Child dysentery in the Limpopo Valley: a cohort study of water, sanitation and hygiene risk factors

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ABSTRACT

The objective of this cohort study was to assess risk factors for child dysentery and watery diarrhoea. The study participants consisted of 254 children aged 12–24 months in rural South Africa and Zimbabwe in households where drinking water was collected from communal sources. The main outcome measure was the most severe diarrhoea episode: dysentery, watery diarrhoea or none. For dysentery, drinking water from sources other than standpipes had a relative risk ratio of 3.8 (95% CI 1.5–9.8). Poor source water quality, as indicated by *Escherichia coli* counts of 10 or more cfu $100\,ml^{-1}$, increased risk by 2.9 (1.5–5.7). There were no other significant risk factors for dysentery and none for watery diarrhoea. In this study, endemic dysentery is associated only with faecal contamination of source water. Sources other than standpipes, including improved groundwater, are of greater risk. Remediation of water quality by treatment at source or in the household will be required to achieve access to safe drinking water in accordance with the 7th Millennium Development Goal.

Key words | diarrhoea, dysentery, risk factors, Southern Africa, water microbiology

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INTRODUCTION

Dysentery and watery diarrhoea together account for 2.5 million child deaths per year in developing countries (Kotloff *et al.* 1999; Kosek *et al.* 2003). Epidemics of dysentery are caused by *Shigella dysenteriae* type 1, but endemic dysentery, caused by *S. flexneri* and other enteric bacteria, has a higher mortality rate (Bennish & Wojtyniak 1989; WHO 1994) and greater impact on child growth (Victora *et al.* 1993; Alam *et al.* 2000). Watery diarrhoea, which has a lower case fatality, is caused by a variety of pathogenic protozoa, bacteria and viruses.

Most field studies (Esrey *et al.* 1991; Gundry *et al.* 2004; Fewtrell *et al.* 2005) have combined child dysentery and watery diarrhoea as a single endpoint, ascribing risk to a complex interaction of water quality and quantity, household sanitation and hygiene. As a result, current policy emphasises water source improvements, coupled with better sanitation and hygiene, to reduce this disease burden. The 7th Millennium Development Goal includes: 'Target 10: Halve, by 2015, the proportion of people without sustainable access to safe drinking water and basic sanitation'. To assess progress, the United Nations (2008) 'monitors access to improved water sources based on the assumption that *improved* sources are likely to provide *safe* water' (emphasis ours).

Differences in disease ecologies suggest that it may be possible to distinguish risk factors for dysentery and watery diarrhoea. In this paper, we assess and compare risk factors for the two diseases in children aged 12–24 months in rural southern Africa.

METHODS

Study areas

Our study areas, Vhembe District in South Africa and Zaka District in Zimbabwe, are located on either side of the Limpopo River. Both had high rates of childhood diarrhoeal disease (e.g. in Vhembe in 2002, diarrhoeal incidence for children under 5 years was 224.3 per 1,000 compared with the average for South Africa of 133.4 per 1,000; Health Systems Trust 2003). Neither district was experiencing epidemics of dysentery during the study period 2002/03. Both were below the national averages of 93% for South Africa and 81% for Zimbabwe (Unicef/World Health Organisation 2008) in access to improved water supplies and sanitation (59% for South Africa and 46% for Zimbabwe).

Ethical approval

Free and informed consent of the participating households was obtained and the study protocol was approved by the Research Ethics Committee of the Royal College of Surgeons in Ireland (Ref REC 046).

Selection of households

In each study area, we identified the five health centres with the highest rates of child diarrhoea. From two villages in each clinic catchment we randomly selected 12 households, plus two extras as replacements. Only children from households that had no piped water into the home were recruited for study. Households selected had at least one child aged 12–24 months. We chose this group because children experience the highest diarrhoea rate of any age group at 24% in South Africa (Department of Health and Macro International Inc. 2003) and a high rate of diarrhoea of 20% in Zimbabwe (Central Statistical Office and Macro International Inc. 2007). In addition, by 18 months the majority of children in both countries are no longer breastfed (Department of Health and Macro International Inc. 2003; Central Statistical Office and Macro International Inc. 2007) and they are therefore exposed to pathogens in drinking water. The nature and purpose of the study was explained to participants and consent obtained from the head of each household. In South Africa, 14 extra households, unused as replacements, were retained in the study. The sample size was 254 children/households (South Africa 134; Zimbabwe 120).

Household characteristics

For each household, we collected data about the child, the child's carer, socio-economic status (based on housing type), water source used, water vessels, sanitation and hygiene, including a swab of the carer's hands. We used the swab results as a potential predictor of stored water quality, reflecting the potential for contamination when dipping vessels into containers. Hand swabs were used alongside a question about handwashing to counteract potential recall bias in responses to this question. To take the swab, an enumerator wearing sterile gloves used a sterile cotton bud to swab both the carer's hands, rinsing the swab in a 100-ml bottle of distilled water. This sample was then tested for *Escherichia coli* and total coliforms using the microbiological procedures described below.

Testing water quality

In rural areas, many households change water sources seasonally. In two survey rounds, in dry and wet seasons, we identified four classes of communal water sources in use in the study areas:

I.   Standpipes (where water has been piped from a source remote from the village)

II. Improved groundwaters (protected wells and boreholes)

III. Unimproved groundwaters (unprotected wells and springs)

IV. Surface waters (rivers, canals, streams and dams)

We recorded whether these sources were functioning, fenced for protection against animals and within 50 paces of a latrine. During each round, we sampled each household's source, the storage vessel and the drinking cup used by the child. Collection and testing were in accordance with WHO protocols (WHO 1997). We used the Colilert® system (Covert *et al.* 1989) to enumerate *E. coli* and total coliforms in 500-ml samples. The Colilert method uses chromogenically labelled substrates to give a most probable number estimate of indicator organisms. During preliminary fieldwork, three replicates from each sample were processed to verify the laboratory procedures used. Samples were transported in iced water to laboratories based in the two study districts and processed on the day of collection. For all samples, we used a dilution factor of 10 in Zimbabwe and five in South Africa, reflecting the higher *E. coli* counts found in preliminary samples from Zimbabwe. Sample bottles and quantitrays in the laboratory were identified using bar-codes and results were recorded using hand-held computers (Wright *et al.* 2004).

Monitoring diarrhoea

Mothers or carers recorded daily child diarrhoea across the two seasons using pictorial diaries (Gundry & Wright 2004). Respondents were able to record instances of loose or watery stools on each day using pictures shown on the diary. They were also able to indicate via the diary when the child had passed a bloody or mucoidal stool on a given day. These were checked weekly by trained enumerators in each village. These enumerators were Village Health Workers in

Zimbabwe and well-educated (generally female) members of the community in South Africa. The diaries enabled separate episodes of dysentery and watery diarrhoea to be identified in accordance with WHO guidelines (WHO 1994). To account for temporal variations in water quality and source use, we selected from the whole monitoring period the two fortnights immediately following water testing.

Occurrence of diarrhoea was based on the most severe episode occurring in the fortnight. In other words, where multiple, different episodes of diarrhoea occurred (2.6% of subjects), dysentery was given precedence. The episode was classified as: (a) dysentery (one or more days with at least one mucoid or bloody stool); (b) watery diarrhoea (one or more days of diarrhoea, but without blood or mucus); or (c) no diarrhoea.

Data analysis

Data were analysed using Stata Version 8.2, with robust variance estimation to compensate for the inclusion of two observation periods for the majority of children. Multinomial logistic regression was used to model dysentery and watery diarrhoea as alternative events during each fortnight following water testing. Effects of factors are expressed as relative risk ratios. The relative risk ratio (sometimes called the multinomial odds ratio) is the risk of the outcome in question occurring rather than no outcome. Analysis was stratified by round and country with village defined as the primary sample unit.

RESULTS

Sample size

In South Africa, the headman of one village refused study permission, meaning that all 12 selected households in that village declined to participate and a replacement village was selected. Aside from this village, 98% of households agreed to participate in the study. Two rounds of data collection, a median of 5.4 months apart, gave a maximum possible 508 observations (South Africa 268; Zimbabwe 240). Intermittent water supplies occurred in both rounds preventing source samples being obtained for 93 households. Children therein did not differ in their

experience of diarrhoea from children in households with source sample data ($p = 0.696$, Chi-squared test). Relocation or temporary absence during the observation fortnights resulted in insufficient diarrhoeal data for 111 children, who were on average 2.3 months older ($p = 0.045$) but did not differ in the type of water source or country. After dropping these records, 304 observations (South Africa 160; Zimbabwe 144) were available for analysis.

In the first round, the median age of the children was 18.6 months, with equal proportions of boys and girls. Their nutritional status was not abnormally poor relative to other developing country settings. The prevalence of wasting (weight for height), showing acute malnutrition, was less than 6% and that of stunting (height for age), showing chronic malnutrition, was 18%.

Table 1 shows characteristics of the participating households. In South Africa, 77% of households used improved sources (mainly standpipes), compared with 34% in Zimbabwe (mainly boreholes); 44% of households changed water source between rounds. Water storage vessels were similar in both countries. Only 2% of households treated their water. Households in South Africa were more likely to have sanitation facilities and better quality housing.

Water quality

Faecal contamination, indexed by *E. coli* counts, increased between source and household storage (Table 2). The effect

Table 2 | Number of samples in each category of *E. coli* count for sources and storage vessels, by country, for both survey rounds (*E. coli* counts in children's drinking cups were not significantly different from those in the corresponding households' storage vessels)

E. coli count category	South Africa		Zimbabwe	
	Source	Storage	Source	Storage
0	113	68	54	35
<10	12	19	7	7
10–99.9	15	45	47	57
100–999.9	19	18	22	33
≥1000	1	10	14	12
Total	160	160	144	144

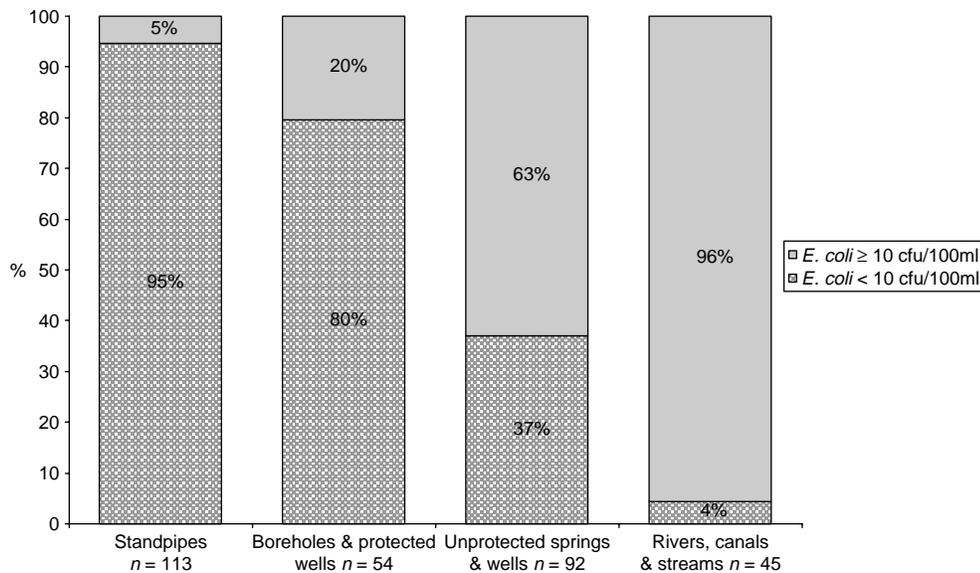was more marked in South Africa where source water was of better microbiological quality.

For the improved sources (classes I and II), 90% of samples had *E. coli* counts less than $10 \, \text{cfu} \, 100 \, \text{ml}^{-1}$ (Figure 1). For the unimproved sources (classes III and IV), only 26% of samples had *E. coli* counts below $10 \, \text{cfu} \, 100 \, \text{ml}^{-1}$. Observed proximity of a latrine was not significantly related to groundwater source contamination.

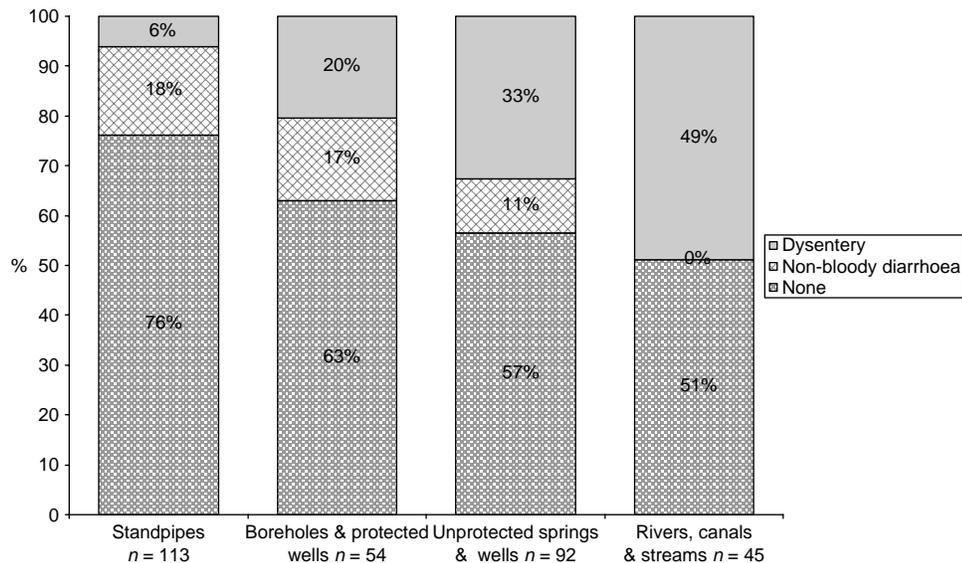## Dysentery and watery diarrhoea

Over the full monitoring period, the average rate of dysentery was equivalent to 6.79 episodes per annum (South Africa 3.97; Zimbabwe 9.93) and of watery diarrhoea 4.08 episodes (South Africa 2.77; Zimbabwe 5.55). For the 304 selected fortnights, the expected (*observed*) numbers of episodes were therefore: dysentery 79 (*70*) and watery diarrhoea 48 (*47*), confirming that the observation periods were typical of the full monitoring period.

Risk factors for dysentery

Figure 2 shows the most severe episode of diarrhoea recorded in the observation periods by source class. Separate episodes of dysentery and watery diarrhoea occurred in only 2.6% of observation periods. All diarrhoea episodes in children drinking surface water met criteria for dysentery. For children drinking from the other three source classes, the number of watery diarrhoea episodes did not vary significantly.

Table 1 | Characteristics of participating households during round 1 (dry season)

	South Africa	Zimbabwe
Number of households	85	94
Water source type:		
I Standpipe	57 (68%)	4 (4%)
II Improved groundwaters	8 (9%)	28 (30%)
III Unimproved groundwaters	8 (9%)	47 (50%)
IV Surface waters	12 (14%)	15 (16%)
Water vessel type:		
Small hole	52 (61%)	58 (62%)
Large hole/uncovered	33 (39%)	36 (38%)
Sanitation facility:		
Pit latrine	46 (54%)	19 (20%)
None	39 (46%)	75 (80%)

Figure 1 | Percentages of source water samples with *E. coli* ≥ 10 cfu 100 ml^{-1} by source type ($n = 304$).

Figure 2 | Percentages of dysentery and watery diarrhoea episodes in a fortnight following water testing, by source class ($n = 304$).

Dysentery events by source class (Figure 2) parallel the pattern observed for percentage of water samples with *E. coli* counts of 10 cfu 100 ml^{-1} or above (Figure 1).

Multinomial logistic regression (Tables 3 and 4) identified two significant predictors of dysentery, after adjusting for country and survey round:

- Source class. Compared with children drinking water from standpipes, those drinking from other sources had

a relative risk ratio of 3.8 (95% CI 1.5–9.8, $p = 0.005$). Relative risk ratios for source classes other than standpipes were not significantly different from one another. Differences in relative risk between these three classes were not significant ($p = 0.685$, adjusted Wald test).

- Presence of *E. coli* of at least 10 cfu 100 ml^{-1}. Sources showing at least this level of *E. coli* had a relative risk ratio of 2.9 (1.5–5.7, $p = 0.002$), compared with those

Table 3 | Risk ratios, adjusted for country and season, by source class, for watery diarrhoea and dysentery, relative to source class I, with *E. coli* < 10 cfu $100\,\text{ml}^{-1}$

Diarrhoea type and risk factors	Relative risk ratio	Sig	Lower 95% CI	Upper 95% CI
Watery diarrhoea				
Source class II	1.06	0.898	0.43	2.61
Source class III	0.73	0.530	0.27	1.97
Source class IV	No cases			
E. coli $\geq 10\,\text{cfu}\ 100\,\text{ml}^{-1}$	1.24	0.655	0.48	3.19
Dysentery				
Source class II	3.24	0.032	1.11	9.48
Source class III	4.18	0.009	1.43	12.18
Source class IV	5.39	0.010	1.49	19.48
E. coli $\geq 10\,\text{cfu}\ 100\,\text{ml}^{-1}$	2.37	0.037	1.05	5.34

sources with counts of less than $10\,\text{cfu}\ 100\,\text{ml}^{-1}$. Above this cut-off point, higher levels of *E. coli* count were not associated with a higher risk of dysentery.

After adjusting for the two predictors above, *E. coli* in household storage vessels was not associated with dysentery. Similarly there was no association with type of storage vessel, household sanitation facilities, proportion of sanitation in the village, contamination of mothers'/carers' hands, age of child, sex of child or socio-economic status.

Risk factors for watery diarrhoea

As noted, children drinking surface water experienced only dysentery during the observation periods. With this exception, for watery diarrhoea there was no association with any factor.

Table 4 | Risk ratios, adjusted for country and season, for source classes II, III and IV combined, for watery diarrhoea and dysentery, relative to source class I, with *E. coli* < 10 cfu $100\,\text{ml}^{-1}$

Diarrhoea type and risk factors	Relative risk ratio	Sig	Lower 95% CI	Upper 95% CI
Watery diarrhoea				
Source classes II, III & IV	0.83	0.651	0.38	1.84
E. coli $\geq 10\,\text{cfu}\ 100\,\text{ml}^{-1}$	0.74	0.516	0.30	1.83
Dysentery				
Source classes II, III & IV	3.83	0.005	1.50	9.76
E. coli $\geq 10\,\text{cfu}\ 100\,\text{ml}^{-1}$	2.89	0.002	1.47	5.68

DISCUSSION

Distinguishing dysentery and watery diarrhoea

No previous field studies have distinguished risk factors for dysentery and watery diarrhoea, occurring over the same period, in the same populations. Our study shows well-defined, disease-specific risk factors for endemic dysentery. For watery diarrhoea, we found no significant associations.

Endemic dysentery

Endemic dysentery was associated only with source water characteristics and not with faecal contamination occurring after collection. Standpipes provided drinking water with the lowest risk of dysentery. Drinking water from the other three source classes–improved groundwaters, unimproved groundwaters and surface waters–carried a risk 3.8 times higher than for standpipes. Although there was a gradient of increasing risk, the differences between the three classes were not statistically significant. Furthermore, the inclusion of 'improved groundwaters' in the higher risk category implies that *improved sources are not necessarily safe sources.*

In source classes with *E. coli* counts of at least $10\,\text{cfu}$ $100\,\text{ml}^{-1}$, the risk of dysentery increased further by a factor of 2.9. Full enumeration of *E. coli* provided no additional information about the risk. Simple, qualitative testing for *E. coli* may provide sufficient information to identify water sources associated with risk of dysentery.

The findings are consistent with previous reports of the presence of dysenteric pathogens present in surface waters in the South African study area. A microbiological assessment (Obi *et al.* 2002) of river water quality found *Shigella* spp. in 11 of 14 sample points in seven rivers. Other studies elsewhere have found increased dysentery risks from groundwater sources (Lewis *et al.* 1982; VanEvery & Dawson 1995; Pedley & Howard 1997; Tshimanga *et al.* 1997; Mazari-Hiriart *et al.* 1999; Alamanos *et al.* 2000; Maurer & Sturchler 2000).

In contrast with some earlier studies of dysentery (Ahmed *et al.* 1994; Curtis & Cairncross 2003), we found no significant association between dysentery and type of household water storage vessel, sanitation, hygiene practices, wealth, education, age or gender.

Watery diarrhoea

In common with a previous study in Zimbabwe (Moy *et al.* 1991), watery diarrhoea was not associated with any of the factors that we assessed. We found no other studies that reported specific risk factors for watery diarrhoea based on simultaneous monitoring with dysentery in the same households.

Weaknesses in our study

Our multivariate analysis found no evidence of confounding by socio-demographic or behavioural variables. It may be that other variables, unmeasured by us, are correlated with both dysentery and water sources. For example, three studies (Arskii *et al.* 1961; Levine & Levine 1991; Alam & Zurek 2004) suggest that flies are important vectors of endemic dysentery, with seasonal correlation between fly populations and incidence rates.

Our results show 10.87 episodes per annum (South Africa 5.74; Zimbabwe 15.48) for dysentery and watery diarrhoea combined, greater than the median of 3.9 (95% CI 2.0–5.5) episodes per annum for children aged 12–24 months reported elsewhere (Kosek *et al.* 2003). As we deliberately selected villages and districts with known, high levels of child diarrhoea, this was not unexpected. The daily pictorial diaries used may also capture more diarrhoea episodes than data collection based on longer recall periods. However, the percentage of dysentery episodes in our study (62.5%) was significantly higher than the WHO-reported (WHO 1994) estimate 'of about 10% of diarrhoea episodes in children under 5 years of age'. It is also possible that the high rates observed are an artefact of the pictorial diaries used to gather the data. However, there were no significant differences in the proportion of diarrhoea recorded via the diary and that recorded via a small sample of questionnaires, administered independently of the diary.

Although we adjusted our analysis for differences in absolute risks of dysentery and watery diarrhoea between countries and between seasons, we had insufficient data to test for differences in the effects of risk factors between countries or seasons.

CONCLUSION

This study is based on a small sample of households and the findings may not be generalisable to other settings, particularly given the high rates of dysentery recorded. However, it would be possible to investigate the relationship between groundwater source usage and dysentery using much larger, international data sets, such as the Demographic and Health Surveys or Multiple Indicator Cluster Surveys. If larger scale studies do confirm these findings, there are two main areas for further research: 1) a better understanding would be required of why groundwaters are contaminated with dysenteric pathogens, including the potential role of pit latrines and other sanitation; 2) further research would be required to develop better source testing and devise improved metrics for monitoring progress towards Target 10 of the Millennium Development Goals.

Our study suggests that endemic dysentery is associated only with faecal contamination of source water. Subsequent contamination of water during transport or in the home, sanitation, hygiene and other household characteristics are not significant risk factors for dysentery in this study. If corroborated, these findings suggest that water and sanitation policy would achieve reductions in the burden of disease by prioritising the installation of lower risk, improved sources, such as standpipes. Where existing higher risk sources (which in our small-scale study included boreholes and wells) cannot be replaced, appropriate interventions for remediation of water quality by treatment at source or in the household would ensure that 'access to safe drinking water' could still be achieved in accordance with the 7th Millennium Development Goal.

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