Effect of water and sanitation on childhood health in a poor Peruvian peri-urban community

William Checkley, Robert H Gilman, Robert E Black, Leonardo D Epstein, Lilia Cabrera, Charles R Sterling, Lawrence H Moulton

Summary

Background Inadequate water and sanitation adversely affect the health of children in developing countries. We aimed to assess the effects of water and sanitation on childhood health in a birth cohort of Peruvian children.

Methods We followed up children once a day for diarrhoea and once a month for anthropometry, and obtained data for household water and sanitation at baseline.

Findings At 24 months of age, children with the worst conditions for water source, water storage, and sanitation were 1·0 cm (95% CI 0·1–0·8) shorter and had 54% (–1 to 240) more diarrhoeal episodes than did those with the best conditions. Children from households with small storage containers had 28% (1–63) more diarrhoeal episodes than did children from households with large containers. Lack of adequate sewage disposal explained a height deficit of 0·9 cm (0·2–1·7) at 24 months of age. Better water source alone did not accomplish full health benefits. In 24-month-old children from households with a water connection, those in households without adequate sewage disposal and with small storage containers were 1·8 cm (0·1–3·6) shorter than children in households with sewage and with large storage containers.

Interpretation Our findings show that nutritional status is a useful endpoint for water and sanitation interventions and underscores the need to improve sanitation in developing countries. Improved and more reliable water sources should discourage water storage at risk of becoming contaminated, decrease diarrhoeal incidence, and improve linear growth in children.

Lancet 2004; 363: 112–18
See Commentary page 94

Introduction

Improvements in water supply and sanitation have been historically documented to benefit health and improve life expectancy.1–4 In industrialised countries, death and disease due to poor water supply and sanitation are generally restricted to occasional outbreaks affecting vulnerable subpopulations. But much less progress in water and sanitation has been attained in the developing world. Such a trend is perhaps evidenced most by the slow improvements in infrastructure achieved during the International Water and Sanitation Decade (1981–90), the coverage outcomes of which were well short of expectations, especially in sanitation.5 Nonetheless, that period stimulated research on the benefits of water supply and sanitation on health, complemented studies that assessed the role of improved water and sanitation on childhood health, and reported reductions in death,6–8 in diarrhoeal diseases,9–11 and in parasitic infections.12–15 Nonetheless, the effects of improved water supply and sanitation on childhood growth have not been clearly established. Although most studies have documented benefits on weight gain11 and weight-for-height,14,15 findings have been less clear on long-term growth outcomes such as stature or height-for-age.16–21 A better understanding of the effects of water and sanitation on linear growth is warranted, in view of current knowledge on the interaction between diarrhoea and malnutrition and their adverse effects on childhood health. Here, we assess the effects of water and sanitation on linear growth, diarrhoea, and the prevalence of parasites in a birth cohort of Peruvian children.

Materials and methods

Participants

Between April, 1995, and December, 1998, we did a field study in Pampas de San Juan, a periurban community in Lima, Peru, to assess the effects of water and sanitation on linear growth, diarrhoeal diseases, and prevalence of parasites. The study design has been described elsewhere.22 Children were recruited at birth and followed up for 35 months. Only the first child born during the recruitment period was recruited in each household.

At recruitment we also did a survey of living conditions in the households, including water source, water storage, and sanitation. Households obtained water via a home connection, from cistern trucks operated by the public water company, from a community standpipe, or from a neighbour. A home connection was most frequently available in houses closest to paved roads. Households stored water in containers of varying sizes, from large cement cisterns to small uncovered containers.

Procedures

We classified water source, water storage, and sanitation into three categories each. The household water sources were classified as home connection, cistern truck or
community standpipe, and water obtained or purchased from a neighbour. If water was stored in the household, we classified the container size as: large, medium, or small. Large containers were generally cement cisterns covered with a lid, flat platform, or large plastic bag. Small containers included pots, pans, barrels, and buckets, and were often found uncovered. Other containers were generally 50 gallon (189.5 L) drums and were classified as medium sized. Water storage quality was measured as the size of the smallest container used. Household sanitation was classified as: sewage connection, latrine or equivalent, and no facility available. We defined the best conditions for water and sanitation as having a home connection and sewage, and water storage in large containers; and, worst conditions as lack of a home connection, lack of sewage connection, and water storage in small containers. We recorded the height of each child once a month to the nearest 0·1 cm. Recumbent length was measured with a wooden platform and sliding footboard in children younger than 2 years. We measured standing height in children aged 2 years or older.

Diarrhoeal surveillance was done once a day. A diarrhoeal episode began with the first day the mother indicated that the child had diarrhoea and that the child passed three or more liquid or semiliquid stools, and ended when the child passed fewer than three liquid or semiliquid stools in each of two consecutive days. We took stool samples once a week. Field workers provided mothers regularly with 5 mL plastic cups and spoons. At the beginning of the study, field workers instructed mothers on how to fill the plastic cups with fresh stool. Stool samples were tested for Giardia lamblia and Cryptosporidium parvum. G lamblia was identified in fresh samples with light microscopy, and C parvum with a modified acid-fast Ziehl-Neelsen method.

To study the effects of water and sanitation on height, we used a linear model with random effects and with a continuous autoregressive error term. This model has been described in detail by us previously. The dependent variable was height and predictors were age, water and sanitation, sex, breastfeeding, and maternal height. Random effects accounted for growth heterogeneity across children. The continuous autoregressive error term modelled the serial correlation among measurements within the same child (webappendix, http://image.thelancet.com/extras/03art2140webappendix.pdf).

To assess the individual effects of water source, water storage, and sanitation on height we used separate regression models. These models included interactions with age to estimate age-specific effects. With an additional regression model, we investigated the relation between height difference and sewage and storage in large-to-medium containers versus no sewage and storage in small containers in households with a home connection.

In a subsequent analysis we assessed age-specific differences in height between children with best conditions and children with the worst conditions for water and sanitation. We assessed whether diarrhoeal prevalence, maternal education, and household income per head confounded these effects. We investigated the interaction between diarrhoeal prevalence and water and sanitation in a regression model that included age-stratified indicator variables for worst conditions of water and sanitation, age-stratified cumulative diarrhoeal prevalence, and interaction terms.

We estimated the overall effect of diarrhoeal prevalence on height with a model that excluded water and sanitation but included the history of diarrhea. For comparability with other studies, we report results on height at 24 months of age. We restricted our analysis of best versus worst conditions for water and sanitation to children aged younger than 29 months because more than half of the cohort did not have data after this age.

We used multivariate time-to-event models to study the effects of water and sanitation on diarrhoeal incidence. Briefly, we fitted incidence data with the counting process model of Andersen and Gill. This method extends the proportional hazards model to account for repeated events in the same child. The model accounted for seasonal effects and controlled for age, nutritional status, breastfeeding, and sex. We used bootstrapped SEs, a robust method to account for disease heterogeneity (webappendix). We regressed diarrhoeal incidence on water source, water storage, and sanitation on diarrhoeal incidence in separate models to assess their individual contributions. A second model was used to determine age-specific differences in diarrhoea between children from houses with worst conditions for water and sanitation and those from houses with the best conditions. We interpreted variables on the relative hazard scale.

We also assessed whether nutritional status, maternal education, and household income per head confounded the effects of water and sanitation on diarrhoea.

Table 1: Facilities in participating households 1995–98

<table>
<thead>
<tr>
<th>Water storage</th>
<th>Large</th>
<th>Medium</th>
<th>Small</th>
</tr>
</thead>
<tbody>
<tr>
<td>Home connection</td>
<td>133 (58%)</td>
<td>85 (37%)</td>
<td>12 (5%)</td>
</tr>
<tr>
<td>Cistern truck or standpipe</td>
<td>112 (49%)</td>
<td>18 (8%)</td>
<td>40 (43%)</td>
</tr>
<tr>
<td>Neighbour</td>
<td>77 (33%)</td>
<td>43 (19%)</td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Relation between height and household water source

<table>
<thead>
<tr>
<th>Age (months)</th>
<th>Home connection Height (cm) n</th>
<th>Cistern truck or standpipe Height (cm) n</th>
<th>Water from standpipe Height (cm) n</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 to &lt;6</td>
<td>60·3 (4·8) 67</td>
<td>60·7 (4·8) 65</td>
<td>59·8 (4·7) 392</td>
</tr>
<tr>
<td>6 to &lt;12</td>
<td>69·4 (3·1) 695</td>
<td>70·5 (3·0) 62</td>
<td>68·8 (3·2) 420</td>
</tr>
<tr>
<td>12 to &lt;18</td>
<td>75·7 (2·9) 566</td>
<td>76·5 (3·0) 54</td>
<td>74·8 (3·2) 346</td>
</tr>
<tr>
<td>18 to &lt;24</td>
<td>80·8 (2·9) 458</td>
<td>80·7 (2·7) 41</td>
<td>79·8 (3·4) 253</td>
</tr>
<tr>
<td>24 to &lt;30</td>
<td>84·9 (3·0) 376</td>
<td>84·3 (3·0) 25</td>
<td>83·8 (3·2) 226</td>
</tr>
<tr>
<td>30 to &lt;35</td>
<td>88·9 (3·0) 284</td>
<td>86·9 (2·0) 23</td>
<td>88·4 (3·6) 121</td>
</tr>
</tbody>
</table>

Table 3: Relation between height and water storage

<table>
<thead>
<tr>
<th>Water source</th>
<th>Large containers Height (cm) n</th>
<th>Medium containers Height (cm) n</th>
<th>Small containers Height (cm) n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Home connection</td>
<td>60·3 (4·7) 543</td>
<td>60·3 (4·9) 87</td>
<td>59·9 (4·9) 494</td>
</tr>
<tr>
<td>Cistern truck or standpipe</td>
<td>69·1 (3·1) 564</td>
<td>69·1 (3·2) 87</td>
<td>69·1 (3·2) 490</td>
</tr>
<tr>
<td>Neighbour</td>
<td>75·7 (2·9) 486</td>
<td>75·4 (2·7) 69</td>
<td>75·0 (3·1) 411</td>
</tr>
<tr>
<td>Large containers</td>
<td>80·8 (3·0) 392</td>
<td>80·1 (2·8) 65</td>
<td>80·0 (3·2) 294</td>
</tr>
<tr>
<td>Medium containers</td>
<td>84·9 (3·0) 318</td>
<td>84·0 (3·2) 55</td>
<td>84·0 (3·2) 254</td>
</tr>
<tr>
<td>Small containers</td>
<td>88·9 (3·0) 240</td>
<td>88·1 (3·3) 38</td>
<td>88·6 (3·1) 150</td>
</tr>
</tbody>
</table>
We regressed diarrhoeal duration on water and sanitation with a mixed-effects gamma model after adjustment for age, nutritional status, breastfeeding, and sex. The gamma model we used was a generalised linear mixed model with a reciprocal link, gamma errors, and a random intercept (webappendix).

We modelled the prevalence of *C parvum* and *G lamblia* with a log-linear model using a generalised linear mixed model with a log link, binomial errors, and a random intercept. We used this model to investigate the effects of water and sanitation on the prevalence of parasitic infections after controlling for age, sex, breastfeeding, season, and nutritional status. Regression variables were interpreted on the rate ratio scale.

**Role of the funding source**

The sponsors of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report.

**Results**

Data for diarrhoeal surveillance, water source, water storage, and sanitation were available in 230 children. There were 159 551 child-days of diarrhoeal surveillance. To study the effects on height, we had data for 224 children, with 5038 height measurements. To study the effects on the prevalence of parasites, we had data for 226 children, with 21 294 weekly stool samples. 76% (175 of 230) of children had data for maternal education, and 94% (216) had data for household income per head.

Table 1 shows the facilities in the participating households. 25% (58 of 230) of the children lived in households with best conditions for water and sanitation (home connection and sewage, and water storage in large containers) and 23% (53) lived in households with worst conditions (lack of a home connection, lack of sewage and water storage in small containers).

Tables 2, 3, and 4 show age-stratified height averages by water source, water storage, and sanitation, respectively. Linear regression results are shown in figure 1. By the mixed-effects linear model we found that, at 24 months of age, children from households without sewage were 0·9 cm (95% CI 0·2–1·7) shorter than were children from households with a sewage connection; children from households that stored water in small containers were 0·8 cm (0·4–1·6) shorter than were children from households that stored water in medium to large containers; and children without a home connection were 0·6 cm (–0·1–1·4) shorter than were children with a home connection. In children with a home connection, those without sewage and whose family stored water in small containers were 1·8 cm (0·1–3·6) shorter at 24 months of age than those with sewage and whose family stored water in large containers.

Children from households with the worst conditions for water and sanitation grew less in height than children from households with the best conditions (figure 2). In a subsequent analysis with the linear model, children with the worst conditions at 24 months of age were 1·0 cm (0·1–1·8) shorter than those with the best conditions. Diarrhoeal prevalence, maternal education, and household income per head did not confound the effect of water and sanitation on height, and were not included in the final model. Furthermore, we did not find significant age-specific interactions between the cumulative...
Table 5: Diarrhoeal diseases by water and sanitation

<table>
<thead>
<tr>
<th>Water source</th>
<th>Child-days</th>
<th>Diarrhoeal episodes</th>
<th>Incidence (child-years)</th>
<th>Relative hazard (95 % CI)</th>
<th>Mean diarrhoeal duration (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Home connection</td>
<td>93 738</td>
<td>743</td>
<td>2.9</td>
<td>1.00</td>
<td>3.0</td>
</tr>
<tr>
<td>Cistern truck or standpipe</td>
<td>8202</td>
<td>75</td>
<td>3.3</td>
<td>1.09 (0.60–1.98)</td>
<td>3.5</td>
</tr>
<tr>
<td>Neighbour</td>
<td>57 611</td>
<td>569</td>
<td>3.6</td>
<td>1.21 (0.96–1.52)</td>
<td>2.8</td>
</tr>
<tr>
<td>Water storage</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Large</td>
<td>80 790</td>
<td>628</td>
<td>2.8</td>
<td>1.00</td>
<td>3.0</td>
</tr>
<tr>
<td>Medium</td>
<td>11 987</td>
<td>106</td>
<td>3.2</td>
<td>1.12 (0.64–1.96)</td>
<td>3.0</td>
</tr>
<tr>
<td>Small</td>
<td>66 774</td>
<td>653</td>
<td>3.6</td>
<td>1.28 (1.01–1.63)</td>
<td>2.8</td>
</tr>
<tr>
<td>Sanitation facility</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sewage</td>
<td>76 324</td>
<td>567</td>
<td>2.7</td>
<td>1.00</td>
<td>3.0</td>
</tr>
<tr>
<td>Latrine or equivalent</td>
<td>53 125</td>
<td>508</td>
<td>3.7</td>
<td>1.17 (0.88–1.56)</td>
<td>3.1</td>
</tr>
<tr>
<td>No facility</td>
<td>31 102</td>
<td>312</td>
<td>3.7</td>
<td>1.19 (0.89–1.60)</td>
<td>2.9</td>
</tr>
</tbody>
</table>

Data are incidence rates per row. Relative hazards estimated with time-to-event regression models, and adjusted for age, nutritional status, sex, and breastfeeding practices.

Table 3: Linear growth by level of water and sanitation, 1995–98

(Upper) mean height (cm) estimates versus age (in months). (Lower) height difference between children with worst conditions and children with best conditions of water and sanitation versus age (in months). Smoothed average line highlights time trend. *No home connection, lack of sewage, and storage in small containers. †Home connection, sewage, and storage in large containers.

Figure 3: Diarrhoeal incidence versus age stratified by level of water and sanitation, 1995–98
(Upper) diarrhoeal incidence for each month of age calculated as number of episodes per 365 child-days. *No home connection, lack of sewage, and storage in small containers. †Home connection, sewage, and storage in large containers. Thick line is smoothed average of diarrhoeal incidence for worst conditions. Thin line is smoothed average of diarrhoeal incidence for best conditions. (Lower) difference in diarrhoeal incidence between children with worst conditions and those with best conditions of water and sanitation versus age (in months). Smoothed average line highlights time trend.
Inadequate water and sanitation were associated with poorer childhood health. Children with worst conditions for water source, water storage and sanitation were 1·0 cm shorter in stature and had 54% more diarrhoeal episodes than did those with the best conditions.

Our findings show that nutritional status is a useful measure for water and sanitation interventions. In field trials, morbidity, and in particular diarrhoea, is more commonly used as an indicator of childhood health than is nutritional status. Nutritional status, as measured by child anthropometry, however, is one of the most important long-term childhood health indicators second to mortality. Our results support nutritional status as a primary endpoint in water and sanitation interventions.

Second, we found that better water source does not accomplish full health benefits if it is not accompanied by improved sanitation and better practices of water storage. This is best illustrated by our finding that among children with a home connection, those from households without sewage that stored water in small containers were significantly shorter than children from households with sewage that stored water in large containers. Our results are consistent with those of a large cross-sectional multicountry study that showed increases in height for children aged younger than 3 years ranging from 0·8 cm to 1·9 cm with better sanitation.

Third, the effect of water and sanitation on height was independent of the effect of diarrhoeal prevalence. One interpretation of these data is that some of the effect of water and sanitation might have been confounded by socioeconomics. In our analysis, however, neither household income per head nor maternal education confounded the effects of water and sanitation on height. An alternative interpretation is that inadequate water and sanitation is a source of asymptomatic gastrointestinal infections, which are known to affect adversely nutrient absorption and linear growth.30–32

Fourth, inadequate water and sanitation were associated with an increased diarrhoeal incidence but were not associated with diarrhoeal duration. Better water and sanitation probably reduces exposure to fecal contamination but might have no effect on host response once diarrhoea has occurred. Thus, water and sanitation interventions are not likely to affect the severity of diarrhoea and it underscores the need for multiple interventions to reduce mortality and severe morbidity from diarrhoea.

Fifth, inadequate water and sanitation services were associated with an increased diarrhoeal frequency and reflects the importance of water storage practices on childhood health. All households in our study stored water, even those with a water connection. Although several studies discuss the role of water source on diarrhoeal risk,31,33,34 in our study the greatest risk reductions were associated with better storage practices as measured by container size. Small containers recycle their water more frequently than large containers, however, small containers are generally kept inside the household uncovered and open to fecal contamination. By contrast, most households keep large containers outside and covered. These findings would be further strengthened by a measurement of water quality, which we did not do in this study. In a separate field trial, 70 drinking water samples were obtained from households in Pampas de San Juan. Culture on MacConkey agar revealed that 53% of the samples contained potentially pathogenic coliform bacteria (Gilman RH, personal communication). Our data are

diarhoeal prevalence and worst conditions for water and sanitation (p=0·70), as assessed by the mixed-effects linear model.

At 24 months of age, the average child from Pampas de San Juan was 2·5 cm shorter than the WHO/National Center for Health Statistics reference. Diarrhoeal prevalence since birth and throughout the first 24 months of life explained on average 0·4 cm of the height deficit (figure 1). Although the history of diarrhoeal prevalence explained 16% (0·4 cm of 2·5 cm) of the height deficit at 24 months of age, the height difference between worst and best conditions for water and sanitation explained 40% (1 cm of 2·5 cm) of this deficit.

Inadequate water and sanitation increased risk of diarrhoea. Children with the worst conditions for water and sanitation had more diarrhoea than did those with best conditions (figure 3). The multivariate time-to-event model showed that children from households with small water containers had a 28% greater frequency of diarrhoea than did children with large water containers (table 5). The risk of diarrhoea did not change significantly with less adequate levels of water source and sanitation.

A second analysis with the multivariate time-to-event model showed that the risk of diarrhoea per month of age in children with worst conditions was 2% greater (relative hazard, exp(0·018)=1·02; 95% CI 1·00–1·04, p=0·057) than in children with best conditions. At age 24 months, children with worst conditions for water and sanitation had a 54% greater frequency (exp(0·018×24)=1·54; −1 to 240) of diarrhoea than did children with best conditions. Nutritional status confounded the effect of water and sanitation on diarrhoeal incidence and was thus included in the model, but household income per head or maternal education did not.

Water and sanitation were not associated with diarrhoeal duration (table 5). The largest difference seen in diarrhoeal duration was between children in households with a latrine or equivalent and those with no facility available. However, this difference was not significant (difference 0·7 days, p=0·48). Children with the worst conditions for water and sanitation did not have longer disease episodes than children with best conditions (p=0·81), as assessed by the mixed-effects gamma regression model.

The prevalence of C parvum and G lambia was greater in children who did not have adequate sanitation than in those with adequate sanitation (table 6). Children without sewage had a 62% greater prevalence of C parvum (relative risk 1·62, 95% CI 1·03–2·50) than those with sewage, as assessed by the log linear model. The log linear model also showed that inadequate sanitation did not significantly increase the prevalence of G lambia (p=0·17).

### Table 6: Household water source, water storage practices, sanitation facilities, and prevalence of C parvum and G lambia

<table>
<thead>
<tr>
<th>Water source</th>
<th>Child-weeks</th>
<th>C parvum</th>
<th>G lambia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Home connection</td>
<td>12399</td>
<td>88 (0·7%)</td>
<td>1711 (13·8%)</td>
</tr>
<tr>
<td>Cistern truck or standpipe</td>
<td>1059</td>
<td>5 (0·5%)</td>
<td>176 (1·4%)</td>
</tr>
<tr>
<td>Neighbour</td>
<td>7836</td>
<td>73 (0·9%)</td>
<td>940 (12·0%)</td>
</tr>
<tr>
<td><strong>Water storage</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Large</td>
<td>10680</td>
<td>61 (0·7%)</td>
<td>1303 (12·9%)</td>
</tr>
<tr>
<td>Medium</td>
<td>1064</td>
<td>27 (1·1%)</td>
<td>242 (1·4%)</td>
</tr>
<tr>
<td>Small</td>
<td>8970</td>
<td>78 (0·9%)</td>
<td>1282 (14·2%)</td>
</tr>
<tr>
<td><strong>Sanitation facility</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sewage connection</td>
<td>9822</td>
<td>67 (0·7%)</td>
<td>1201 (12·2%)</td>
</tr>
<tr>
<td>Latrine or equivalent</td>
<td>7176</td>
<td>50 (0·7%)</td>
<td>960 (13·4%)</td>
</tr>
<tr>
<td>No facility</td>
<td>4296</td>
<td>49 (1·1%)</td>
<td>666 (15·5%)</td>
</tr>
</tbody>
</table>

Prevalence (%) was calculated as ratio of isolates to child-weeks, and presented for each row.
consistent with studies done in various settings, including an earlier study in a Peruvian pueblo joven, which found an association between uncovered water storage and a greater diarrhoeal incidence. We cannot exclude the possibility, however, that container size reflects socioeconomic status. Although the relative effects of water and sanitation on diarrhoea were independent of socioeconomic status (ie, household income and maternal education), unmeasured differences in access and period of time living in Pampas might explain in part household water-storage practices. Other factors that contribute to the practice of water storage, even among households with a water connection, include low water pressure, frequent water rationing, and inadequate if any indoor plumbing. Hence, although in our study population the proportion of households with a private water connection has increased from less than 1% in 1980 to more than 50% in 1995, unreliable water supply and high cost of water has forced most households in pueblo jovenes to continue to store water for long periods of time.

In summary, diarrhoea and stunting are important health concerns in children from Peruvian pueblos jovenes. Malnutrition, even when moderate, can affect cognitive ability and might lead to decreased work and social mobility later in adulthood. In our study, better water and sanitation were associated with an improved rate of linear growth and a decreased risk of diarrhoea.

Provision of water and sanitation to disadvantaged sectors might be one of the most reliable policies to achieve poverty reduction in developing countries. Such an approach requires multinational agencies and governments to make water and sanitation infrastructure one of their highest priorities.

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