Int. J. Epidemiol. Advance Access published May 24, 2006

Published by Oxford University Press on behalf of the International Epidemiological Association

International Journal of Epidemiology
doi:10.1093/ije/dyl105

Consumption of untreated tank rainwater and gastroenteritis among young children in South Australia

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Accepted 13 April 2006

Background Tank rainwater is a source of untreated drinking water in Australia and elsewhere. The aim of this study was to determine whether the risk of gastroenteritis among children who drank tank rainwater differed from that of children who drank treated public mains water.

Methods A cohort study of 1016 4- to 6-year old children who drank rainwater or treated mains water in rural South Australia was undertaken in 1999. Parents kept a daily diary of their child's gastrointestinal symptoms and water consumption for a period of 6 weeks. Data on respiratory illness and other risk factors for gastroenteritis were also collected.

Results The incidence of gastroenteritis among children was 3.8–5.3 episodes per child-year, but most episodes (60%) lasted just 1 day. No increase in odds of gastroenteritis was observed among children who drank rainwater compared with treated mains water. The adjusted odds ratio for gastroenteritis associated with rainwater consumption compared with mains consumption was 0.84 (95% confidence interval 0.63–1.13).

Conclusions Gastroenteritis was found to be a significant cause of morbidity among young children. Young children, who were regular consumers of tank rainwater, were at no greater odds of gastroenteritis than those who drank treated public mains water.

Keywords Gastroenteritis, drinking water, rainwater, children

Tank rainwater, which is water collected from domestic roofs and stored on-site in above-ground or below-ground tanks, is a common source of water in Australia and elsewhere.[1–3] A study of 3014 households in South Australia found that the proportion of households using tank rainwater as their main source of drinking water was similar to the proportion using public mains supply water: 42 and 40%, respectively.[2] However, this tank may be contaminated by dirt, leaves, and the faeces of birds and animals that traverse domestic roofs or that roost in trees overhanging roofs. It is generally an untreated supply, apart from natural sedimentation. Hence, it is potentially a source of gastrointestinal disease in the community. Acknowledging the community preference for rainwater consumption and the need to conserve water, the South Australian Department of Human Services wished to promote the use of tank rainwater as a sustainable source of water for consumption, if it could be shown that it did not present a significant risk to health.

Much of the data on health risk resulting from rainwater consumption arises from descriptive studies enumerating the levels of indicator organisms in tank rainwater. The levels of faecal indicator organisms typically found indicate that it is potentially a health hazard.[4,5] Since 1978 there have been six disease outbreaks associated with rainwater reported

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worldwide.[6–12] While these data suggest rainwater, like other water sources, may be a risk factor for specific disease outbreaks, information on the contribution of tank rainwater to sporadic cases of gastroenteritis is limited. Rainwater is more often a household supply of water, with small numbers of persons exposed to each tank, and hence it may be an important source of sporadic gastroenteritis. Identifying the exposure pathways and agents responsible for sporadic gastroenteritis is important as these comprise the majority of gastroenteritis cases.[13] In the US, for example, sporadic illness accounted for 88% of all Salmonellosis notifications.[13]

Substantial resources are committed to supplying water and maintaining the infrastructure for rural water supplies in Australia. A number of these systems require upgrading at considerable cost to comply with Australian Drinking Water Guidelines.[14] Yet rainwater is the main source of drinking water for 82% of rural households in South Australia.[2] While some people choose not to use the public mains supply, others, including those in remote Aboriginal communities, do not have access to a public supply or have access to water of a poor aesthetic quality. These communities are dependent on rainwater, groundwater, and private surface water collections. Thus, it is appropriate to review the health risks of rainwater storage as an alternative water supply. Furthermore, access to reliable and affordable sources of water is still a fundamental health issue for many regions of the world. In Africa, Asia, Latin America, and the Caribbean, 21% of the population has no access to a water service.[15] In many of theses regions rainwater is potentially a relatively safe water supply.

A number of authors have highlighted the need for better data enumerating the actual risk to health from drinking rainwater.[1,16] This study aimed to provide data to assist in the health risk assessment of rainwater consumption. The specific objectives of this study were 2-fold. The first was to determine the incidence of gastroenteritis among 4- to 6-year-old children in rural South Australia and the Adelaide Hills, a semi-rural region on the outskirts of the City of Adelaide. The second was to determine whether the risk of gastroenteritis among 4- to 6-year old children who drank tank rainwater differed from that of children who drank treated public mains water in rural South Australia and the Adelaide Hills.

Methods

Study population

The sample was selected from 9543 children who had participated in an earlier statewide survey on gastroenteritis and water consumption.[17] To be eligible for the current study children had to: (i) reside in rural South Australia or the Adelaide Hills; and (ii) drink public mains water that was filtered and disinfected, as their main source of drinking water, or drink rainwater from an above-ground tank as their main source of drinking water; and (iii) not have an ongoing illness or treatment that led to gastrointestinal symptoms. Children of Aboriginal or Torres Strait Islander descent were excluded because of the difficulty in controlling for the broader range of poor environmental health conditions experienced by many of these children in remote communities. While these children are at greater risk of gastroenteritis,[18,19] it would be difficult to distinguish the impact of drinking water from the overall impact of poorer living conditions.

Of the 9543 respondents to the earlier survey, 3413 lived in rural South Australia or the Adelaide Hills, and among these, 1960 parents (57%) indicated their willingness to participate in a second study. However, 869 children of the 1960 parents were ineligible for one of the other reasons indicated above. Forty-nine children were no longer contactable, leaving 1042 children available for study.

Recruitment into the study occurred from January 1999 to March 1999.

Survey instruments

Participants completed four survey instruments: a baseline questionnaire; a daily diary (42 days); 3 and 6 week telephone questionnaires. Data on daily gastrointestinal and respiratory symptoms, water consumption, and risk factors that were likely to vary on a daily basis were collected via the daily diary. These risk factors included antibiotic use, hay fever, and consumption of soft drinks and cordial (a drink made up of flavoured concentrates containing 25% fruit juice or artificial flavours, 25% sweeteners, added colours and preservatives, and water). Respiratory symptoms were included to distinguish between gastrointestinal symptoms occurring as a result of respiratory illness rather than gastroenteritis.

The baseline questionnaire and telephone questionnaires at 3 and 6 weeks obtained data on factors that would not vary enough over the 6 week diary period to warrant daily data collection. These variables included rainwater tank construction and maintenance, number of children in household, pets, contact with farm animals, attendance at preschool or school, swimming, contact with a sick pet, and time spend away overnight from home by child. Data on any action taken as a result of the gastroenteritis and the parents' belief of the cause were also collected in the 3 and 6 week questionnaires.

Parents were also provided with an information booklet, which included clarification on the meaning of different symptoms, information on cup size, and other assistance for completing the diary. All survey instruments were piloted among parents with young children in Adelaide before the study commenced.

Definition of gastroenteritis

The definition of gastroenteritis was based upon highly credible gastrointestinal symptoms (HCGI).[20] HCGI was the presence of vomiting or liquid bowel movements, or nausea or soft bowel movement/s combined with abdominal cramps in a 24 h period, unless a chronic cause for these symptoms was known to exist. A new episode of gastroenteritis was defined when there were seven symptom-free days preceding the onset of gastrointestinal symptoms.

Statistical analysis

Incidence rates

For the incidence rate, each episode of HCGI was considered a separate event and for a child who had multiple events, the time-at-risk for each episode was determined. Subsequent days of the episode and the 7 day symptom-free period were not included in the time-at-risk. For children who had no HCGI the time-at-risk was the period of follow-up for that child or the end of the study period, whichever came first.

Model selection

Logistic regression was used to model the dependence of the binary response, HCGI, on water consumption and the other potential risk factors and confounders. Because of the repeated measures, random effects models were used to allow for correlations between the responses from the same subject on different occasions.[21] These analyses were computed using STATA V8 software (Stata Corporation, College Station, TX).

Modelling strategy

The approach taken to modelling followed the four stages recommended by Kleinbaum and Klein.[22] (i) variable specification; (ii) interaction assessment; (iii) confounding assessment; and (iv) selection of the final model. Variable specification was determined by incorporating those variables that have been shown to be risk factors for gastroenteritis, including potential confounders. Potential confounders were included on both a statistical and biological basis. Those for which the simple regression relationship with gastroenteritis was significant at a *P*-value of <0.25 were considered as potential confounders in the full model.[23] Other variables that were considered potential confounders on a biological basis were also considered in the full model. Evidence of confounding in the full model was then assessed by comparing the estimated odds ratio of subsets of the full model to that obtained from the full model. A meaningful difference in these odds was a change in the estimated effect on HCGI associated with tank rainwater of 5% or greater. This analysis was undertaken using the STATA program 'Assessing confounding effects in epidemiological studies (epiconf)'.[24] Factors that were significant risk factors for gastroenteritis, but did not confound the relationship, were retained in the model. Those interactions between tank rainwater and other risk factors that were considered biologically important were investigated.

Results

Response

Of the 1042 parents who were approached to participate, 1015 (97%) agreed, 982 parents (94%) completed at least one component of the study and 965 parents (93%) completed all components.

The characteristics of children whose parents were willing to participate in the study compared with those children of parents who were not willing are shown in Table 1. Willing participants were more likely to have a child who had had HCGI in the previous 2 weeks, to be of a higher socioeconomic status (SES), live out of town, and have two or more young children. Willingness to participate was not associated with water consumption.

Incidence rate—Rural SA Childhood Gastroenteritis Diary Study

Over the 6 week diary period there were 524 episodes of HCGI among 965 children; 33% ($n = 317$) had one episode, 9% ($n = 84$) had two episodes, and 1% ($n = 13$) had three episodes. Nineteen episodes occurred on the first day of the diary, leaving 505 episodes occurring over 34 646 days-at-risk. The incidence rate of all HCGI was 5.3 episodes per child-year [95% confidence interval (95% CI) 4.9–5.8 episodes per child-year].

Considering the 380 episodes that did not have associated respiratory symptoms, and excluding the 15 that occurred on the first day, the incidence of non-respiratory HCGI was 3.8 episodes per child-year (95% CI 3.5–4.3 episodes per child-year).

Table 1 Characteristics of children of parents willing to participate in the study compared with children of non-willing parents ($n = 3413$)

Factor	Willing to participate[a] ($n = 1960$)		Not willing to participate[a] ($n = 1453$)		
	n[b]	%	n[b]	%	χ^2 (*P*-value)
Sex					
Male	1046	53.4	757	52.2	
Female	914	46.6	694	47.8	0.5 (0.49)
No of other children aged 4 or less in household					
0 or 1	1768	90.4	1325	93.4	
2 or more	188	9.6	93	6.6	10.0 (<0.01)
SES					
1 (most disadvantaged)	248	12.7	241	16.6	
2	1082	55.5	837	57.6	
3	408	20.9	237	16.3	
4 (least disadvantaged)	213	10.9	138	9.5	20.3 (<0.01)
Place of residence					
In town	1754	89.6	1361	94.1	
Out of town	204	10.4	85	5.9	22.1 (<0.01)
HCGI in last 2 weeks					
Yes	319	16.3	180	12.6	
No	1582	81.0	1201	83.8	
Do not know	51	2.6	52	3.6	11.6 (<0.01)
Drinks rainwater					
Yes	1401	71.5	1012	69.7	
No	558	28.5	439	30.3	1.26 (0.26)

[a] Data from earlier prevalence survey from which sample was selected.
[b] Totals may vary slightly from 3413 as a result of missing values.

Water consumption

The type of water drunk by participants is shown in Table 2. The mean daily consumption of all water, regardless of type, was 4.2 cups per day. Children who drank either rainwater alone or public mains alone on average drank a similar daily amount, 4.3 and 4.4 cups per day, respectively. Each cup was between 160 and 200 ml and hence on average children drank 672–840 ml each day.

On the basis that repeated exposures to infectious agents may have possibly inferred longer-term immunity to these agents, duration of exposure to tank rainwater was potentially

Table 2 Incidence of all HCGI by water group—Rural SA Gastroenteritis Diary study (n = 946 children[a–c])

Type of water drunk during diary period	No. of children[b]	No. of episodes	Years-at-risk	Incidence/child/year	95% Confidence Interval[d]
Public mains only	140	99	13.5	7.3	6.0–8.9
Rainwater only	406	196	41.8	4.7	4.1–5.4
Rainwater plus public mains	314	176	31.0	5.7	4.9–6.6
Public mains and spring water	29	12	2.9	4.1	2.3–7.2
Public mains, rainwater and spring water	57	22	5.7	3.8	2.5–5.8

[a] 19 of 965 children who had HCGI on the first day were excluded.
[b] One child was reported to drink only fruit juice or milk but no water during the diary period.
[c] Included 19 children who drank rainwater and spring or bottled water.
[d] Overall P-value = 0.003.

important in determining the association between tank rainwater and gastroenteritis. For the 710 children who drank some tank rainwater, parents were asked the length of time their child had been drinking tank rainwater; 94% had been drinking tank rainwater for more than 2 years and 98% for more than 1 year.

Rainwater tank environment

The majority of rainwater tanks in this study were constructed of galvanized iron (59%) and 43% of tanks were at least 10 years old. Overall the maintenance of rainwater tanks in this study was rudimentary. Few tanks had first flush diversion devices (8%) but most had sealed roofs (82%). Just 40% had a screened inlet. For tanks that were more than 2 years old, the sludge had never been removed in 42% of tanks and 26% of respondents were unaware of whether the sludge had ever been removed. For roof catchments, 77% were reported to be free of overhanging trees and 65% of gutters had been cleaned in the last year.

Incidence rate of all HCGI by water group

The incidence of all HCGI by water source over the diary period is shown in Table 2. The incidence of HCGI was significantly greater among children who drank *public mains water only* compared with those who drank *tank rainwater only*. The incidence among children who drank *public mains and tank rainwater* was intermediate. The incidence in *public mains, rainwater, and spring water* group was also significantly less than that for public mains.

Tank rainwater and gastroenteritis

The single variable analysis of the association between tank rainwater and gastroenteritis indicated that relative to public mains water consumption, there was a significantly decreased odds of gastroenteritis among children (Table 3). Regardless of the amount of tank rainwater drunk there was a significant reduction in odds, but there was no apparent dose–response relationship (Table 3). Length of time a child had been drinking tank rainwater was also significantly associated with HCGI (Table 3).

Table 3 Associations between HCGI episode and drinking water variables—single variable logistic regression analyses

	HCGI		
Risk factor	Days-at-risk	Odds Ratio	95% CI
Model 1: Main drinking water source	35 545		
Public mains only	5034	1 (ref)	
Rainwater only	15 661	0.6	0.5–0.8
Rainwater and public mains water	11 600	0.7	0.6–1.0
Public mains and spring/bottled water	1099	0. 6	0.3–1.1
All three	2151	0.5	0.3–0.8
Model 2: Treatment of water at home	35 461		
No treatment	31 033	1 (ref)	
Water filtered	2762	1.1	0.7–1.7
Water boiled	1666	1.1	0.7–1.5
Model 3: Length of time child has drunk tank rainwater	32 370		
Never drunk tank rainwater	6133	1 (ref)	
12 months or less	613	0.8	0.4–1.8
13–24 months	905	0.5	0.2–1.0
More than 24 months	24 719	0.7	0.6–0.9
Amount of tank rainwater drunk	35 545		
None (public mains only)	6133	1 (ref)	
0.5 to <3 cups/day (low)	10 703	0.7	0.5–0.9
3 to <5 cups/day (medium)	12 752	0.8	0.6–1.0
5 or more cups/day (high)	5957	0.7	0.5–0.9

Potential confounders

The variables that were considered in the full model were: antibiotic use; ear infection; sore throat; hay fever symptoms; contact inside or outside the home with someone who had vomiting or diarrhoea (two variables); month of diary; pet dog; attendance at school or kindergarten; number of children aged

15 years or less; frequency of takeaway consumption; frequency of eating at café and restaurant; storage of leftovers; wheeze in the past year; asthma medication during diary period; where a child swam; and rating of risk to health from drinking rainwater. None of these variables showed evidence of confounding with water consumption, apart from rating of risk to health from drinking rainwater, but several were important independent risk factors (Table 4). None of the interactions was statistically significant and were not included in the full model.

The odds ratio for childhood gastroenteritis associated with tank rainwater consumption in the adjusted model was 0.84 but this was not significantly different from that for the reference category, treated public mains (95% CI 0.63–1.13).

Discussion

Association between tank rainwater and gastroenteritis

This study indicates that among children who were regular consumers of tank rainwater, the odds of HCGI associated with drinking this water was no greater than that associated with drinking treated public mains water. A potential protective effect was observed but this was not statistically significant. Furthermore, it was observed that the maintenance of rainwater tanks was not of a high standard among this study population.

Consistent with the current study, an earlier study of cryptosporidiosis notifications in South Australia, found a significantly reduced risk of cryptosporidiosis associated with tank rainwater, whereas public mains water and spring water were both associated with an increased risk of cryptosporidiosis.[25] On the other hand a New Zealand case–control study of sporadic campylobacteriosis[26] showed an increase in odds of illness associated with tank rainwater consumption. The small numbers exposed to tank rainwater and multiple comparisons in the study limited the inferences that could be drawn from it.

One potential explanation for the lack of an observed increased in odds of gastroenteritis associated with tank rainwater is acquired immunity to a range of potential microbial contaminants. Payment and Hunter[27] have argued that the rates of waterborne illness within the community are lower than the expected rates given the levels of exposure to diarrhoeal pathogens. The difference between expected and observed disease was hypothesized as resulting, in part, from pre-existing immunity in the community that has developed from previous exposure to micro-organisms. Furthermore, studies have shown immunity to develop after exposure to a range of organisms; rotavirus,[28] adenoviruses and astroviruses,[29] and *Cryptosporidium parvum*.[30,31]

The children drinking tank rainwater in this study had been exposed to potentially low levels of contaminants. Nearly all children who drank tank rainwater had drunk this water for more than 1 year (98%) and during this time may have developed immunity to some organisms. The unadjusted analyses of *tank rainwater only* drinkers indicated that the odds of gastroenteritis were lower among children who were longer-term consumers of tank rainwater. Unfortunately the small numbers of children who were recent consumers of tank rainwater precluded further investigation.

Table 4 Final Model, HCGI and drinking water source—multivariable logistic regression (34 722 days-at-risk)

	HCGI	
Variable	Odds ratio	95% CI
Drinking water source		
Public mains	1 (ref)	
Rainwater only	0.8	0.6–1.1
Rainwater and public mains	0.9	0.7–1.3
Public mains and bottled/spring water	0.6	0.3–1.1
All three	0.6	0.4–1.0
Sore throat, cold or influenza		
No	1 (ref)	
First day of episode	3.4	2.3–5.0
Subsequent day of episode	2.3	1.8–2.9
First day of ear ache or infection		
No	1 (ref)	
Yes	2.8	1.3–6.2
First day of antibiotic use		
No	1 (ref)	
Yes	4.8	2.3–10.0
Contact inside the home with a person who had gastroenteritis on the same day		
No	1 (ref)	
Yes	2.1	1.2–3.7
Contact inside the home with a person who had gastroenteritis on the same day or previous 3 days		
No	1 (ref)	
Yes	1.8	1.1–2.9
Contact outside the home with someone who had gastroenteritis on same day		
No	1 (ref)	
Yes	3.5	2.4–5.0
Do not know	1.2	1.0–1.5
Pet dog in the household		
No	1 (ref)	
Yes	0.9	0.7–1.0
Swam during diary period		
No	1 (ref)	
Yes, in a private pool	1.8	1.2–2.6
Yes, swam elsewhere	1.1	0.9–1.3
Average frequency of consumption of takeaway foods		
Less than once per week	1 (ref)	
1 or more times per week	1.3	1.1–1.6
Respondent rating of risk to health from tank rainwater		
Low/medium risk	1 (ref)	
High risk	1.7	1.2–2.4
Not sure	1.7	1.2–2.5

The lack of a significant association and suggestion of a reduced odds associated with tank rainwater also raises questions about the appropriateness of the treated public mains as a reference group. Treated public mains water has been shown to be associated with an increased risk of gastroenteritis by some investigators[20,32] but not by others.[33] It has been suggested that these differences in the results arose in part because of a difference in the quality of the source water.[33] In the current study the source water for the public mains group varied considerably and this raised the question as to whether the odds of gastroenteritis associated with public mains water was higher in certain areas within rural South Australia and the Adelaide Hills. However, when the study areas of the Adelaide Hills and rural South Australia were stratified into smaller regional areas, the incidence of gastroenteritis did not vary significantly across these sub-regions. Also no differences in incidence were observed when a stratified analysis of children drinking public mains only was undertaken (data not shown). Hence it appears that the quality of the treated public mains water was reasonably uniform over the regions studied and, thus, provided a suitable reference.

Incidence of childhood gastroenteritis in rural South Australia

The incidence of gastroenteritis for children aged 4–6 years in rural South Australia ranged from 3.8 episodes per child-year for gastroenteritis with no associated respiratory symptoms, to 5.3 episodes per child-year for all gastroenteritis. These episodes were predominantly mild gastroenteritis lasting 1 day. In total 26% of gastroenteritis was associated with respiratory illness, which is consistent with earlier incidence studies.[34,35]

While the high incidence rate is in keeping with the observations in an earlier South Australian study, 3.7 episodes per child-year,[17] estimates of the incidence of childhood gastroenteritis from other studies in developed countries are generally lower.[36–38] de Wit *et al.*[37] reported a 5-fold lower incidence among children aged 1–4 years in The Netherlands, 0.9 episodes per person-year (95% CI 0.8–1.0). In contrast, a French study of 2033 children aged 7–11 years found an incidence of gastroenteritis of 5.7 episodes per person-year.[32]

Variations in the definition of gastroenteritis make comparisons between studies problematic as do the variations in the prevalence of risk factors for gastroenteritis. The definition used in the current study was based upon that used by Payment *et al.*[20] de Wit *et al.*[37] in The Netherlands used a more stringent definition; gastroenteritis was defined as at least three loose stools per day or at least three vomits per day, or diarrhoea (two or more loose bowel actions) with two or more additional symptoms, or vomiting with two or more additional symptoms. The additional symptoms included fever, nausea, blood or mucus in stool, abdominal pain or cramps, or vomiting or diarrhoea. When the definition used by de Wit *et al.* (2001) was applied to the current study, a lower incidence of 1.3 episodes per person-year (95% CI 1.0–1.5) was obtained. Because data on blood or mucus in stools were not collected, the definition could not be strictly applied, yet this suggests that the differences in the estimated incidence were predominantly a result of differences in the definitions.

We used a broad definition and hence more sensitive definition in this study because we wanted to capture mild as well as more severe gastroenteritis. This lack of specificity may have led to a larger proportion of non-infectious gastroenteritis being included in our estimate of incidence. Finding an appropriate balance between sensitivity and specificity is not clear-cut. When a more specific definition of gastroenteritis was applied in a study of *Campylobacter* and *Salmonella* infections, the incidence of gastroenteritis decreased 4-fold, but approximately half of the verified *Campylobacter* and *Salmonella* infections were also excluded from this estimate of incidence.[39]

Self-reporting of symptoms and the shorter period of follow-up may also be potential reasons for the higher estimate of incidence in this study. A number of diary-based studies have observed that 'diary fatigue' appears to occur and reporting of gastrointestinal symptoms reduces steadily over time.[33,37] Over a 68 week follow-up period, Hellard *et al.* (2001) found a 69% decline in the reporting of gastrointestinal symptoms for all ages, from 1.4 cases per person-year in the first 13 weeks to 0.4 cases per person-year in the last 13 weeks of the study.

A potential source of selection bias in the current study was that parents who participated on behalf of their child were a self-selected sample rather than a random sample. While this may have limited the external validity, it was considered that maximizing internal validity was more important. The study groups were selected to optimize the detection of an increase in risk. By limiting the study to parents willing to participate, the extent of loss to follow-up as well as missing data was reduced. While these parents were more likely to have a child who had had gastroenteritis during the initial SA Childhood Gastroenteritis Survey, the proportion of children who had gastroenteritis in the preliminary survey of the current diary study was very similar to that observed in the initial survey; both were ~14%.[17] If the effect of this self-selection bias had been significant, then a higher proportion than that previously observed would have been expected. Nonetheless, it is acknowledged that the population represented by this study is one of larger and higher SES families.

There are other limitations in the generalizability of the results of this study. The results can be generalized only to persons who are regular consumers of tank rainwater. There may be an increase in risk among persons who have recently commenced drinking tank rainwater, but this risk could not be assessed in this study. The results also cannot be applied to Aboriginal children, children aged <4 years old, or to the elderly as these groups are at higher risk of gastroenteritis, generally, and may be more susceptible to contaminants in water due to reduced immunity.[40] Further work is needed in these susceptible populations.

The implications of the findings beyond South Australia depend upon local conditions such as the maintenance and construction of rainwater tanks and catchments, as well as carriage of pathogens by local fauna. In the current study, the overall maintenance of tanks was poor to average while the maintenance of catchment areas was generally good. Most tanks had not been cleaned for some time whereas the majority of gutters had been cleaned within the last 6 months. Tanks were sealed but not necessarily screened and few had first flush diverters. This limited evidence suggests that tank maintenance was not a major factor in changing the risk experienced by children.

Conclusion

The incidence of gastroenteritis was high compared with that previously reported, but much of this was mild gastroenteritis lasting just 1 day. Consumption of tank rainwater did not increase the odds of gastroenteritis relative to public mains water consumption among 4- to 6-year-old children in South Australia. Possibly this reflected a level of acquired immunity among regular users of tank rainwater and may not reflect the risk in new users of this water supply.

Further studies are needed to clarify the role of immunity in the risk of tank rainwater consumption and whether new consumers are at a greater risk of gastroenteritis. These studies would be supported by studies that assess the carriage of human pathogens by local fauna, the potential of these pathogens to survive in the tank environment, and the relative contribution of re-suspension and incoming contamination on the levels of pathogens in tank rainwater.

Acknowledgements

The South Australian Department of Human Services (DHS) provided Aus $30,000 to fund the study of drinking water consumption and childhood gastroenteritis.

KEY MESSAGES

- Consumption of tank rainwater did not increase the risk of gastroenteritis relative to public mains water consumption among four to six-year-old children in South Australia.
- The incidence of gastroenteritis among children was high compared with that previously reported, but much of this was mild gastroenteritis lasting just one day.
- Further studies are needed to clarify the role of immunity in the risk of tank rainwater consumption and whether new consumers are at a greater risk of gastroenteritis.

References

1 Lye D. Microbiology of rainwater cistern systems; a review. *J Environ Sci Health* 1992;**A27:**2123–66.

2 Heyworth J, Maynard E, Cunliffe D. Who drinks what?: Potable water use in South Australia. *Water* 1998;**25:**9–13.

3 Australian Bureau of Statistics. *Environmental Issues: People's Views and Practices*. Canberra: ABS, 2001.

4 Fuller C, Martin T, Walters R. *Quality Aspects of Water Stored in Domestic Rainwater Tanks (A Preliminary Study)*. Adelaide: Engineering and Water Supply, 1981.

5 Thomas P, Greene G. Rainwater quality from different roof catchments. *Water Sci Technol* 1993;**28:**291–9.

6 Brodribb R, Webster P, Farrell D. Recurrent Campylobacter fetus suspecies fetus bacteraemia in a febrile neutropaenic patient linked to tank water. *Commun Dis Intell* 1995;**19:**312–13.

7 Merritt A, Miles R, Bates J. An outbreak of Campylobacter enteritis on an island resort, north Queensland. *Commun Dis Intell* 1999; **23:**215–19.

8 Simmons G, Hope V, Lewis G. *Auckland Roof Water Quality Survey: Pilot Survey*. Auckland: Auckland Healthcare, 1997.

9 Simmons G, Hope V, Lewis G, Whitmore J, Gao W. Contamination of potable roof-collected rainwater in Auckland, New Zealand. *Water Res* 2001;**35:**1518–24.

10 Simmons G, Smith J. Roof water probable source of Salmonella infections. *N Z Public Health Rep* 1997;**4:**5.

11 Koplan J, Deen R, Swanston W, Tota B. Contaminated roof-collected rainwater as a possible cause of an outbreak of salmonellosis. *J Hyg (Lond)* 1978;**81:**303–09.

12 Schlech WF 3rd, Gorman GW, Payne MC, Broome CV. Legionnaires' disease in the Caribbean. An outbreak associated with a resort hotel. *Arch Intern Med* 1985;**145:**2076–79.

13 CAST. *Foodborne Pathogens: Risk And Consequences*. Ames, IA: Council for Agricultural Science and Technology, 1994.

14 NHMRC/ARMMC. *Australian Drinking Water Guidelines 2004*. Canberra: National Health and Medical Research Council and Australian National Resource Management Ministerial Council, 2004.

15 Heijnen H. Towards water quality guidance for collected rainwater. In: Proceedings of the 10th International Conference on Rainwater Catchment Systems. Mannheim: FAKT, fbr, Margraf Verlag, 2001.

16 Simmons G, Heyworth J, Rimajova M. Assessing the microbial health risks of tank rainwater used for drinking water. *Environ Health* 2001;**1:**57–64.

17 Heyworth JS, Baghurst P, McCaul KA. Prevalence of gastroenteritis among 4-year-old children in South Australia. *Epidemiol Infect* 2003;**130:**443–51.

18 Gracey M. Diarrhoea in Australian Aborigines. *Aust J Public Health* 1992;**16:**216–25.

19 Gunzburg S, Gracey M, Burke V, Chang B. Epidemiology and microbiology of diarrhoea in young Aboriginal children in the Kimberley region of Western Australia. *Epidemiol Infect* 1992;**108:** 67–76.

20 Payment P, Richardson L, Siemiatycki J, Dewar R, Edwardes M, Franco E. A randomised trial to evaluate the risk of gastro-intestinal disease due to consumption of drinking water meeting current microbiological standards. *Am J Public Health* 1991;**81:**703–08.

21 Diggle P, Liang K, Zeger S. *Analysis of Longitudinal Data*. Oxford: Oxford Science Publications, 1996.

22 Kleinbaum D, Klein M. *Logistic Regression, a Self-learning Text*. 2nd edn. New York: Springer-Verlag, 2002.

23 Hosmer D, Lemeshow S. *Applied Logistic Regression*. New York: John Wiley & Sons, 1989.

24 Wang Z. Assessing confounding effects in epidemiological studies, sbe27. *Stata J* 1999;STB 49.

25 Weinstein P, Macaitis M, Walker C, Cameron S. Cryptosporidial diarrhoea in South Australia. *Med J Aust* 1993;**158:**117–19.

26 Eberhart-Phillips J, Walker N, Garret N *et al*. Campylobacteriosis in New Zealand: results of a case-control study. *J Epidemiol Community Health* 1997;**51:**686–91.

27 Payment P, Hunter P. Chapter 4. Endemic and epidemic infectious intestinal disease and its relationship to drinking water. In: Fewtrell L, Batram J (eds). *Water Quality-Guidelines, Standards and Health: Assessment of Risk and Risk Management for Water-Related Infectious Disease*. IWA on behalf of WHO: London, 2001,pp. 61–88.

[28] Mrukowicz, JZ, Thompson J, Reed GW *et al*. Epidemiology of rotavirus in infants and protection against symptomatic illness afforded by primary infection and vaccination. *Vaccine* 1999;**17:**745–53.

[29] Glass, R, Bresee J, Jiang B *et al*. Gastroenteritis viruses: an overview. Novartis Foundation Symposium, 2001.

[30] Frost FJ, Calderon RL, Muller TB *et al*. A two-year follow-up survey of antibody to Cryptosporidium in Jackson County, Oregon following an outbreak of waterborne disease. *Epidemiol Infect* 1998;**121:** 213–17.

[31] Craun GF, Hubbs SA, Frost F, Calderon RL, Via SA. Waterborne outbreaks of cryptosporidiosis. *AWWA J* 1998;**90:**81–91.

[32] Zmirou D, Rey S, Courtois X *et al*. Residual microbiological risk after simple chlorine treatment of drinking ground water in small community systems. *Eur J Public Health* 1995;**5:**75–81.

[33] Hellard ME, Sinclair MI, Forbes AB, Fairley CK. A randomized, blinded, controlled trial investigating the gastrointestinal health effects of drinking water quality. *Environ Health Perspect* 2001;**109:** 773–78.

[34] Monto A, Koopman J, Longini I, Isaacson R. The Tecumseh study. XII. Enteric agents in the community, 1976–1981. *J Infect Dis* 1983; **148:**284–91.

[35] Dingle J, Badger G, Jordan W. *Illness in the Home: A Study of 25,000 Illnesses in a Group of Cleveland Families*. Cleveland: The Press of Western Reserve University, 1964.

[36] Kuusi M, Aavitsland P, Gondrosen B, Kapperud G. Incidence of gastroenteritis in Norway—a population-based survey. *Epidemiol Infect* 2003;**131:**591–97.

[37] de Wit MA, Koopmans MP, Kortbeek LM *et al*. Sensor, a population-based cohort study on gastroenteritis in the Netherlands: incidence and etiology. *Am J Epidemiol* 2001;**154:**666–74.

[38] Herikstad H, Yang S, Van Gilder TJ *et al*. A population-based estimate of the burden of diarrhoeal illness in the United States: FoodNet, 1996–7. *Epidemiol Infect* 2002;**129:**9–17.

[39] de Wit M, Hoogenboom-Verdegaal A, Goosen E, Sprenger M, Borgdorff M. A population-based longitudinal study on the incidence and disease burden of gastroenteritis and Campylobacter and Salmonella infection in four regions of the Netherlands. *Eur J Epidemiol* 2000;**16:**713–18.

[40] Savarino S, Bourgeois A. Diarrhoeal disease: current concepts and future challenges. Epidemiology of diarrhoeal disease in developed countries. *Trans R Soc Trop Med Hyg* 1993;**87(Suppl 3):** 7–11.