPC 2014; Mommen *et al.* 2017).

The focus of this assessment was children under 5 years living in rural households whose main source of drinking water was piped onto the premises (i.e. piped into the dwelling, yard or plot). The outcome variable assessed was diarrhoea in the previous 2 weeks, which is a standard diarrhoea-related question included in DHS questionnaires. Where households had more than one child under the age of 5, only the youngest child was included in the analysis to avoid violating the independence of observations assumption underpinning standard regression analysis. Children deemed to be exclusively breastfed were excluded from the analysis and, where possible, were replaced with the next oldest child under the age of 5 living in the same household. The explanatory variable of interest was source of water for the piped scheme (borehole vs. spring vs. surface water), a characteristic that was obtained from the water supply inventory. The DHS did not collect information on whether rainwater collection systems were located on or off premises, and hence, these systems could not be included in the analysis. The data from the household survey and the water supply inventory were matched based on a combination of island name, village name and GPS coordinates.

The analysis controlled for a range of potential confounders, including household wealth, sanitation facility, village-wide open defaecation rate, point-of-use water treatment practices, presence of handwashing facilities, child age, mother's education level, breastfeeding practices and infrastructure age (constructed pre- and post-2000). Data for household-level covariates were drawn from the DHS dataset and infrastructure age was determined from the water supply inventory dataset. The analysis employed generalised estimating equation (GEE) logistic regression in order to adjust for within-village autocorrelation.

RESULTS AND DISCUSSION

For children under 5 years, the analysis included 120 households in 25 villages across 10 islands (Table 1 and Table S1 in the online Supplementary Material). Piped systems pumped groundwater from boreholes in six villages, were fed by springs in eight villages and drew on surface water in 11 villages. Compared with households receiving piped water from a spring or surface water, households relying on a borehole-supplied piped scheme tended to be wealthier, better educated and more likely to treat water before drinking,

Table 1 | Characteristics of sampled households by the source of piped water

	Source of piped water			
	Borehole	**Spring**	**Surface water**	**All sources**
Children <5 years				
Sample size:				
No. villages	6	8	11	25
No. children <5 years	24	40	56	120
Percentage with diarrhoea in previous 2 weeks	8%	25%	14%	17%
Percentage of households with:				
Improved sanitation	58%	85%	64%	70%
Water treated before drinking	54%	33%	36%	38%
Handwashing facilities with soap and water	33%	35%	52%	43%
Mother educated beyond primary school	59%	15%	36%	34%
Child still being breastfed	50%	51%	55%	53%
Wealth index in highest two quintiles	58%	33%	13%	28%
Percentage of villages with:				
No open defaecation	37%	80%	62%	63%
Piped system constructed pre-2000	58%	68%	54%	61%

but they were less likely to have improved sanitation and were located in areas where open defaecation was more common.

The 2-week period prevalence of diarrhoea among children under 5 years was 17% (Table 1). The prevalence of diarrhoea was highest for those receiving spring-fed piped supplies (25%), compared with 14% for those receiving piped supplies drawing on surface water and 8% for those receiving borehole-supplied piped water. The GEE analysis found that the water source supplying a piped scheme had a significant effect on diarrhoea: compared with borehole-supplied systems, piped systems fed by springs were associated with a 5.8-fold increase in the adjusted odds of diarrhoea (95% confidence interval [CI] 1.1–31, $p = 0.040$) (Table 2). No significant association between diarrhoea and piped systems drawing on surface water was observed.

The relationship between spring-fed piped supplies and diarrhoea could have major implications for child health in Vanuatu. More than half of Vanuatu's small piped systems are fed by springs, serving around one quarter of the country's rural population. The inadequate standard of source protection for the spring-fed schemes included in the analysis may be a key reason behind the large effect size observed: of the five systems with information on sanitary conditions, all were deemed to lack sufficient protection. This issue appears to be widespread, with the inventory data suggesting that 59% of spring-fed piped schemes across Vanuatu lack adequate protection at the source. Photographic evidence indicates that spring boxes are not always covered and, in some cases, the spring resembles an open body of surface water by the time it is captured.

Table 2 | Results of GEE analysis assessing the association between the source of piped water and diarrhoea among children under 5 years in rural Vanuatu

	Unadjusted			**Adjusted[a]**		
Source of piped water	**Odds ratio**	**95% CI**	***p*-value**	**Odds ratio**	**95% CI**	***p*-value**
Spring vs. borehole	3.6	0.53–24	0.189	**5.8**	**1.1–31**	**0.040**
Surface water vs. borehole	1.8	0.328–12	0.537	2.7	0.52–14	0.234
Surface water vs. spring	0.50	0.20–1.2	0.136	0.5	0.20–1.1	0.081

CI, confidence interval.
Bold figures indicate statistically significant result.
[a]Adjusted GEE analysis adjusts for household wealth, sanitation facility, point-of-use water treatment practices, presence of handwashing facilities with soap and water, age of child, age of piped water infrastructure, mother's education, village-wide open defaecation rate, and breastfeeding practices.

While borehole-supplied systems were associated with the lowest diarrhoeal disease burden, any ambitions to simply preference these schemes over those supplied by springs or surface water would need to grapple with hydrogeological and financial realities. As it stands, a paucity of hydrogeological information in Vanuatu makes it difficult to appraise the feasibility of exploiting groundwater to a greater extent. Addressing this knowledge gap is an important area for future investigation. Moreover, the logistical challenges and costs associated with transporting drilling equipment between and within islands are significant.

To provide more conclusive results on the health outcomes associated with different sources of piped water, a larger study that also assesses faecal contamination levels is needed. More definitive outcomes would provide guidance as to where and how water quality risks could be most effectively managed. Ideally, the treatment of water prior to distribution might mitigate water quality risks; however, this would also create new operation and maintenance complexities, particularly in light of the remote island context that characterises rural communities in Vanuatu.

Although not the primary purpose of this study, the multivariable analysis highlighted another area that could be targeted to reduce the burden of diarrhoeal disease in Vanuatu. When a piped system was constructed prior to 2000, the adjusted odds of diarrhoea was 4.9 times higher [95% CI 1.9–13; $p < 0.001$] than for schemes constructed after 2000. This may reflect the degraded condition of older schemes, which, in turn, could increase the risk of faecal contamination entering the system. There was insufficient data to confirm this hypothesis for the 25 schemes included in the analysis, but the wider inventory data indicate that piped schemes constructed prior to the year 2000 are in substantially poorer condition than those constructed after this point (Figure S1 in the online Supplementary Material).

The study has a number of limitations. First, a key weakness is the cross-sectional nature of the study, which constrains the degree to which causal relationships can be inferred. Second, DHS questions relating to child diarrhoea rely on mothers' self-reporting and hence may be subject to recall bias and inconsistent interpretations of the case definition of diarrhoea (Boerma *et al.* 1991). Third, although the analysis adjusted for key risk factors for diarrhoeal disease, unobserved confounders (e.g. food preparation and storage) may have still influenced results. Fourth, faecal contamination and incidence of diarrhoeal disease tend to vary seasonally (Naumova *et al.* 2007; Kostyla *et al.* 2015; Levy *et al.* 2016), and hence, the results may not hold for times of the year outside of those captured in this assessment. Fifth, households in rural Vanuatu commonly make use of multiple water sources (Foster & Willetts 2018). This investigation examined households identifying water piped to the premises as their 'main' source of drinking water, but it is possible some households supplemented their piped water with other sources (especially rainwater) at the time of the survey.

The strength of the study lies in the unique dataset created by spatially integrating Vanuatu's most recent DHS with the country's water supply inventory. While use of DHS data to assess the relationship between drinking water and child health is by no means novel (see, e.g., Fink *et al.* 2011), the standard questionnaires underpinning these surveys do not divulge the source of water for piped supplies. This study overcame this limitation by capitalising on a national water supply inventory that was assembled shortly after the DHS data collection. Uniquely, the two datasets were able to be combined because Vanuatu's DHS dataset included village names that could be pinpointed, whereas standard DHS datasets include GPS coordinates for surveyed clusters which are randomly displaced by up to 5 km (Burgert *et al.* 2013).

CONCLUSIONS

This study sought to understand whether the source of water for untreated piped supplies influences the prevalence of diarrhoea among children in rural Vanuatu. The analysis was based on a dataset integrating a nationally representative DHS and a nationwide water supply inventory, and adjusted for a range of potential confounders. The source of water supplying a piped scheme had a significant effect on diarrhoea: compared with borehole-supplied systems, piped systems fed by springs were significantly associated with a 5.8-fold increase in the adjusted odds of diarrhoea. Older water supply infrastructure also exhibited a significant association with diarrhoea. The results point to the need for improvements in spring protection as well as the importance of ongoing maintenance of water supply infrastructure.

Larger studies that also assess faecal contamination levels (and ideally, specific pathogens) are needed to generate more definitive results about the health implications of different water sources for untreated piped supplies. A stronger evidence base will help policymakers and practitioners more effectively target measures to manage water quality risks and accelerate progress towards the SDG target of safe water for all.

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