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Provision of private, piped water and sewerage connections and directly observed handwashing of mothers in a peri-urban community of Lima, Peru

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Abstract

OBJECTIVES—To estimate the association between improved water and sanitation access and handwashing of mothers living in a peri-urban community of Lima, Peru.

METHODS—We observed 27 mothers directly, before and after installation of private, piped water and sewerage connections in the street just outside their housing plots, and measured changes in the proportion of faecal-hand contamination and hand-to-mouth transmission events with handwashing.

RESULTS—After provision of water and sewerage connections, mothers were approximately two times more likely to be observed washing their hands within a minute of defecation, compared with when they relied on shared, external water sources and non-piped excreta disposal (RR = 2.14, 95% CI = 0.99–4.62). With piped water and sewerage available at housing plots, handwashing with or without soap occurred within a minute after 48% (10/21) of defecation events and within 15 min prior to 8% (11/136) of handling food events.

CONCLUSIONS—Handwashing increased following installation of private, piped water and sewerage connections, but its practice remained infrequent, particularly before food-related events. Infrastructural interventions should be coupled with efforts to promote hygiene and ensure access to water and soap at multiple on-plot locations convenient to mothers.

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Keywords

handwashing; water supply; sanitation; hygiene; Peru

Introduction

Globally, despite overall declines in child mortality over the past decade, diarrhoeal diseases remain a leading cause of mortality among children under 5, attributed to 11% of the 6.9 million deaths that occurred in 2011 (You *et al.* 2012). The diarrhoeal diseases that cause these deaths are preventable. Most enteric pathogens are transmitted through a number of environmental routes (Wagner & Lanoix 1958). Hands in particular can become contaminated through contact with faecal matter, during anal cleaning of adults and children after defecation (Aung Myo *et al.* 1986), which can then be transferred to the mouth through food preparation, eating or feeding a child. Handwashing with soap is an effective means of interrupting the transmission of pathogens through this faecal–oral route by removing pathogens from hands (Feachem 1984). A review of randomised controlled trials estimated that handwashing with soap could reduce diarrhoeal episodes in low- or middle-income countries by 31% (Ejemot *et al.* 2008).

In Peru, handwashing frequency in peri-urban shanty towns, or *pueblos jóvenes*, located in the coastal desert surrounding the capital city of Lima is related to the total amount of water used by the family (Gilman *et al.* 1993). However, water is a scarce and expensive resource in these communities (Adrianzen & Graham 1974). While the proportion of households in Peru with access to water and sewerage is increasing, of the population in urban areas, approximately 9% still relies on unimproved water sources and 19% still relies on unimproved or shared sanitation facilities (WHO/UNICEF 2012). In Lima, more than 800 000 people still lack potable water and thus rely on alternative sources likely providing water of limited quantity and poorer quality compared with a piped water connection (SEDAPAL 2010).

Hygiene promotion efforts could fail to bring about behaviour change under these circumstances, where infrastructural intervention remains necessary. Alternatively, the provision of private water and sewerage connections may improve domestic hygiene behaviour in the absence of educational or promotional activities. The objective of the current study was to examine the change in frequency of handwashing among mothers at specific times for the prevention of transmission of faecal material from hands to mouths after installation of private, piped water and sewerage connections.

Methods

Study site

The study was conducted in a *pueblo joven*, or shanty town, of approximately 450 households located in Las Pampas de San Juan de Miraflores, a well-described peri-urban area of Lima, Peru (Gilman *et al.* 1993; Checkley *et al.* 2003, 2004; Harvey *et al.* 2003; Oswald *et al.* 2007; Sterling *et al.* 2012).

Study design

The pre–post study involved two stages, before and after, private water and sewerage connections were installed for 62 households of three adjacent sections of the *pueblo joven*. The Peruvian non-governmental organisation A.B. PRISMA (www.prisma.org.pe) coordinated the installation of the piped water and sewerage connections. The pre-water stage took place from November 2004 and January 2005, at which time the water and sewerage connections had been installed but were not yet functioning. Lima's drinking water and sanitation authority, SEDAPAL (Servicio de Agua Potable y Alcantarillado de Lima), activated and then approved the systems for use in late January 2005. The post-water stage occurred from August to November 2005, after all 62 households had both an active water connection and a functioning sewerage discharge connection in the street immediately outside their housing plot, which were considered off-plot.

Study population

Of the 62 households that received water and sewerage connections, those that agreed to participate in both stages of the study and where the youngest child was 10 years or younger at the start of the study and cared for by their mother were included in the current analysis. Observational data from 32 households on mothers' handwashing and household water usage during the pre-water stage have been described previously (Oswald *et al.* 2008).

Data collection, coding and detection of handwashing

A team of enumerators used direct observation for a maximum of 12 h, from 7:00 AM to 7:00 PM, on three separate visits during both stages of the study. Regular meetings were held with enumerators to provide support, feedback, and maintain motivation, and they were encouraged to interact with residents during observation visits to prevent onset of fatigue but to avoid discussing hygiene issues. Observation days were scheduled according to the family's availability, so the number of days between visits and the length of visits varied. Informed consent was obtained from participants prior to the start of the study, explaining that residents would be observed for water storage practices, activities in the kitchen and the bathroom, and personal hygiene. The Ethics Committee of A.B. PRISMA and the Johns Hopkins Bloomberg School of Public Health Institutional Review Board approved the data collection protocol.

During the observations, enumerators continuously monitored the activities of mothers and recorded on paper forms the start time and duration of events. The occurrence of events was indicated under four areas: manipulation of food; placing something in a mouth; contamination with faeces; or water usage. Enumerators identified the event from a pre-coded list or wrote in a description of the event. Events were then coded during form revision based on the descriptions, prior to double data entry. Of primary interest were events when hands could have been contaminated by faecal material (faecal-hand contamination events) or faecal material on hands could have been passed to food ready for consumption or directly to the youngest child's or mother's mouth (hand-to-mouth transmission events).

Enumerators attempted to differentiate between defecation and urination using detectable clues. During pre-water observations, forms included a code to record defecation events but not urination events, and, during post-water observations, forms allowed both defecation and urination events to be specifically recorded. Pre-water, to further specify recorded defecation events, they were subsequently recoded as urination if they were 1 min or less in duration or as defecation if they were longer than 1 min. Post-water, all defecation and urination events were differentiated, recorded and coded accordingly. Other recorded faecal-hand contamination events included diaper changing or cleaning children after their defecation, both coded as cleaning-child events, and handling faeces directly or faecally soiled toilet paper, both coded as handling-faeces events.

Enumerators described all events in which hands or cutlery manipulated food or placed food directly into a mouth. The events were then coded based on the descriptions as one of two hand-to-mouth transmission events: handling food ready to be eaten or feeding the child directly and mother's eating. Eating events, such as eating a single snack, feeding a child or eating an entire meal, were coded as single events, despite possibly constituting various hand-to-mouth contacts.

The mothers' handwashing events were recorded as well as the volume and type of water and use of soap. The enumerators' method of measuring the volume of water used depended on the water source. Mothers were provided with a 1 l jug, or the vessel that they regularly used was measured, and instructed to use these vessels to collect water stored in containers. This approach allowed enumerators to record the volume of water used. After the installation of piped systems, the volume of water obtained from a tap or shower was calculated from the time that water flowed and the tap's flow rate, measured at the start of each visit.

We developed a program using Microsoft Visual Foxpro v.6.0 to identify handwashing at faecal-hand contamination and hand-to-mouth transmission events from the fully coded data (Microsoft Corporation, Redmond, WA, USA). The program determined the time after each faecal-hand contamination event until the first subsequent handwashing, and the program retrospectively determined the time since the last handwashing had occurred from the start of each hand-to-mouth transmission event. Handwashing was considered dedicated to an event if observed within a specified period of time for detection, either after a faecal-hand event or before a hand-to-mouth event. A 15-min detection period was used for comparability with a previous study (Gilman *et al.* 1993), and a 1-min detection period was also used because the longer period may not adequately reflect hygiene recommendations and could capture handwashing unrelated to the event of interest.

Participants' demographic and socioeconomic information was collected in April 2004 as part of a separate ongoing cohort study.

Statistical analysis

The main outcome was the proportion of mothers' events with dedicated handwashing, observed during household visits. The exposure of interest was a dichotomous variable indicating either the pre-water stage (0) or post-water stage (1). Observations were repeated

on the same mothers during both stages of the study, so each mother served as her own control. Because the two stages of the study were only a year apart, we did not expect confounding of the relationship of interest. Other possible determinants of hygiene behaviour, such as type of sanitation facility and total household water usage, were directly influenced by the stage of the study and not controlled for in the analysis.

The unit of analysis was each of the mother's events where handwashing is indicated based on standard hygiene. A log-binomial model was used to estimate the relative risk of handwashing before and after the installation of private water and sewerage connections, stratifying by each type of event. Generalised estimating equations with robust standard errors were used to account for repeated measures within mothers. An exchangeable working correlation structure was assumed. For each type of event, the measure of association was estimated with two models that defined the outcome as any handwashing (HW) with or without soap, using either a detection period of 15 min or 1 min.

Post-water, enumerators recorded the number, type and location of all on-plot water taps and showers installed by households following installation of the private, off-plot water and sewerage connections. This information was used to examine *post hoc* the association between the location of on-plot taps and the occurrence of handwashing. For the analysis, we identified a household's optimal tap for the outcomes: HW within 1 min after a faecal-hand contamination event (excluding urination) and HW within 15 min before eating or handling food. For faecal-hand events, an on-plot tap in the toilet was considered optimal for handwashing. The next best on-plot tap location was considered to be elsewhere in the home. Alternatively, for food-related handwashing, a kitchen tap was considered optimal, and any other tap elsewhere in the home was considered next best. If the household only had a tap in the yard, this was the least optimal. For both types of event, the household's optimal tap, out of three possible locations, was then modelled using two dichotomous variables. An additional model examined both outcomes with a variable for a private, off-plot connection vs. any on-plot tap.

Sensitivity analyses were conducted to assess the influence of two potential biases. In the pre-water stage, 16 households had their observation visits repeated because their first series of visits were conducted before the data collection form was altered. First, the association between a dichotomous variable identifying these households and handwashing was assessed in the pre-water stage only, and then, changes in the estimated association of stage with handwashing were examined, adjusting for the same variable. Changes in estimates were also assessed excluding three visits among two households in the pre-water stage conducted on or after 25 January 2005, the first date when a household was observed to have begun using their water connections.

For all regression analyses, the change in estimates from outlier exclusions was assessed. Mothers with a calculated Cook's distance (D) $>4/n$, where n equalled the number of clusters, were considered outliers. Between-group analyses for continuous variables were conducted using either Wilcoxon rank-sum tests or signed-rank tests in the case of paired observations. Chi-squared or Fisher's exact tests were used for between-group analyses of categorical variables. All statistical analyses were conducted in SAS v.9.3 (SAS Institute

Inc., Cary, NC, USA). Data cleaning was conducted in Stata v.12 (StataCorp LP, College Station, TX, USA).

Results

Study population

Of 62 households that received water and sewerage connections, 32 households were included in the pre-water observations. Of these, one household was not evaluated post-water because the mother left the community, and four families declined to participate. Mothers' demographic information and reported monthly household income from these five households were not significantly different compared with those of households included in the post-water stage (results not shown). Observation data is presented here from 27 mothers. The demographic and socioeconomic information of observed mothers is presented in Table 1. In April 2004, of 27 households, 26 (96%) used either a private or shared pit latrine. By November 2004, of 27 households, 11 (41%) were utilising sewerage connections, through a pour or cistern-flushed riser toilet, a direct pipe, or for emptying a bucket.

Direct observation visits

In the pre-water stage, data from 4 observation visits were excluded. One household's data from one visit were excluded because an earlier version of the data collection form had been used. Data from two visits in one household and one visit in another were excluded because the visits occurred after the water connections had been installed and were being used by these households. Data on handwashing are presented from a total of 1789 h of observation (pre-water = 856 h; post-water = 933 h). The median total observation time per household was 35 h, which did not differ significantly between stages ($P = 0.31$).

Observation visit durations ranged from 4 h, 46 min to 12 h, 19 min (Median = 11 h, 43 min) per household. The median length of observation visit duration did not differ significantly between stages ($P = 0.62$).

Association of private, piped water connections and handwashing

Table 2 shows the proportion of events and risk ratios for dedicated handwashing before and after the installation of private, piped water and sewerage connections. The increase in handwashing after defecation using a 15- min detection period was not significant. Mothers were approximately twice as likely to be observed washing their hands within a minute following defecation (RR = 2.14, 95% CI = 0.99–4.62) after the installation of water and sewerage infrastructure, indicating marginally significant change, compared with when they relied on a shared water source and non-piped excreta disposal. Excluding an outlier, increased the magnitude and significance of this association (RR = 2.69, 95% CI = 1.32–5.47). Post-water, handwashing with or without soap occurred within a minute of 48% of defecation events (10/21). The increases in handwashing, after cleaning of a child or handling of faeces or faecally soiled materials, between stages were not statistically significant. No change was observed in the occurrence of handwashing after urination

between stages, except when excluding an outlier (HW, 15 min: RR = 0.71, 95% CI = 0.51–1.01).

Although observed more frequently, the proportions of handling food or eating events preceded by handwashing were much lower in both stages than those for faecal-hand contamination events. Of 275 handling food events observed in both stages, only one was followed by handwashing within a minute. Using a 15-min detection period resulted in more handwashings considered dedicated to the specific events. No significant change was associated with the installation of private water and sewerage connections based on this detection period. After excluding three outliers, a significant increase in handwashing 15 min before eating was detected between stages (RR = 2.03, 95% CI = 1.09–3.77). Post-water, handwashing was observed within 15 min of 8% and 10% of handling food (11/136) and eating (28/283) events, respectively. Excluding outliers did not change the direction or interpretation of other results.

No significant association was found between an indicator for repeated visits and occurrence of handwashing at events in the pre-water stage (results not shown), and adjustment for the indicator did not meaningfully change estimates of association between stage and handwashing (results not shown). For example, the estimated measure of association between stage and any handwashing 1 min after defecation changed by only 5%, adjusting for repeated baseline visits (RR = 2.04, 95% CI = 0.92–4.52). Excluding visits that occurred on or after 25 January 2005 did not meaningfully change estimates or interpretation (results not shown).

Water and soap usage for handwashing

The median volume of water used for handwashing within a minute of faecal-hand contamination (excluding urination) and hand-to-mouth transmission events did not change significantly between stages (pre-water: 0.7 l, IQR = 0.5–1.4; post-water: 0.8 l, IQR = 0.6–1.0; $P = 0.65$). Clean (non-reused) water was used for 95% (19/20) and 89% (33/37) of these handwashings, respectively, pre- and post-water ($P = 0.65$). Soap was used during 42% (8/19, one event missing information) and 57% (21/37) of these handwashings, respectively, pre- and post-water, and this was not a significant change ($P = 0.40$).

Installation of on-plot water points and sanitation facilities

At the time of the post-water stage, of 27 households, 6 (22%) had not installed any water points within their property, while 12 (44%) had installed a single water point (Table 3). Eighty-one per cent (22/27) of households had installed a water-flush toilet, and the median reported time to its installation after the community system was activated was 5.0 months. The median reported amount paid for the on-plot systems, combining either water or sewerage connections, was 175 Peruvian Nuevos Soles (53USD), and most households (18/23) reported that a neighbour or relative did the work.

Association of on-plot taps and handwashing

Post-water, accounting for repeated measures, no significant difference was detected in the occurrence of handwashing 1 min after faecal-hand contamination events between mothers

in households with a tap in the toilet room or in the home and those with only a tap in the yard (Table 4). After excluding three outliers, mothers in households with a tap in the toilet were approximately two times more likely to wash their hands after possible faecal contamination than mothers with only a tap in their yard (RR = 2.25, 95% CI = 1.43–3.55). Having a tap elsewhere in the home did not significantly alter the proportion of faecal contamination events followed within a minute by handwashing, excluding outliers (RR = 0.75, 95% CI = 0.24–2.32).

Post-water, mothers in households without on-plot taps were more likely to wash their hands after faecal-hand contamination events than mothers with any on-plot taps (RR = 1.69, 95% CI = 0.96–2.98), and this association was strengthened by excluding two outliers (RR = 1.84, 95% CI = 1.17–2.89). No association was detected between the occurrence of handwashing 15 min before handling food or eating and the availability of a tap in the kitchen or in the home, compared with a yard tap, or comparing mothers in households with only off-plot connections vs. any on-plot taps (results not shown).

Discussion

The probability of handwashing occurring after defecation and other faecal-hand contamination events increased among the mothers in our study after the installation of private, piped water and sewerage connections external to each housing plot. Prior to this intervention, mothers and their households collected and transported water from either a shared community standpipe or a neighbour's connection and relied on non-piped excreta disposal facilities. The installation of unmetered connections that provided clean water 24 h per day represented an improvement in both access and availability. Increases in handwashing were small, however, and this infrastructural improvement in the public domain was not enough to ensure consistent handwashing at times necessary to prevent the potential transfer of faecal material from hands to mouths. The occurrence of handwashing after faecal-hand contamination events, and particularly prior to hand-to-mouth transmission events, likely remained too low to affect patterns of diarrhoeal disease. While on-plot infrastructure installed by the household subsequent to the intervention may have facilitated handwashing, not all households installed on-plot taps, so despite an improvement in water access, they continued to rely on water collected and stored in the home. Furthermore, among households that did install on-plot taps, these were not necessarily installed at optimal locations convenient for handwashing after defecation or prior to food preparation. Our findings reinforce the understanding that hygiene promotion efforts should address contextual and technological factors to permit immediate and convenient access to water for handwashing, when and where it is needed, in addition to the psychosocial determinants of individual behaviour (Devine 2010; Dreifelbis *et al.* 2013).

The type of event was a determinant of handwashing in our study. Mothers were much more likely to be observed washing their hands after defecating, handling faeces, or cleaning a child than before handling food, breastfeeding, or eating. Other studies from Peru and elsewhere have also found that handwashing is more frequent after faecal-hand events, as opposed to food-related events (PRISMA 2004; Curtis *et al.* 2009; Aunger *et al.* 2010). The authors of another study in Peru suggested that handwashing is motivated more by an

automatic reaction to contact with faeces rather than a deliberate effort to comply with the commonly reported survey response that handwashing is most necessary before eating (PRISMA 2004). These findings reflect described psychosocial determinants of hygiene behaviour, such as disgust, social norms and knowledge (Dreibelbis *et al.* 2013). The low rates of handwashing prior to food-related events indicate, as others have noted, the need for additional motivators for the promotion of handwashing prior to food preparation (Luby *et al.* 2011).

The proportion of faecal-hand contamination and hand-to-mouth transmission events when handwashing occurred differed by the length of the detection period. Earlier studies used a 15-min period for the detection of handwashing (Gilman *et al.* 1993). However, handwashing within such a long period of time may not be related to the event of interest. In our analysis, using a shorter detection period of 1 min resulted in fewer handwashings being counted. For defecation and other faecal-hand events, the use of a shorter detection period reflects current recommendations to perform handwashing as soon after as possible to minimise the opportunity for transmission of faecal material from hands to mouths, food or fomites. But based on a 1-min detection period, almost no hand-to-mouth transmission events were preceded by handwashing. Alternatively, using a 15-min detection period, the proportion of food-handling events with handwashing were closer to the rates of any handwashing (22%) found in another study from Peru (PRISMA 2004). In retrospect, a longer detection period may be warranted for this type of event because food preparation and child-feeding activities involve additional steps, rather than a single event like defecation.

A consideration for the timing of handwashing in relation to events when it is indicated will be important for subsequent studies examining the influence of water access and availability upon hygiene and health. Improvements in water and sanitation infrastructure and access within the home should equate greater convenience of handwashing facilities. An alternative conclusion from our study, although not ideally addressed by our protocol, is that provision of water and sanitation infrastructure shortened the time between events and handwashing. The proportion of defecation events with handwashing in the pre-water stage decreased when the detection period was reduced from 15 to 1 min, but this decrease was not observed in the post-water stage, which could indicate that handwashing occurred sooner after defecation after water and sewerage infrastructure were provided. Future studies should consider using a time-to-event analysis to examine time following or preceding events of interest until handwashing is observed.

Although limited information was collected on the in-home accessibility of water at locations for handwashing, our *post hoc* analysis attempted to characterise the possible relationship of water access and handwashing frequency. We found a positive and significant association between handwashing and the presence of a tap in the toilet room. Contradictorily, we observed a higher occurrence of handwashing among mothers relying on stored water compared with those with any on-plot taps. A possible explanation for our finding is that it reflects unmeasured increased availability of water closer to the handwashing location. These *post hoc* results should be taken with caution because of the small sample size and the resulting influence of outlier households. The relationship

between handwashing and locations for handwashing within the home could also be confounded by other factors, such as household income or hygiene knowledge. Despite these limitations, studies elsewhere found similar results. Studies from Ghana and Kenya found that having a water source in the house as opposed to on or off, the housing plot was associated with better hygiene behaviours (Scott *et al.* 2007; Schmidt *et al.* 2009). A study in Bangladesh found that having both water and soap available at the handwashing location was associated with handwashing after faecal contact (Luby *et al.* 2009).

The relation of water access and availability to hygiene and health remains to be fully understood. It has been suggested that reductions in diarrhoeal disease resulting from better water supply are brought about by increased availability of water, which enables better hygiene and thus reduced faecal contamination of hands (Esrey *et al.* 1985, 1991; Fewtrell *et al.* 2005). Previous work in Peru highlighted the relationship between water availability and handwashing. A significant association was found between the occurrence of handwashing after faecal-hand contamination and the total amount of water used by the family (Gilman *et al.* 1993) and having a connection within the home (PRISMA 2004). In the current study, better access to and availability of water, external to the housing plot, coupled with sanitation improvements may have increased the occurrence of handwashing after faecal-hand contamination events. The amount of water used daily for hand hygiene was low to begin with (Oswald *et al.* 2008), however, and the volume used per handwashing did not increase, indicating a lag between provision of water and changes in habit. Similarly, improvements in handwashing technique, such as the use of soap, would not be expected to change in the absence of an educational campaign.

The conclusions from our study should be tempered by its limitations. Because of the small sample size, we have attempted to be conservative with our interpretation of findings. The lack of a control group restricted our ability to control for external factors that may have affected the outcome, such as concurrent changes in the population's knowledge of the need for handwashing and hygienic behaviours. We know of no hygiene education campaigns that occurred in the community between stages of the study. So, while we have no direct measures of hygiene knowledge from either stage, the overall low occurrence of hand hygiene reflects limited hygiene knowledge.

Also without a control group, we cannot rule out increased reactivity, or reaction to observation, during the post-water stage as an explanation for the observed increases in handwashing frequency after defecation. The low overall handwashing rates and understanding that reactivity would likely decrease over time reduce the likelihood and impact of this bias. We assessed potential reactivity in our previous analysis and did not find any significant association of observation visit number and the occurrence of handwashing (Oswald *et al.* 2008). In our current analyses, greater exposure to enumerators from repeating the series of observation visits was not associated with handwashing pre-water, indicating little reactivity, and it did not meaningfully change our pre–post comparison estimates when controlled for in the regression model.

Another potential source of bias in the pre-water stage was related to the activation of the community water system. When activated, households were instructed not to utilise water

until it was approved by the water authority. During three visits after 24 January 2005, two households were observed to use installed water points before official approval. We excluded visits from these households from the primary analysis, but included visits after this date in other households where no use of taps was observed. Despite potential misclassification of exposure, it was considered conservative to include these visits, as the estimated measure of association would be closer to the null, driven down by any increased handwashing in the pre-water stage. We found no meaningful change in estimates or conclusions when all visits after this date were excluded.

The installation of in-home plumbing from the off-plot private, piped connections represents a significant expense. While residents contributed funds for the start of the project, the costs for the completion of the community's private, piped systems were covered by A.B. PRISMA with residents providing labour for the installation. Despite this support, in-home plumbing remained out of reach for many households. As such, basic and affordable technologies providing stored water and soap near the toilet and food preparation areas to facilitate and motivate handwashing in the interim may bring about considerable improvements in hand hygiene (Devine 2010; Hulland *et al.* 2013). Future research should further examine this issue, and the impact on handwashing and health of scaling rungs on the water and sanitation 'ladders' through incremental improvements in household infrastructure.

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References

- Adrianzen B, Graham GG. The high cost of being poor: water. *Archives of Environmental Health*. 1974; 28:312–315. [PubMed: 4829084]
- Aung Myo H, Khin Nwe D, Tin A, Thein H. Personal toilet after defaecation and the degree of hand contamination according to different methods used. *The Journal of Tropical Medicine and Hygiene*. 1986; 89:237–241. [PubMed: 2948025]
- Aunger R, Schmidt WP, Ranpura A, et al. Three kinds of psychological determinants for hand-washing behaviour in Kenya. *Social Science & Medicine*. 2010; 70:383–391. [PubMed: 19914758]
- Checkley W, Epstein LD, Gilman RH, Cabrera L, Black RE. Effects of acute diarrhea on linear growth in Peruvian children. *American Journal of Epidemiology*. 2003; 157:166–175. [PubMed: 12522024]
- Checkley W, Gilman RH, Black RE, et al. Effect of water and sanitation on childhood health in a poor Peruvian peri-urban community. *Lancet*. 2004; 363:112–118. [PubMed: 14726164]
- Curtis VA, Danquah LO, Aunger RV. Planned, motivated and habitual hygiene behaviour: an eleven country review. *Health Education Research*. 2009; 24:655–673. [PubMed: 19286894]
- Devine, J. [Accessed May 10, 2013] Beyond Tippy-Taps: The Role of Enabling Products Role in Scaling Up and Sustaining Hand Washing. 2010. Available at: http://www.wsscc.org/sites/default/files/publications/6_devine_beyondtippy-taps_vietnam_2010.pdf
- Dreibelbis R, Winch PJ, Leontsini E, et al. The integrated behavioural model for water, sanitation, and hygiene: a systematic review of behavioural models and a framework for designing and evaluating

- behaviour change interventions in infrastructure-restricted settings. *BMC Public Health*. 2013; 13:1015. [PubMed: 24160869]
- Ejemot RI, Ehiri JE, Meremikwu MM, Critchley JA. Hand washing for preventing diarrhoea. *Cochrane Database of Systematic Reviews*. 2008; (1):CD004265. [PubMed: 18254044]
- Esrey SA, Feachem RG, Hughes JM. Interventions for the control of diarrhoeal diseases among young children: improving water supplies and excreta disposal facilities. *Bulletin of the World Health Organization*. 1985; 63:757–772. [PubMed: 3878742]
- Esrey SA, Potash JB, Roberts L, Shiff C. Effects of improved water supply and sanitation on ascariasis, diarrhoea, dracunculiasis, hookworm infection, schistosomiasis, and trachoma. *Bulletin of the World Health Organization*. 1991; 69:609–621. [PubMed: 1835675]
- Feachem RG. Interventions for the control of diarrhoeal diseases among young children: promotion of personal and domestic hygiene. *Bulletin of the World Health Organization*. 1984; 62:467–476. [PubMed: 6331908]
- Fewtrell L, Kaufmann RB, Kay D, et al. Water, sanitation, and hygiene interventions to reduce diarrhoea in less developed countries: a systematic review and meta-analysis. *The Lancet Infectious Diseases*. 2005; 5:42–52. [PubMed: 15620560]
- Gilman RH, Marquis GS, Ventura G, et al. Water cost and availability: key determinants of family hygiene in a Peruvian shantytown. *American Journal of Public Health*. 1993; 83:1554–1558. [PubMed: 8238677]
- Harvey SA, Winch PJ, Leontsini E, et al. Domestic poultry- raising practices in a Peruvian shantytown: implications for control of *Campylobacter jejuni*-associated diarrhea. *Acta Tropica*. 2003; 86:41–54. [PubMed: 12711102]
- Hulland KR, Leontsini E, Dreifelbis R, et al. Designing a handwashing station for infrastructure-restricted communities in Bangladesh using the integrated behavioural model for water, sanitation and hygiene interventions (IBM-WASH). *BMC Public Health*. 2013; 13:877. [PubMed: 24060247]
- Luby SP, Halder AK, Tronchet C, et al. Household characteristics associated with handwashing with soap in rural Bangladesh. *The American Journal of Tropical Medicine and Hygiene*. 2009; 81:882–887. [PubMed: 19861626]
- Luby SP, Halder AK, Huda T, Unicomb L, Johnston RB. The effect of handwashing at recommended times with water alone and with soap on child diarrhea in rural Bangladesh: an observational study. *PLoS Medicine*. 2011; 8:e1001052. [PubMed: 21738452]
- Oswald WE, Lescano AG, Bern C, et al. Fecal contamination of drinking water within peri-urban households, Lima, Peru. *The American Journal of Tropical Medicine and Hygiene*. 2007; 77:699–704. [PubMed: 17978074]
- Oswald WE, Hunter GC, Lescano AG, et al. Direct observation of hygiene in a Peruvian shantytown: not enough handwashing and too little water. *Tropical Medicine & International Health*. 2008; 13:1421–1428. [PubMed: 19055623]
- PRISMA . [Accessed May 12, 2013] Joint Publication 11E: Behavioral study of handwashing with soap in peri-urban and rural areas of Peru. 2004. Available at: http://www.ehproject.org/PDF/Joint_Publications/JPO011E-PeruHandwashingformat.pdf
- Schmidt WP, Aunger R, Coombes Y, et al. Determinants of handwashing practices in Kenya: the role of media exposure, poverty and infrastructure. *Tropical Medicine & International Health*. 2009; 14:1534–1541. [PubMed: 19793069]
- Scott B, Curtis V, Rabie T, Garbrah-Aidoo N. Health in our hands, but not in our heads: understanding hygiene motivation in Ghana. *Health Policy and Planning*. 2007; 22:225–233. [PubMed: 17526639]
- SEDAPAL . [Accessed May 3, 2012] Servicio de agua potable y alcantarillado de Lima – SEDAPAL S.A.: Plan estratégico de las tecnologías de información y comunicaciones 2009–2013. 2010. Available at: <http://www.sedapal.com.pe/plan-estrategico-de-tecnologias-de-informacion-y-comunicacion-2009-2013>
- Sterling R, Miranda JJ, Gilman RH, et al. Early anthropometric indices predict short stature and overweight status in a cohort of Peruvians in early adolescence. *American Journal of Physical Anthropology*. 2012; 148:451–461. [PubMed: 22552904]

- Wagner, EG.; Lanoix, JN. Excreta Disposal for Rural Areas and Small Communities. WHO Monograph Series. World Health Organization; Geneva, Switzerland: 1958.
- WHO/UNICEF. [Accessed February 8, 2013] Estimates for the use of Improved Drinking- Water Sources: Peru. 2012. Available at: <http://www.wssinfo.org/data-estimates/introduction/>
- You, D.; New, JR.; Wardlaw, T. [Accessed February 8, 2013] Levels and trends in child mortality. 2012. Available at: http://www.childinfo.org/files/Child_Mortality_Report_2011.pdf

Table 1

Baseline demographic and socioeconomic characteristics of 27 mothers and household water and sanitation facilities in a peri-urban community of Lima, Peru

Characteristic	Distribution, No. (%) or mean $\pm$ SD (range)
Education	27 (100)
None	1 (4)
Some primary	11 (41)
Completed primary	5 (18)
Some secondary	7 (26)
Completed secondary	3 (11)
Relation to household head	27 (100)
Head	1 (4)
Daughter	2 (7)
Spouse	23 (85)
Other	1 (4)
Marital status	27 (100)
Married	5 (19)
Cohabit	19 (70)
Separated	3 (11)
Region of birth	27 (100)
Coast	6 (22)
Sierra	21 (78)
Years in residence*	26 (100)
<1	3 (12)
1–10	11 (42)
>10	12 (46)
Age (years)	34 $\pm$ 7 (22–52)
Age of youngest child (years)	3 $\pm$ 3 (<1–10)
Reported household income	
Peruvian Nuevos Soles (PEN)	705 $\pm$ 423 (60–1700)
US Dollars (USD) [†]	213 $\pm$ 128 (18–514)
Household excreta disposal (April-2004)	27 (100)
Own latrine	20 (74)
Share latrine	6 (22)
No facility available	1 (4)
Household excreta disposal (November-2004)	27 (100)
Sewerage connection	11 (41)
Latrine	16 (59)
Household water source (November-2004)	27 (100)
Community standpipe	18 (67)
Neighbour's connection	9 (33)

* One mother missing response.

[†]PEN/USD = 0.3022, Average Midpoint Rate, November 2004 (Source: <http://www.oanda.com/currency/historical-rates/>).

Table 2

Proportion of events with handwashing before and after the installation of private, piped water and sewerage connections, considering any handwashing (HW) either with or without soap within 15 min or 1 min of events of 27 mothers in a periurban community of Lima, Peru

	Pre-water		Post-water		RR*	95% CI
	Events	%	Events	%		
Defecation						
HW, 15 min	23/51	45	11/21	52	1.18	0.63–2.20
HW, 1 min	11/51	22	10/21	48	2.14	0.99–4.62
Urination						
HW, 15 min	12/36	33	30/102	29	0.83	0.53–1.28
HW, 1 min	10/36	28	20/102	20	0.70	0.38–1.31
Cleaning child after defecation						
HW, 15 min	16/42	38	20/47	42	1.11	0.66–1.88
HW, 1 min	5/42	12	13/47	28	2.10	0.74–6.00
Handling faeces						
HW, 15 min	3/6	50	11/16	69	–	–
HW, 1 min	1/6	17	9/16	56	3.38	0.67–17.06
Handling food						
HW, 15 min	11/139	8	11/136	8	0.89	0.21–3.76
HW, 1 min	0/139	0	1/136	1	–	–
Eating						
HW, 15 min	19/240	8	28/283	10	1.20	0.54–2.66
HW, 1 min	3/240	1	4/283	1	1.03	0.17–6.40

*. Binomial regression (family: binomial, link: log) adjusted for clustering at the household level (GEE). Hyphens indicate where parameter was not estimable.

Table 3

Distribution of type and number, costs, and construction of on-plot water points and sanitation facilities built after the installation of private, piped water and sewerage connections among 27 households in a peri-urban community of Lima, Peru

On-plot water points and sanitation facilities	Distribution, No. (%) or Median (IQR)
Total number of on-plot water points in household	27 (100)
0	6 (22)
1	12 (44)
2	3 (11)
3	3 (11)
4	3 (11)
Households with points of specified type and location	21 (100)
Tap in patio	13 (62)
Tap in toilet	7 (33)
Tap in living room	1 (5)
Tap in kitchen	8 (38)
Tap on second floor	1 (5)
Shower	8 (38)
Months after community system activation (January-05) until installation of first on-plot water point* ($n = 20$)	1.5 (1–5)
Sanitation facilities	27 (100)
Water-flush toilet connected to sewerage connection	22 (81)
Bucket (emptied to sewerage connection)	3 (11)
Pit latrine	1 (4)
Share toilet	1 (4)
Months after community system activation (January-05) until installation of water-flush toilet† ($n = 15$)	5.0 (3–7)
Who installed on-plot water or sanitation systems	23 (100)
Neighbour/relative	18 (78)
Professional plumber	5 (22)
Amount paid for on-plot water or sanitation system‡ ($n = 19$)	
Peruvian Nuevos Soles (PEN)	175 (45–300)
US dollars (USD)§	53 (14–91)

* One household was missing information on time until installation.

† Three households installed and connected a flush toilet prior to the sewerage system being officially activated and were excluded from distribution. Four households were missing information.

‡ Four households were missing information.

§ PEN/USD = 0.3022, Average Midpoint Rate, November 2004 (Source: <http://www.oanda.com/currency/historical-rates/>).

Table 4

After installation of private, piped water and sewerage connections, proportion of faecal-hand contamination events (excluding urination) with handwashing (HW) within 1 min, by location of most optimal water tap in household, among mothers in a peri-urban community of Lima, Peru

Optimal tap location	Distribution of optimal connection locations in households <i>n</i> = 27 (100%)			Events	%	RR*	95% CI
On-plot/Tap in yard	8 (30)	8/26	31	–	–	–	–
On-plot/Tap in home	6 (22)	5/19	26	0.83	0.47–1.48		
On-plot/Tap in toilet	7 (26)	6/15	40	0.77 [†]	0.46–1.30		
On-plot taps	21 (78)	19/60	32	–	–		
Off-plot connection	6 (22)	13/24	54	1.69	0.96–2.98		

* Binomial regression (family: binomial, link: log) adjusted for clustering at the household level (GEE). Hyphen indicates referent.

[†] Estimated risk ratio does not reflect ratio of event counts because of clustering of events.