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Is fecal contamination of drinking water after collection associated with household water handling and hygiene practices? A study of urban slum households in Hyderabad, India

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ABSTRACT

Water-borne illness, primarily caused by fecal contamination of drinking water, is a major health burden in the state of Andhra Pradesh, India. Currently drinking water is treated at the reservoir level and supplied on alternate days, necessitating storage in households for up to 48 hrs. We hypothesized that fecal contamination occurs principally during storage due to poor water handling. In this study we tested for coliform bacteria in water samples collected at distribution points as household storage containers were filled, and then tested containers in the same households 24–36 hours after collection. We also conducted an observational survey to make an assessment of water handling and hygiene. Ninety-two percent (47/51) of samples tested at supply points were adequately chlorinated and bacterial contamination was found in two samples with no residual chlorine. Samples collected from household storage containers showed an increase in contamination in 18/50 houses (36%). Households with contaminated stored samples did not show significant differences in demographics, water handling, hygiene practices, or sanitation. Nevertheless, the dramatic increase in contamination after collection indicates that until an uninterrupted water supply is possible, the point at which the biggest health impact can be made is at the household level.

Key words | drinking water quality, fecal contamination, household water handling, hygiene, survey, urban slums

INTRODUCTION

Diseases due to unsafe water are some of the most common causes of death in developing nations, and diarrheal disease represents 4.2% of the global burden of disease, as measured by Disability Adjusted Life Years lost (WHO 2004). Published data on the burden of disease in the state of Andhra Pradesh shows that in both rural and urban areas, diarrheal diseases (commonly caused by fecal contamination of water) cause of over 6% of all deaths in the state (Mahapatra & Reddy 2001). In considering the city of Hyderabad specifically, epidemiological data show the highest incidence of gastroenteritis in the state. Between the years 1996–2000 there were 265 cases of gastroenteritis per 100,000 in the Hyderabad municipal corporation area; this is more than double the incidence in any other district of Andhra Pradesh (Mahapatra & Reddy 2001). This is puzzling since, as the capital of the state, a high level of political and financial investment has been made in improving the city infrastructure. In the last decade the city has been experiencing explosive growth with population increasing at 5.6% a year as it aggressively strives to become a hub for information technology by promising businesses world-class infrastructure.

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Since Hyderabad receives comparatively little rain during the monsoon and has relatively little accessible surface water, it is often faced with severe water shortages, particularly in the summer months. The influx of business investments in recent years has allowed extensive improvements in the water supply. With the help of the World Bank and other funding agencies the city completed the Krishna Water Project in 2003, increasing the daily supply of water to the city by more than 50% at a cost exceeding USD 200 million (HMWSSB 2007). There is still concern that the improvements in water supply are not benefiting the population in most need: slum areas where water remains scarce. Efforts by the local authorities to increase supply and improve treatment of water have been successful in dramatically reducing the incidence of gastroenteritis in the past decade with hospitalized cases dropping from 265/100,000 (Mahapatra & Reddy 2001) to approximately 100/100,000 (unpublished data from the MWB). However events such as the 2005 outbreak of water-borne viral hepatitis in slum areas with 546 confirmed cases (Sarguna *et al.* 2007) indicates that water-borne illness remains a health burden.

In addition to the inadequate water, resulting in intermittent supply, other systemic weaknesses include the lack of consistent, reliable chlorination (wide fluctuations in chlorination levels throughout the distribution system, with household chlorine levels ranging from nil to over 2 mg/L (recommended WHO household level is <0.5 mg/L), have been previously reported by Sarita & Mahapatra 2006) and poor responsiveness to complaints, particularly in slum areas with less political clout. Despite these systemic weaknesses the vast majority of water provided by the Hyderabad Metro Water and Sewerage Board (MWB) meets established drinking water standards (Sarita & Mahapatra 2006). Therefore it is pertinent to ask whether the prevalence of water borne illness can be primarily attributed to the systemic deficiencies or the water handling and storage practices of households.

Many previous studies have shown that there is significant deterioration of the bacteriological quality of water during collection and handling, negating some of the benefits of improvements made in water supply, and contributing to the persistence of water-borne illness (Lindskog & Lindskog 1988; Wright *et al.* 2004). In a meta-analysis of 57 studies, Wright *et al.* found that there were substantial increases in counts of total coliform, fecal coliforms and *E. coli* in over half of the studies. The authors point out the inadequacy of testing water at point of supply since fecal contamination was found in the household containers even when the supply was uncontaminated.

Household water handling and sanitation practices are key factors in the prevalence and risk of water borne illness outbreaks. An intervention study in Zimbabwe found that homes where traditional drinking water containers are replaced with covered, narrow mouthed urns with a tap outlet have significantly less contamination than the control group (Mazengia *et al.* 2002). A combination of special storage vessels with point of use treatment has been shown to be very effective. Mintz *et al.* found fecal contamination in households using a specially designed safe water storage container alone, but not in households using both the container and a 5% calcium hypochlorite solution (Mintz *et al.* 1995). Solar disinfection at the point of use was found to reduce childhood morbidity due to diarrhea in southern India (Rose *et al.* 2006). In Calcutta, India, the introduction of a narrow-mouthed and covered container from which water was poured significantly reduced eltor cholera contamination (Deb *et al.* 1986). Luby *et al.* have shown using randomized control trials in Pakistan that hand-washing initiatives and the introduction of point-of-use disinfection can reduce diarrheal incidence (Luby *et al.* 2006). A Cochrane review of the efficacy of hand washing interventions concluded that diarrheal episodes may be reduced by about 30% (Ejemot *et al.* 2008) Other factors such as number of residents in a household and presence of sewage in streets have been associated with feco-orally transmitted parasitic diseases (Teixeira & Heller 2006). Little is known regarding the water handling practices of households in this region. Therefore, before any intervention is considered, it is vital for the health of the community that the deterioration of water quality in the household be measured and factors associated with contamination identified.

In this study our first objective was to analyze the bacteriological quality of water at the point of supply and point of consumption and to measure putative decline in quality. Our second objective was to survey the households for socio-demographic profile, water handling practices, hygiene, and sanitation, to identify possible correlates with the prevalence of contamination.

METHODS

The site of study, a slum area located in Hyderabad Old City, was selected from 20 slums assigned by the MWB to the IHS Water Quality Laboratory (IHSWQL) for independent testing of water quality. The study was conducted during June and July, 2006. MWB officials suggested looking at those slums in Old City area that had an outbreak of jaundice in April 2005. After this outbreak, the MWB had renovated the water supply network. The renovations involved replacement of old reinforced cement concrete water pipes with cast iron pipes where water and sewage lines crossed.

The investigators, along with IHSWQL field workers, interacted with people in five slums in Old City area and discussed the proposal to test quality of drinking water in households and sought their cooperation. Considering the limited time frame of the study, resident cooperation was critical for the study. Sultan Shahi and adjoining slum areas appeared most cooperative.

Ethics approval

This study protocol was approved by the Institutional Review Board, Human Subjects Office, University of Iowa, Iowa, USA, protocol number 200603811, June 13 2006.

Water supply

The greater metropolitan area of Hyderabad, including the twin city of Secunderabad, derives water from four different dammed river reservoirs for a total supply of 840 million litres per day (MLD). The most recent of these was the Krishna Water Project which began providing water in 2003. However this is still short of the demand for rationed water (two hours of supply per connection, or ~250 L) which is estimated to be 1300 MLD. The amount required to provide continuous supply is estimated to be 1700 MLD.

Water from the river reservoirs is filtered through slow-sand filter beds and chlorinated at five central treatment facilities and then piped to small local reservoirs where the chlorination level is monitored hourly. The local reservoirs then adjust chlorination level if necessary and distribute water on a scheduled basis. The area we studied, akin to most of the metro area, receives 30 minutes to 2 hours of supply on alternate days. The Board is currently experimenting with the feasibility of continuous supply in a small suburb of Hyderabad with assistance from the World Bank, but it is difficult to see this expanded to the whole city without further water source development projects.

Most households collect their drinking water from domestic taps within 10 metres of their homes. The taps are usually constructed for personal use adjacent to or within the property, but water is often shared with neighbors who do not have a household tap. These taps are usually located in a pit at the level of the main water line since in previous years, when they were constructed, the pressure was inadequate to fill containers above ground. Due to improvements, there is now sufficient water supply in most areas to allow attachment of a temporary pipe to the 'pit tap' to fill household storage containers above ground.

Sample collection

The sample collection plan was agreed upon after discussion with the field workers. Local water reservoir managers were contacted to determine supply times in the area of study since supply is intermittent and the timings often change. Houses were selected if a married or previously married woman 18–59 years old was willing to respond to a survey, as it was likely that she would be most familiar with the water collection and handling practices of the home, and if the residents of the household would allow the field workers to take water samples and make observations of the household. Field workers were trained over two days by the investigators in the laboratory and on the field in interview and sample collection protocol.

Sampling was done directly from supply points and 20–36 hours later at the household dispensing point. Since it was important to collect paired samples, testing the same water at storage and supply levels, if a storage sample could not be collected within 36 hours of collecting a supply level sample, a new sample was collected at the supply level.

At the supply level municipal water delivery points were classified in three categories: 1) "household tap" - if the tap was located above ground and on the premises of the house, 2) "pit tap"- if the tap was located in a pit below ground level and 3) public stand posts–if the tap was constructed in a public location by the Board for communal use. Samples were collected in the same way a storage container would be filled, either through a temporary pipe attached to the tap or directly from the tap. At the household storage level the dispensing point was defined as the point where members of the household usually fill a glass for drinking and a sample was collected in the same way a glass for drinking would be filled. The drinking water dispensing container was noted as either 1) poured/tapped, 2) dipped with reserved long handled utensil, 3) dipped with other reserved utensil or 4) dipped with same utensil used for drinking. In the last case a glass used for drinking was used to dip into container and water was then poured into sampling container. If dipping was necessary it was done by a member of the household and poured into the collection bottle.

All samples were collected in a pre-sterilized rigid 125 ml polypropylene bottles treated with aqueous sodium thiosulfate for chlorine inactivation. At supply points the water was allowed to run for at least 1 minute, tested for residual chlorine and collected. Samples were shielded from light and refrigerated within 3 hours. Samples were prepared for testing within one hour of reaching the laboratory and the analysis was completed within 96 hours.

Chlorination

The residual chlorine was measured using the rapid visual color comparison method, by adding one N, N-diethyl-paraphenylene-diamine sulfate (DPD#1R Tes Tab, LaMotte, Maryland, USA) to a 5 ml water sample and comparing to chlorine color chart (LaMotte).

Bacteriological analysis

Coliform counts were determined by the conventional method (APHA 1998). The most probable number of total coliform colonies was determined by the presumptive test, using serial dilutions (10 ml, 1 ml, and 0.1 ml) in MacConkey broth and McCready's tables. Loops of culture from positive tubes were streaked on selective EMB agar plates and incubated at 37°C for 24 hours to isolate *E. coli* colonies. Colony forming units were enumerated by counting dark centered and flat colonies with metallic sheen that were confirmed to be *E. coli* by IMViC biochemical tests. Indole positive with cherry growth and gas production confirmed the presence of *E. coli*.

Survey

A total of 52 households were surveyed during June 1 and July 5, 2006, in the Sultan Shahi and adjoining areas of Hyderabad. The aims of the study were explained and permission requested to collect samples and conduct a brief survey of the household.

The survey was usually administered before sample collection to minimize surveyor bias due to knowledge of contamination status, but in 9 households it was administered after collecting the samples. The survey collected socio-demographic information using a 20-part questionnaire and 18 observation points. Questions and observations assessing selected hygiene indicators were taken from the Strategic Report 8 (Kleinau & David 2004) and modified slightly, after two days of field testing, to make locally applicable. The following indicators were selected for survey:

1. Access to hardware: availability of an improved water source (defined as "household connections, public standpipes, boreholes, protected dug wells, protected springs, and rainwater collections" Kleinau & David 2004), access to improved and hygienic toilet facility, access to hand washing place with essential supplies.
2. Essential family practices: presence of all hand washing supplies and mention of at least two critical hand washing times, and safe drinking water management.
3. Household technologies and materials: presence of soap, drinking water treatment supplies, safe drinking water dispensing method and observation of dispensing containers.

At the end of the survey an assessment of risk was made using an observational sanitary survey of the piped water supply based on Form WS-3 (WHO 1997). A score out of 7 was given to each household with 7 indicating lowest risk.

RESULTS

Demographics

There were an average of 6.26 people per home surveyed, with the average age of the respondent being 42.0 and the mean household age 28.5. Households with satisfactory drinking water were older in terms of mean household age, and showed an increased age and education of respondent, and a decreased household size, however these differences were not predictive (Table 1).

Water supply

51 source samples (47 pit taps, 3 house taps and 1 public stand-post) were analyzed for residual chlorine and bacteriological contamination. No residual chlorine was found in 4 samples (Table 2), and two were contaminated with thermotolerant coliforms (3.8%), one of which was confirmed as *E. coli*. Proportion of pit taps used was significantly greater in households with uncontaminated storage samples (Table 3).

Stored drinking water

Samples were collected from storage containers in 52 households. Only 50 households were included in the analysis (Table 1), Since 2 of the households' source samples were contaminated. Fecal coliforms were found in 18 storage samples (36%). 10 of these were confirmed to be *E. coli*. Since storage sample collection varied between 20–40 hours after source sample collection, contamination levels were compared to storage time. There was a trend showing a decrease in total coliform count with increased storage time, with a mean total coliform count of 753 CFU/100 ml in samples collected before 24 hours and 228 CFU/100 ml in samples collected after 24 hours. However the correlation with storage time was not statistically significant, with a Pearson correlation coefficient of -0.240 and $p = 0.338$.

Indicators of hygiene

Access to hardware

(1.1, 1.2, 1.3, 1.4, and 1.5) Corresponding indicator codes for measured indicators are given for reference as listed in the Strategic Report 8 (Kleinau & David 2004): all houses had access to an improved water source within 30 minutes walking distance, 23/48 were on the household premises. Availability was limited to a maximum of two hours supply on alternate days. In some instances we observed that supply was available for less than one hour. An accessible flush toilet with connection to public sewer and a superstructure providing privacy and protection from animals was within 50 metres of all surveyed houses. 7/42 households shared the toilet facility between more than one household. However only 52% of toilet facilities had a hand-washing place nearby and 26% were clean (i.e., no visible feces on floor, seat or walls). Therefore only 22% of households had access to an improved and hygienic toilet facility. 19% of houses with uncontaminated storage samples had an improved and hygienic toilet facility,

Table 1 | Demographics—Means reported with standard deviations and range (min-max)

	All households	Households with uncontaminated storage samples	Households with contaminated storage samples	*P*-value*
N	50	32	18	
Mean household age	28.46 ± 10.3 (9.83–69)	29.16 ± 11.9 (9.83–69)	27.2085 ± 6.82 (16.20–35.75)	0.525
Mean age of respondent	41.96 ± 10.4 (23–65)	42.66 ± 10.8 (23–65)	40.72 ± 9.9 (28–59)	0.534
Mean years of education	5.96 ± 4.8 (0–15)	6.44 ± 5.02 (0–15)	5.11 ± 4.4 (0–12)	0.354
Mean number of residents	6.26 ± 2.6 (1–15)	6.03 ± 2.48 (1–11)	6.67 ± 2.81 (4–15)	0.411

*Means compared by two tailed independent-samples *t*-test, equal variances assumed.

Table 2 | Water Quality at Source and Storage Points—A comparison of the proportion of samples tested with residual chlorine below 0.5 mg/L and proportion of samples which showed coliform contamination. TCC = Total Coliform Count

	Source	Storage	*P*-value*
N	51	52	
Residual chlorine <0.5 mg/L	0.08 (4)	0.96 (50)	<0.001*
Coliform contamination	0.04 (2)	0.38 (20)	0.001*
Mean TCC (MPN/100ml)	879.5	548.9	0.298†

*chi-square test.
†Two tailed independent-samples *t*-test, equal variances assumed.

as compared to 28% of households with contaminated storage samples.

Households were surveyed for the presence of all essential items for hand washing. Hand washing compliance was measured as the presence of all essential items: designated location, water, soap, clean towel and the identification of two crucial times for hand-washing without prompting. Only 12/50 households were fully hand washing compliant (Table 3). There were no significant differences in availability of essential supplies between houses with contaminated storage samples and houses with uncontaminated storage samples (Figure 1).

Household technologies and materials

(1.11, 1.12, 1.13): Safe water management was measured by considering seven elements: 1) improved water source, 2) water source within 30 min, 3) source available daily, 4) storage in covered container, 5) storage in narrow-neck container, 6) storage in elevated container, 7) container cleaned within past seven days. A safe water management score was calculated out of seven by giving houses a point for the presence of each element. All houses were within 30 minutes of an improved water source but none of these were available daily. The average safe water management score for all houses was 3.66, out of a best possible score of 7. Differences in houses with contaminated storage samples and houses with uncontaminated storage samples did not achieve statistical significance when compared by mean rank (Mann-Whitney test $p = 0.793$), by low and high risk hand washing scores (Table 2) or by each element separately (Figure 1).

Sanitary score (WHO guidelines for water supply)

Risk assessment for water supply contamination was made by observing the following factors: cleanliness of taps, tap

Table 3 | Water handling and Hygiene—proportion (*n*) of households listed for each characteristic

	All Households	Households with uncontaminated storage samples	Households with contaminated storage samples	*P*-value*
N	50	0.64 (32)	0.36 (18)	0.005
Source is pit tap	0.98 (47)	1.00 (32)	0.83 (15)	0.042
Dispensing drinking water by pouring or by tap	0.30 (15)	0.32 (10)	0.28 (5)	0.775
Treat drinking water at point of storage†	0.54 (27)	0.50 (16)	0.61 (11)	0.559
Drinking water in covered, elevated, narrow containers	0.12 (6)	0.06 (2)	0.22 (4)	0.171
Hand washing compliant (all essentials present)	0.24 (12)	0.22 (7)	0.28 (5)	0.639
Improved toilet facility	0.22 (11)	0.19 (6)	0.28 (5)	0.459
Low water handling risk score (>3/7, best = 7)	0.52 (26)	0.5 (16)	0.56 (10)	0.706
Low sanitary risk score (>4/7, best = 7)	0.34 (17)	0.34 (11)	0.33(6)	0.941

*chi-square test.
†Treat = either by chemical, boil or filter.

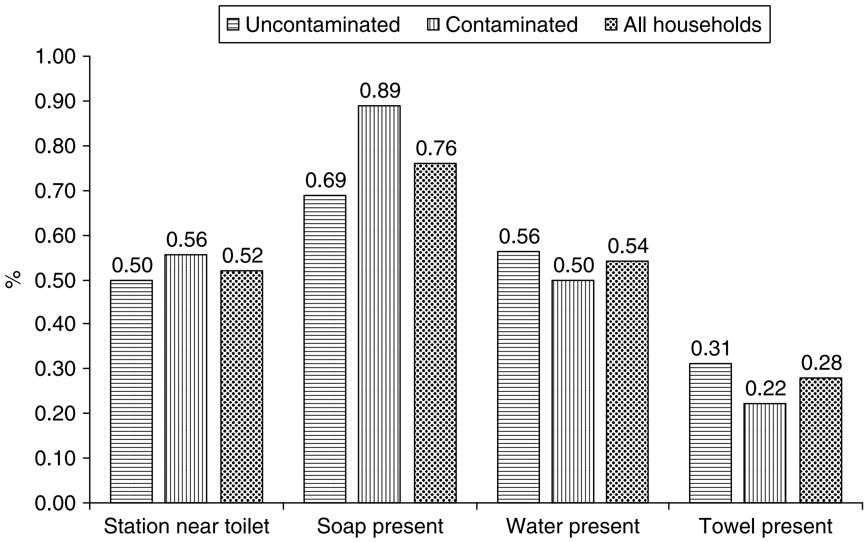

Figure 1 | Hand washing supplies—all houses had a designated hand washing station. Households with contaminated storage samples are compared to households with uncontaminated storage samples. Presence of various supplies was not significantly different between groups by chi-square test (*p*-values 0.109–0.706).

leakage, water accumulation near tap, feces within 5m of taps and pipes, proximity of sewage and water lines, and supply frequency (Form WS-3 (WHO 1997)). A higher score indicates a lower risk for water supply contamination. All houses had intermittent supply so one point was deducted. Sanitary risk scores for uncontaminated houses (mean rank = 25.8) were slightly higher than for contaminated households (mean rank = 24.8), but the differences were not statistically significant by the Mann-Whitney test, $p = 0.575$. The WHO Guidelines for Drinking Water Quality stratify sanitary risk assessment into low, medium, high and very high (WHO 2006). Due to the small sample size we compared households with low risk (less than 3 risk factors) and high risk (greater than 3 risk factors). 11/50 households were low risk, and there was no statistically significant relationship between sanitary risk level and contamination rate.

DISCUSSION

There has been a large decrease in gastrointestinal disease outbreaks in recent years which may largely be attributed to the substantial increases in water supply due to the development of the Krishna Water Project in 2003. Many in the slums reported that the water pressure has increased considerably, often eliminating the need for placing taps below ground level. Despite these developments sporadic outbreaks and in general an unacceptably high incidence of gastroenteritis continues.

All houses surveyed received filtered and chlorinated water supplied by the MWB, and rarely used alternate untreated sources such as bore-well water for drinking or cooking. However, supply is limited to alternate days, necessitating storage of drinking water in the home. Our data is consistent with other studies (Wright *et al.* 2004) showing that the majority of contamination occurs during collection, storage, and use. The WHO target for bacteriological quality of drinking water is zero *E. coli* per 100 ml, even in emergencies (WHO 2006). This goal cannot be met by improvements at the supply level alone, so interventions at the point of use are indicated.

The difference in sourcing of water from pit taps, between the contaminated and uncontaminated categories is statistically significant but in the opposite direction from what we may expect (Table 2). Pit taps may give rise to some contamination during collection of water due to its location below ground level. Hence one would expect more of the contaminated category to have obtained water from pit taps. But, the reverse is the case. As mentioned earlier, the pit taps were installed in an earlier period when water pressure in the system was generally low. At present the water pressure is quite good and people have attached flexible pipes to pit taps to collect water above ground. Thus collection through pit taps is not likely to have contributed to contamination of water.

We failed to find any statistically significant correlation of contamination to demographics, sanitation, or household practices of water handling and hygiene. It should be noted that there is a slight trend of increased contamination with increasing number and decreasing age of residents, and decreasing age and education of respondent. This trend makes intuitive sense because a larger number of residents would result in more opportunities for contamination of stored drinking water and it has been observed as a significant factor in prior studies (Teixeira & Heller 2006).

Our data shows that current household water handling and hygiene practices leave drinking water vulnerable to contamination. Only 24% of households had all essential supplies for hand washing present, and the supply most often lacking was water. The shortage of water for hand washing often leads to household members washing by dipping their hands into a single container. Kaltenthaler *et al.* (1991) found that hand washing by dipping hands into a bowel was significantly less effective than the use of large quantities of water and vigorous hand rubbing. Furthermore such hand washing practices may allow for the spread of bacteria between household members. We observed that the majority of households (Figure 2) use unsafe methods of water storage such as wide mouthed containers and dipping with the same utensil used for drinking, allowing hands to contact water and potentially introduce contamination. The safe storage of water is particularly important because even if water is disinfected, unsafe storage will lead to its contamination (Oswald *et al.* 2007).

A little over half of our study population treated their drinking water (Figure 2). Simple interventions–particularly at the household level–such as provision of chlorine tablets for household disinfection, with which the local population is very familiar, and use of safe storage containers, have been shown to be effective in intervention studies in India and other parts of the world (Clasen *et al.* 2007). A meta-analysis of interventions such as chlorination at the point of use and hand washing initiatives showed a reduction of diarrheal episodes by 39% and 45% respectively (Fewtrell *et al.* 2005). Such efforts have the potential to make a considerable impact in reducing fecal contamination of drinking water and hence the risk of gastroenteritis in our study population. However any future initiatives to improve hand washing or water treatment practices must consider including education regarding the protection of stored drinking water.

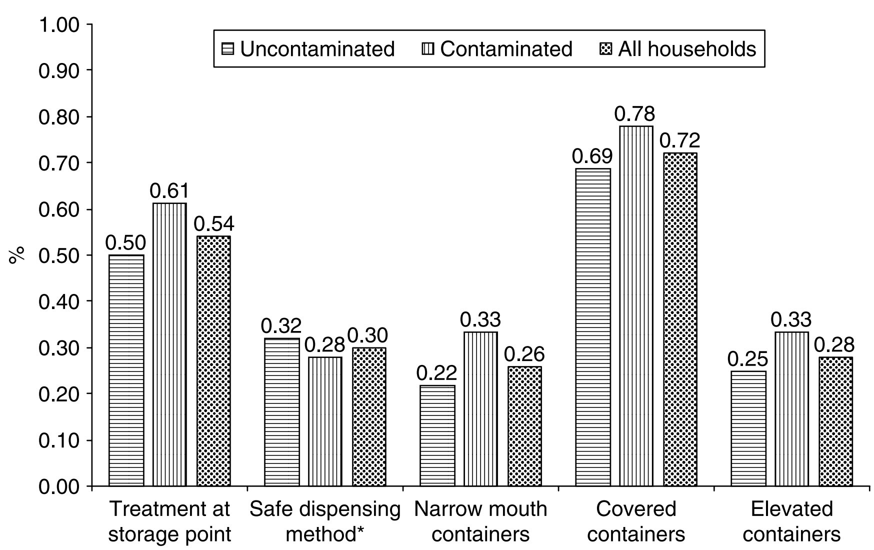

Figure 2 | Drinking water handling practices—households with contaminated storage samples compared to households with uncontaminated storage samples. Practices were not significantly different between groups by chi-square test (*p*-values 0.375–0.775). *Dispensing methods were categorized as safe if the household dispensed drinking water by pouring or using a tap.

A major limitation of this study is that the sampling of households was not randomized. Houses were selected based on availability of eligible respondent and cooperativeness. Perhaps this biased our selection toward wealthier households where it was possible for someone to stay at home during the day. In addition, since parts of the survey require the surveyor to enter the home and observe hand washing and toilet facilities, some of the field workers were initially uncomfortable and hesitant. Through training and practicing in pairs along with supervisors the importance of complete and accurate observations was reinforced. Only when they were comfortable and demonstrated competency in administering the survey were field workers sent alone. Even so, it is possible that in some cases thorough and accurate observations were not done due to field worker or participant hesitation.

A successful intervention toward reducing water-borne illness needs to be effective and accepted by the community. Our study clearly shows a decline in water quality but was unable to identify potential causes which could be targeted as an intervention. There are many potential mechanisms by which stored drinking water may be contaminated (Trevett *et al.* 2005), so before an intervention is made it would be prudent to determine the most important causes of deterioration with a larger study. Moreover, it is unclear if the rates of contamination we found are consistent long-term and if the levels of contamination are sufficient to cause significant morbidity. Studies to investigate the correlation of water handling with incidence of morbidity such as diarrheal illness as well as long-term analysis of contamination rates are necessary. It is also important to conduct an interventional study with input from the community to determine which interventions are both accepted by the community and effective in protecting water after collection.

CONCLUSIONS

The provision of safe drinking water remains a challenge, particularly in impoverished areas with poor infrastructure. However the provision of a safe tap-water supply is not enough as long as prolonged home storage of drinking water is required, as is the case in Hyderabad, because it is important to protect from contamination after collection. Significant increase in contamination was found when comparing point of supply to stored drinking water. Although specific household characteristics or water handling practices did not correlate with increased contamination, until continuous supply of drinking water is achieved there is an acute need for educating the community regarding safe water handling. Relatively inexpensive education efforts have had tremendous success in similar settings and could have a major health impact if conducted in the population we studied.

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