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Water, Waste, and Well-Being: A Multicountry Study

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Data collected in the late 1980s from eight countries in Sub-Saharan Africa (Burundi, Ghana, Togo, and Uganda), Asia/North Africa (Sri Lanka and Morocco), and the Americas (Bolivia and Guatemala) were combined and analyzed to test whether incremental health effects regarding diarrhea and nutritional status result from incremental improvements in water and sanitation conditions. Rural (n = 11,992) and urban (n = 4,888) samples were analyzed separately. Optimal (i.e., on the premises) and intermediate (improved public water) water supplies were compared with unimproved water conditions. Optimal (flush toilets or water-seal latrines) and intermediate (latrines) sanitation levels were compared with unimproved sanitation. Nationally representative (random) samples of ever-married women aged 15–49 years, with or without children, were interviewed in all countries, and children aged 3–36 months with available weight and height data were included in the analyses. Multiple linear regression controlled for household, maternal, and child-level variables; in addition, dummy variables were included for each country. Improvements in sanitation resulted in less diarrhea and in taller and heavier children with each of the three levels of water supply. Incremental benefits in sanitation were associated with less diarrhea and with additional increases in the weights and heights of children. The effects of improved sanitation were greater among urban dwellers than among rural dwellers. Health benefits from improved water were less pronounced than those for sanitation. Benefits from improved water occurred only when sanitation was improved and only when optimal water was present. These findings suggest that public health interventions should balance epidemiologic data with the cost of services and the demand for water. There should be efforts to develop compatible technologies so that incremental improvements in service can be made. *Am J Epidemiol* 1996;143:608–23.

developing countries; diarrhea; nutrition; sanitation; water supply

In the past 15–20 years, many epidemiologic studies have examined the role of improved water supplies and sanitation in child health by measuring child diarrhea, nutrition, and mortality parameters. In general, a variety of health benefits have been reported from these improvements (1). The magnitude of these benefits, however, has been variable, ranging from large effects to no benefits whatsoever. Ideally, maximum health benefits from improved water and sanitation should be sought, yet we know relatively little about how to achieve them. Achieving maximum impact may be a function of many factors, including type of service available (e.g., water or sanitation), level of improvement (e.g., communal or household water), and the complementary mix of interventions. In an era of dwindling resources, the search for a least-cost solution may take precedence over maximizing health benefits. For example, if a communal tap is less expensive than a household connection, communal taps may be the service most frequently offered. A focus on communal water supplies, primarily to provide safe water, may lead to a smaller health impact than would potentially more costly interventions.

Presently, the number of people with access to safe water exceeds the number of those with sanitation (2). While safe water coverage is catching up with population increases, sanitation coverage is slipping. This is partly because communities express a higher demand for water and there are more skilled people and options available for providing water. If the same rates of coverage continue in the future, more people will be without adequate sanitation in the year 2000 than were in 1980. If sanitation has a larger impact on improving health than water (1), this growing disparity between water and sanitation will result in fewer benefits to the population.

Until recently, factors required to achieve maximum impact have remained unknown, because many projects usually provide only one type of service (e.g., water or sanitation) and that service has only been

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Abbreviations: CI, confidence interval; DHS, Demographic and Health Surveys.

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provided at one level (e.g., communal taps). Other limitations of past studies have been insufficient sample sizes, failure to control for confounding factors, study of populations whose health was not compromised, and study of populations who usually had just received an intervention, allowing little time for them to adjust to new conditions (3, 4). Recently obtained data from the international Demographic and Health Surveys have provided us with an opportunity to examine the issues surrounding maximization of health impacts while correcting for the limitations of previous studies. The data are representative of each country and pertain to a random selection of people, regardless of their type or level of service and regardless of how long they have had access to that service. Several countries were included in this study in order to obtain a sample with a sufficient number of children aged 3–36 months, the most vulnerable population. Countries selected were those known to have problems with diarrhea and malnutrition. In addition, data on potentially confounding variables were available and were included in the analyses.

The objective of this study was to examine whether incremental improvements in water and sanitation services result in incremental improvements in health. Two major outcomes, anthropometric measures and diarrhea prevalence in children, were analyzed. With regard to water, it is generally expected that the health impact will increase as societies upgrade from less accessible, poor quality water to community facilities and finally to household connections. With regard to sanitation, it is expected that health status will be best with flush toilets, next best with pit latrines, and worst without any facilities.

MATERIALS AND METHODS

Nationally representative data from eight countries (5–12) were used in this study. Selection of countries was based on several factors, the first being the availability of a data set from the Demographic and Health Surveys (DHS) as of March 15, 1992. The DHS is a program funded by the US Agency for International Development with technical assistance from Macro International, Inc. (Calverton, Maryland). Thirty data sets from the DHS were available. Of these, only 15 countries had data on the appropriate variables: diarrhea prevalence; weight, height, age, and sex of children; source of drinking water; and type of sanitation facility. Of the 15 countries with information on the appropriate variables, data from two were unavailable because of contractual arrangements between the DHS and those countries, and another data set was a sample for only part of a country. Of the 12 remaining countries, selection was based on several criteria: representation of Africa, Asia, and Latin America, with a focus on Africa because the health status of the people there is poorer and water and sanitation coverage is lower than in other parts of the world; known problems with diarrhea or malnutrition; and sample size, with preference being given to countries with larger samples. The eight countries selected were Burundi, Ghana, Togo, and Uganda in Sub-Saharan Africa; Morocco and Sri Lanka in the Middle East and Asia; and Bolivia and Guatemala in Latin America. The four countries not selected were Columbia, the Dominican Republic, Paraguay, and Thailand.

The DHS data contained information obtained from ever-married women aged 15–49 years, regardless of whether they had any preschool children, in a cross-section of time, from nationally representative (random) samples in each country. All countries used the same standard questionnaire. The variables included in the questionnaire were defined and responses were collected using similar methodologies. A more detailed description of the methods used for each study can be found elsewhere (5–12). The eight countries included in the study had anthropometric data on children aged 3–36 months, ranging from nearly 1,300 children in Togo to 2,500 in Morocco and Bolivia. In total, data on about 17,000 children, nearly 5,000 of them living in an urban environment, were available for analysis. Data from each country were collected toward the end of the 1980s, representing coverage levels at the end of the International Drinking Water Supply and Sanitation Decade.

The data on diarrhea were obtained by asking mothers, according to their judgement, about the occurrence of diarrhea in their children during the previous 24 hours. The anthropometric data were obtained by data collectors who had been trained to weigh and measure children using standard techniques. Children were weighed in hanging scales which went up to 25 kg in 100-g increments. Their heights were measured with portable measuring boards that went up to 120 cm in 0.1-cm increments. Children under the age of 24 months were measured in a supine position, while older children were measured standing.

For nutritional status, three indices were created from knowledge of a child's age, sex, weight, and stature: height-for-age, weight-for age, and weight-for-height (based on the algorithm developed by the World Health Organization and the Centers for Disease Control (13)). *Z* scores were used as the continuous outcome (14), because *Z* scores approximate the normal curve and facilitate analyses across countries over time. Low height-for age indicates chronic nutritional insults; low weight-for-height indicates acute nutritional insults; and low weight-for age indicates either chronic or acute insults or both.

Communities without water or sanitation coverage rely on unimproved water supplies (e.g., rivers, ponds, lakes, and unprotected springs) or unimproved sanitation facilities (e.g., holes in the ground, bushes, and other places where human waste is not contained to prevent it from contaminating the environment). Communities considered to have improved water and sanitation do not all have the same services. There is wide variation in types of service, but for the purpose of this study, service was classified as either "intermediate" or "optimal." Intermediate-type water facilities were defined as a centrally located hand pump, tap, or well. Optimal water supplies were those located on the premises or inside the household. For sanitation, intermediate service was defined as a pit latrine or a similar fecal disposal system. A water-based system or flush toilet was considered the optimal type of system.

Potentially confounding variables related to household, maternal, and child characteristics were included in the analyses. Data on most of these variables were dichotomous in their original form. Other variables were further defined from their original codes. For example, mother's education, number of household members, number of children aged ≤5 years in the home, maternal age, pregnancy interval, age of child, and birth order were dichotomized or categorized to increase precision and to combine cells containing few cases.

Data for each country were analyzed (15) separately before the files were appended to each other. Multiple regression analysis was performed for each country, and the variables found to be important potential confounders (16) at $p \leq 0.20$ were included in the multiple-country file. Some of these variables were found to be significant for all countries, others for only some countries. Any variable found to be important for an individual country was included in the multicountry analysis. In some instances, data on a variable found to be important in one country were unavailable for another country. In such instances, the variable was not included in the multicountry analysis.

One of the primary reasons for doing a multicountry analysis was to increase sample size so that urban and rural populations could be analyzed separately, because of general differences between urban and rural living conditions that could not be captured in combined analysis (e.g., exposure to new ideas, exposure to different forms of pollution, or density of living conditions). Therefore, urban and rural samples were always analyzed separately. Of the 16,880 children available in the sample, 11,992 were rural and 4,888 were urban. A dummy variable was created for each country for inclusion in the multicountry analysis.

Nine levels of water and sanitation services were constructed: group 1, unimproved water and unimproved sanitation; group 2, intermediate water and unimproved sanitation; group 3, optimal water and unimproved sanitation; group 4, unimproved water and intermediate sanitation; group 5, intermediate water and intermediate sanitation; group 6, optimal water and intermediate sanitation; group 7, unimproved water and optimal sanitation; group 8, intermediate water and optimal sanitation; and group 9, optimal water and optimal sanitation. Group 1 served as the default group when all groups were included simultaneously in the same model (model 1).

The characteristics of children in each service category may have differed. For example, children with optimal sanitation may have been very different from children with unimproved sanitation with regard to a number of key variables, making multiple regression potentially difficult. Thus, a series of six stratified analyses were also conducted (model 2) in which children with each type of service were analyzed separately from children with other types of service. Model 2a included only children with unimproved sanitation, thus comparing the incremental effect of water service levels among children with unimproved sanitation. This type of analysis was repeated for each of the other service categories: model 2b (incremental effects of water at intermediate sanitation), model 2c (incremental effects of water at optimal sanitation), model 2d (incremental effects of sanitation with unimproved water), model 2e (incremental effects of sanitation with intermediate water), and model 2f (incremental effects of sanitation with optimal water). Analyses for models 1 and 2 were carried out separately for rural and urban children.

Ordinary least squares estimation was employed for each outcome—diarrhea in the previous 24 hours and height-for-age, weight-for-age, and weight-for-height Z scores—to estimate differences in diarrhea prevalence and Z scores. For all multicountry models analyzed, models 1 and 2a–2f, multiple linear regression analyses were conducted. A type I error of 0.05, two-tailed, was used for comparison between service categories. Therefore, all confidence intervals were 95 percent confidence intervals.

RESULTS

The prevalences of diarrhea were similar in the urban and rural samples (table 1), with one in six children experiencing diarrhea at any point in time. The prevalence of diarrhea was highest in Bolivia (22

TABLE 1. Summary of outcome variables among urban and rural children in a study of improvements in water and sanitation facilities

Country	Sample size	Age of child (months)	Diarrhea prevalence (%)	Height-for-age Z score Mean (SD*)	Weight-for-age Z score Mean (SD)	Weight-for-height Z score Mean (SD)
			Urban children			
Bolivia	1,393	18.7	22.0	−1.19 (1.48)	−0.57 (1.20)	0.22 (1.05)
Burundi	241	18.6	13.4	−1.13 (1.57)	−0.93 (1.36)	−0.26 (1.16)
Ghana	520	19.0	16.2	−1.20 (1.37)	−1.28 (1.14)	−0.67 (0.94)
Guatemala	621	18.7	12.9	−1.94 (1.45)	−1.24 (1.19)	0.02 (0.93)
Morocco	1,064	19.0	22.5	−0.84 (1.36)	−0.42 (1.17)	0.15 (1.07)
Sri Lanka	282	18.9	1.6	−1.00 (1.08)	−1.36 (1.05)	−0.88 (0.92)
Togo	384	19.0	15.7	−1.06 (1.39)	−0.85 (1.26)	−0.21 (1.05)
Uganda	383	17.7	19.5	−1.29 (1.48)	−0.71 (1.28)	0.16 (1.06)
Total	4,888	18.7	17.9	−1.19 (1.45)	−0.79 (1.24)	−0.04 (1.08)
			Rural children			
Bolivia	1,208	18.9	22.2	−1.77 (1.45)	−0.95 (1.16)	0.21 (1.04)
Burundi	1,615	18.7	11.0	−1.89 (1.43)	−1.64 (1.14)	−0.52 (0.98)
Ghana	1,311	18.3	17.3	−1.38 (1.41)	−1.41 (1.19)	−0.71 (0.95)
Guatemala	1,604	18.4	14.4	−2.40 (1.35)	−1.57 (1.15)	−0.04 (0.93)
Morocco	1,929	18.7	25.1	−1.33 (1.55)	−0.95 (1.34)	−0.14 (1.10)
Sri Lanka	1,462	19.3	3.4	−1.35 (1.17)	−1.65 (1.02)	−1.02 (0.90)
Togo	919	17.9	19.8	−1.49 (1.36)	−1.25 (1.30)	−0.39 (1.06)
Uganda	1,944	18.2	18.1	−1.83 (1.44)	−1.20 (1.23)	−0.03 (1.00)
Total	11,992	18.6	16.4	−1.69 (1.45)	−1.32 (1.23)	−0.31 (1.06)

*SD, standard deviation.

percent) and Morocco (23–25 percent) and lowest in Sri Lanka (2–3 percent). The nutritional status of children was better in urban areas than in rural areas. This was true for all three *Z* score indices: height-for-age, weight-for-age, and weight-for-height. Chronic malnutrition (low height-for-age) was highest in Guatemala and lowest in Morocco. Acute malnutrition (low weight-for-height) was not a problem in either urban or rural children, with the possible exception of Sri Lanka. Males and females were represented equally, and the average child was 18–19 months of age. The average urban child was 3.6 cm shorter and 1.0 kg lighter than the reference child, as defined by the World Health Organization and the Centers for Disease Control (17). The corresponding figures for the average rural child were 5.1 cm and 1.6 kg.

Two countries were disproportionately represented in the urban sample (table 1), with Bolivia and Morocco each contributing more than 20 percent. Burundi, Sri Lanka, Togo, and Uganda, all predominantly rural countries, each contributed less than 10 percent of the total urban sample. The majority of people in the urban sample came from families with improved water and sanitation services, and the majority of children came from families with optimal water and sanitation levels (table 2). Each country contributed 7–16 percent of the rural sample (table 1), and the majority had intermediate levels of service (table 3). Some countries were overrepresented at certain service levels, while others were underrepresented, and in some instances, certain countries did not have all nine levels of service. This was true for both the urban and rural samples.

Most of the potentially confounding variables were not similar across all nine service categories in the urban and rural samples (tables 2 and 3). In general, as the level of service increased, so did socioeconomic status. A higher percentage of people with optimal services, versus those with no service or intermediate service, had bicycles and motorcycles, were better educated, had fewer children aged ≤5 years, and breast-fed for a shorter period of time.

The results from the multiple regression analysis (model 1) of diarrhea and the anthropometric indices are shown in tables 4 (urban) and 5 (rural). These regression analyses included the variables shown in tables 2 (urban) and 3 (rural). For diarrhea, the beta coefficient indicates the difference in diarrhea prevalence in comparison with the reference category. A negative number means less diarrhea in comparison with the reference group. For the anthropometric indices, the beta coefficient indicates the difference in *Z* scores, or standard deviations, from the reference category. A positive number indicates better growth (e.g.,

TABLE 2. Distribution (%) of potentially confounding variables among urban children in a study of improvements in water and sanitation facilities

Variable	Water: / Sanitation:	Group 1: None* / None (n = 99)	Group 2: Int* / None (n = 405)	Group 3: Opt* / None (n = 340)	Group 4: None / Int (n = 254)	Group 5: Int / Int (n = 813)	Group 6: Opt / Int (n = 722)	Group 7: None / Opt (n = 149)	Group 8: Int / Opt (n = 289)	Group 9: Opt / Opt (n = 1,817)	p value
Country											
Bolivia		55	42	70	26	13	26	15	10	28	<0.00
Burundi		0	0	0	0	21	3	0	0	2	
Ghana		17	9	9	19	9	37	1	0	3	
Guatemala		9	9	5	11	12	19	24	8	13	
Morocco		11	4	16	2	1	7	43	18	44	
Sri Lanka		2	4	0	3	3	1	13	41	5	
Togo		6	32	0	2	23	2	0	7	1	
Uganda		0	1	0	37	18	6	4	15	3	
Bicycle (yes)		16	23	22	24	20	14	31	25	23	<0.00
Motorcycle (yes)		6	6	7	7	11	6	16	9	14	<0.00
Household members											
<4		19	22	31	24	25	26	19	22	21	<0.00
5–7		56	44	46	42	40	44	53	45	44	
8–10		11	21	18	24	23	20	15	20	23	
≥11		14	13	5	10	12	10	13	13	12	
≤1 sibling aged ≤5 years		25	27	34	30	32	33	29	39	39	<0.00
Maternal education											
None		40	39	31	21	27	23	34	20	31	<0.00
Primary school		44	40	44	53	52	54	27	27	26	
Secondary school or higher		15	21	25	26	22	23	39	53	43	
Mother married (yes)		95	91	93	88	88	91	97	95	93	<0.00
Mother pregnant (yes)		9	10	11	11	10	9	7	11	8	<0.39
Mother's age (years)											
<20		7	8	6	8	8	8	3	11	5	<0.00
20–29		51	49	57	59	57	58	54	58	53	
30–39		33	35	31	29	29	29	39	28	37	
≥40		9	7	7	4	6	5	4	3	5	
Pregnancy interval											
Previous <15 months		4	6	11	13	9	9	10	6	10	<0.02
Next <15 months		1	2	4	4	3	3	5	7	6	<0.00
Child's sex (male)		54	52	44	53	48	50	54	53	51	<0.26
Child a twin (yes)		4	2	1	3	2	2	0	3	2	<0.06
Percentage of life breastfed		77	79	74	71	78	72	65	65	57	<0.00
Child is firstborn		21	15	18	19	20	22	21	29	25	<0.00
Child's age (months)											
3–6		17	12	10	15	15	11	14	10	13	<0.65
7–12		17	18	21	20	20	20	20	21	20	
13–24		37	38	36	33	35	35	39	37	34	
25–36		28	32	33	32	30	34	27	33	34	

* None, no improved service; Int, intermediate service; Opt, optimal service.

taller or heavier children) in comparison with the reference category. Graphs have been used to illustrate the results of the regression analyses. Results from models 1 and 2 are shown along with the unadjusted results. Results from the stratified analyses (model 2) were similar to those from the multiple regression (model 1). Therefore, model 1 coefficients were used for interpretation.

Diarrhea

Several observations can be made about the association of water and sanitation with diarrhea in the urban sample (figure 1). First, the groups of children with the highest rates of diarrhea generally appeared among persons without improved sanitation, and the groups with the lowest rates of diarrhea were generally found among those with optimal sanitation. Second, the adjusted, stratified, and unadjusted differences in diarrhea were similar in magnitude to each other.

Third, the difference in diarrhea prevalence from improvements in sanitation was largest when improved water was absent and was smallest when optimal water supplies were present. For instance, the difference in diarrhea prevalence between optimal sanitation and unimproved sanitation was 11 percent (95 percent confidence interval (CI) 1.2 to 20.8) when both of the groups had no improved water, 5.2 percent (95 percent CI −0.9 to 11.4) when both groups had intermediate water, and 4.3 percent (95 percent CI

TABLE 3. Distribution (%) of potentially confounding variables among rural children in a study of improvements in water and sanitation facilities

Variable	Group 1: Water: None* Sanitation: None (*n* = 1,628)	Group 2: Water: Int* Sanitation: None (*n* = 2,908)	Group 3: Water: Opt* Sanitation: None (*n* = 462)	Group 4: Water: None Sanitation: Int (*n* = 2,510)	Group 5: Water: Int Sanitation: Int (*n* = 2,985)	Group 6: Water: Opt Sanitation: Int (*n* = 445)	Group 7: Water: None Sanitation: Opt (*n* = 162)	Group 8: Water: Int Sanitation: Opt (*n* = 572)	Group 9: Water: Opt Sanitation: Opt (*n* = 320)	*p* value
Country										
Bolivia	27	11	34	3	4	9	1	0	19	<0.00
Burundi	2	1	0	20	35	0	1	0	3	
Ghana	18	4	3	24	5	28	1	0	2	
Guatemala	17	13	34	6	11	59	4	2	16	
Morocco	1	44	30	0	2	2	10	46	47	
Sri Lanka	10	6	0	14	10	1	80	51	11	
Togo	15	15	0	3	5	0	0	0	0	
Uganda	10	6	0	31	28	1	4	0	3	
Bicycle (yes)	22	21	14	21	25	12	34	33	28	<0.00
Motorcycle (yes)	2	4	8	1	2	2	5	17	14	<0.00
Household members										
<4	23	16	19	21	20	17	23	15	19	<0.00
5–7	43	39	43	46	43	44	44	37	38	
8–10	22	27	21	22	24	24	20	25	22	
≥11	11	18	16	11	13	15	12	23	21	
≤1 sibling aged ≤5 years	25	21	20	27	27	25	45	36	28	<0.00
Maternal education										
None	55	72	53	45	52	36	13	45	43	<0.00
Primary school	38	23	43	43	38	56	30	10	26	
Secondary school or higher	6	5	4	12	10	8	57	45	31	
Mother married (yes)	92	96	93	92	92	89	98	97	95	<0.00
Mother pregnant (yes)	12	12	12	12	11	12	7	10	13	>0.50
Mother's age (years)										
<20	10	5	6	8	6	12	6	4	6	<0.00
20–29	50	51	52	54	52	54	57	55	58	
30–39	32	34	36	33	34	30	34	36	32	
≥40	8	9	5	6	8	4	3	6	5	
Pregnancy interval										
Previous <15 months	7	9	9	6	7	11	5	6	13	<0.00
Next <15 months	2	3	3	3	3	4	6	5	7	<0.00
Child's sex (male)	51	51	50	49	50	49	49	49	53	>0.80
Child a twin (yes)	2	2	2	2	1	2	1	2	1	>0.30
Percentage of life breastfed	83	80	78	82	82	73	76	72	64	<0.00
Child is firstborn	18	14	14	18	18	22	32	27	25	<0.00
Child's age (months)										
3–6	12	15	13	13	12	15	17	12	12	>0.10
7–12	20	18	21	20	21	18	17	19	21	
13–24	38	35	35	35	35	34	28	38	38	
25–36	30	32	31	32	32	33	37	32	30	

* None, no improved service; Int, intermediate service; Opt, optimal service.

−0.4 to 9.0) when both groups had optimal water supplies. The differences in the absolute magnitude of diarrhea can also be expressed as a percentage reduction. The percentage reduction in diarrhea from having optimal sanitation versus no improved sanitation was 44 in the absence of improved water, 13 in the presence of intermediate water supplies, and 19 in the presence of optimal water.

Fourth, differences in diarrhea prevalence were greater when sanitation levels changed than when water levels changed. An improvement from no water and no sanitation to only intermediate water was associated with 2.1 percent (95 percent CI −6.2 to 10.6) fewer diarrhea episodes, whereas a change from no water and no sanitation to only intermediate sanitation was associated with 8.5 percent (95 percent CI 0.5 to 17.5) fewer diarrhea episodes. Thus, 6.4 percent (95 percent CI 0.0 to 12.6) fewer diarrhea episodes would be expected following sanitation improvements than following water improvements.

Finally, no significant differences in diarrhea were found with any changes in level of water supply, regardless of the type of sanitation available. For instance, comparison of the first, fourth, and seventh groups of bars in figure 1 indicate small, insignificant differences in diarrhea when no sanitation was present. This lack of an effect due to water was found not only in the urban sample but also in the rural sample. Sanitation did not have an effect on diarrhea in the rural sample.

TABLE 4. Regression coefficients (model 1) for the relation of water and sanitation services with diarrhea and anthropometric factors among 4,888 urban children aged 3–36 months

Variable (reference category)	Diarrhea		Height-for-age *Z* score		Weight-for-age *Z* score		Weight-for-height *Z* score	
	β	SE*	β	SE	β	SE	β	SE
Water/sanitation group† (group 1)								
2	−0.022	0.043	−0.113	0.147	0.010	0.124	0.138	0.113
3	−0.061	0.043	−0.084	0.149	0.067	0.126	0.174	0.115
4	−0.085	0.046	0.262	0.157	0.205	0.133	0.099	0.121
5	−0.053	0.042	0.196	0.142	0.105	0.120	0.028	0.110
6	−0.068	0.041	0.278	0.141	0.246	0.119	0.131	0.109
7	−0.110	0.050	0.491	0.171	0.273	0.145	−0.013	0.132
8	−0.074	0.046	0.451	0.157	0.290	0.133	0.070	0.121
9	−0.104	0.040	0.563	0.137	0.411	0.116	0.136	0.106
Bicycle (no)	−0.022	0.014	0.117	0.047	0.103	0.039	0.035	0.036
Motorcycle (no)	0.003	0.019	0.234	0.064	0.196	0.054	0.068	0.049
Household members (<4)								
5–7	0.011	0.015	−0.056	0.051	−0.067	0.043	−0.026	0.039
8–10	0.017	0.018	0.184	0.060	−0.201	0.051	−0.086	0.046
≥11	0.053	0.021	−0.068	0.072	−0.068	0.061	−0.025	0.056
≤1 sibling aged ≤5 years (>2)	−0.007	0.013	0.162	0.046	0.124	0.039	0.028	0.035
Maternal education (none)								
Primary education	0.015	0.015	0.270	0.051	0.198	0.043	0.030	0.039
Secondary/higher education	−0.004	0.017	0.584	0.059	0.420	0.050	0.072	0.045
Married (no)	−0.029	0.020	0.132	0.070	0.113	0.059	0.035	0.054
Pregnant (no)	0.014	0.019	−0.180	0.066	−0.086	0.056	0.014	0.051
Maternal age in years (<20 years)								
20–29	−0.024	0.024	0.039	0.081	0.060	0.069	0.029	0.063
30–39	−0.048	0.026	0.200	0.089	0.111	0.075	−0.031	0.069
40–49	−0.062	0.034	0.131	0.117	0.138	0.099	0.039	0.090
Previous pregnancy interval ≤15 months (>15 months)	0.014	0.019	−0.271	0.066	−0.264	0.056	−0.110	0.051
Subsequent pregnancy interval ≤15 months (>15 months)	−0.055	0.028	0.155	0.097	0.141	0.082	0.050	0.075
Male sex (female)	0.020	0.011	0.032	0.037	0.029	0.031	−0.014	0.029
Twin (single birth)	0.069	0.040	−0.570	0.140	−0.437	0.118	−0.112	0.108
Percentage of life breastfed	0.000	0.000	−0.001	0.001	−0.002	0.001	−0.001	0.001
Firstborn (second or higher)	−0.019	0.016	0.007	0.057	−0.047	0.048	−0.055	0.044
Child's age in months (3–6 months)								
7–12	0.092	0.019	−0.453	0.067	−0.867	0.057	−0.555	0.052
13–24	0.055	0.018	−1.123	0.063	−1.280	0.054	−0.804	0.049
25–36	−0.003	0.020	−1.181	0.070	−1.259	0.059	−0.657	0.054
Country (Bolivia)								
Burundi	−0.111	0.029	0.221	0.099	−0.188	0.084	−0.404	0.077
Ghana	−0.081	0.022	0.231	0.074	−0.530	0.063	−0.857	0.057
Guatemala	−0.088	0.019	−0.686	0.066	−0.604	0.056	−0.175	0.051
Morocco	0.033	0.020	0.326	0.068	0.135	0.057	−0.078	0.052
Sri Lanka	−0.183	0.027	−0.105	0.094	−0.944	0.079	−1.086	0.072
Togo	−0.100	0.025	0.428	0.086	−0.060	0.072	−0.376	0.066
Uganda	−0.043	0.024	−0.052	0.082	−0.076	0.070	−0.035	0.064
Constant	0.275	0.057	−1.112	0.194	−0.072	0.164	0.749	0.150

* SE, standard error.

† Group 1, unimproved water and unimproved sanitation; group 2, intermediate water and unimproved sanitation; group 3, optimal water and unimproved sanitation; group 4, unimproved water and intermediate sanitation; group 5, intermediate water and intermediate sanitation; group 6, optimal water and intermediate sanitation; group 7, unimproved water and optimal sanitation; group 8, intermediate water and optimal sanitation; and group 9, optimal water and optimal sanitation.

Height-for-age *Z* scores

A number of observations can be made about the association between sanitation and heights of children. First, unadjusted, stratified, and adjusted effects of improved sanitation were similar and positive in urban (figure 2) and rural (figure 3) children. Second, sanitation had a larger effect in urban dwellers (figure 2 and table 4) than in rural dwellers (figure 3 and table 5). For instance, the increase in height-for-age *Z* scores between no improved sanitation and intermediate sanitation at the three different levels of water supply ranged from 0.262 to 0.361 in urban children and from 0.059 to 0.224 in rural children.

Third, incremental improvements in sanitation were associated with incremental increases in children's height-for-age *Z* scores. For example, in urban children without improved water, the difference between intermediate sanitation and no sanitation was 0.262 *Z* scores (95 percent CI −0.046 to 0.570). The difference between optimal sanitation and intermediate sanitation was associated with an additional 0.299 *Z* scores (95 percent CI −0.044 to 0.502), again if no improved water was present. These incremental improvements in sanitation were associated with increases in height at all levels of water supply, in both urban (figure 2) and rural (figure 3) children.

TABLE 5. Regression coefficients (model 1) for the relation of water and sanitation services with diarrhea and anthropometric factors among 11,992 rural children aged 3–36 months

Variable (reference category)	Diarrhea		Height-for-age *Z* score		Weight-for-age *Z* score		Weight-for-height *Z* score	
	β	SE*	β	SE	β	SE	β	SE
Water/sanitation group† (group 1)								
2	−0.017	0.012	−0.014	0.045	0.017	0.037	0.060	0.032
3	0.004	0.020	0.010	0.071	0.083	0.060	0.113	0.052
4	−0.016	0.013	0.059	0.046	0.072	0.038	0.058	0.033
5	−0.015	0.013	0.126	0.045	0.115	0.038	0.057	0.033
6	0.007	0.020	0.234	0.073	0.221	0.061	0.118	0.053
7	−0.011	0.031	0.254	0.113	0.288	0.095	0.170	0.082
8	0.017	0.020	0.224	0.071	0.215	0.060	0.107	0.052
9	−0.016	0.023	0.630	0.085	0.543	0.071	0.193	0.061
Bicycle (no)	0.007	0.009	0.096	0.031	0.082	0.026	0.019	0.022
Motorcycle (no)	−0.032	0.019	0.173	0.067	0.147	0.056	0.061	0.048
Household members (<4)								
5–7	−0.007	0.010	−0.035	0.035	0.005	0.030	0.026	0.026
8–10	−0.014	0.011	0.005	0.041	0.006	0.034	−0.005	0.029
≥11	−0.005	0.013	−0.029	0.046	−0.039	0.039	−0.026	0.033
≤1 sibling aged ≤5 years (>2)	0.008	0.009	0.145	0.032	0.119	0.027	0.052	0.023
Maternal education (none)								
Primary education	−0.003	0.008	0.195	0.031	0.136	0.026	0.016	0.022
Secondary/higher education	−0.007	0.015	0.447	0.055	0.270	0.046	−0.011	0.040
Married (no)	−0.004	0.014	0.050	0.050	0.054	0.042	0.026	0.036
Pregnant (no)	0.020	0.011	−0.073	0.039	−0.070	0.033	−0.066	0.029
Maternal age in years (<20 years)								
20–29	0.001	0.015	0.016	0.053	0.040	0.045	0.045	0.039
30–39	−0.006	0.016	0.046	0.059	0.013	0.049	−0.010	0.042
40–49	−0.012	0.020	0.105	0.072	0.032	0.060	−0.029	0.052
Previous pregnancy interval ≤15 months (>15 months)	0.017	0.013	−0.129	0.046	−0.122	0.039	−0.057	0.034
Subsequent pregnancy interval ≤15 months (>15 months)	−0.015	0.021	0.541	0.075	0.326	0.062	0.039	0.054
Male sex (female)	0.020	0.007	−0.107	0.024	−0.085	0.020	−0.060	0.017
Twin (single birth)	0.022	0.025	−0.754	0.090	−0.629	0.075	−0.113	0.065
Percentage of life breastfed	0.001	0.000	−0.000	0.001	−0.003	0.000	−0.003	0.000
Firstborn (second or higher)	−0.005	0.011	−0.111	0.040	−0.074	0.034	0.004	0.029
Child's age in months (3–6 months)								
7–12	0.030	0.012	−0.633	0.043	−0.984	0.036	−0.585	0.031
13–24	−0.020	0.011	−1.197	0.040	−1.361	0.033	−0.972	0.029
25–36	−0.074	0.013	−1.365	0.045	−1.357	0.038	−0.751	0.033
Country (Bolivia)								
Burundi	−0.110	0.017	−0.047	0.061	−0.605	0.051	−0.713	0.044
Ghana	−0.052	0.016	0.452	0.057	−0.398	0.048	−0.895	0.041
Guatemala	−0.080	0.015	−0.582	0.053	−0.581	0.044	−0.258	0.038
Morocco	0.040	0.016	0.554	0.058	0.043	0.049	−0.400	0.042
Sri Lanka	−0.185	0.017	0.170	0.061	−0.871	0.051	−1.244	0.044
Togo	−0.030	0.017	0.367	0.061	−0.211	0.051	−0.580	0.044
Uganda	−0.041	0.015	−0.068	0.054	−0.240	0.046	−0.235	0.039
Constant	0.215	0.030	−1.004	0.108	0.150	0.090	1.060	0.078

* SE, standard error.

† Group 1, unimproved water and unimproved sanitation; group 2, intermediate water and unimproved sanitation; group 3, optimal water and unimproved sanitation; group 4, unimproved water and intermediate sanitation; group 5, intermediate water and intermediate sanitation; group 6, optimal water and intermediate sanitation; group 7, unimproved water and optimal sanitation; group 8, intermediate water and optimal sanitation; and group 9, optimal water and optimal sanitation.

Fourth, the magnitude of the effect of sanitation increased as the water supply level improved. This was true in both urban and rural situations. In urban children, intermediate sanitation versus no sanitation was associated with an increase of 0.262 (95 percent CI −0.046 to 0.570) *Z* scores when no improved water was available, 0.309 (95 percent CI 0.145 to 0.473) *Z* scores when intermediate water was available, and 0.361 (95 percent CI 0.186 to 0.537) *Z* scores when optimal water was available.

The situation for water was very different than that for sanitation. First, improvements in water supply were not associated with higher height-for-age *Z* scores in urban children. The largest height difference due to water improvements among urban children was found between optimal water and no improved water when optimal sanitation was present: 0.073 *Z* scores (95 percent CI −0.145 to 0.291). This effect was three times lower than the smallest effect due to any improvement in sanitation among these urban children (0.229 *Z* scores (95 percent CI −0.044 to 0.502) when optimal and intermediate sanitation were compared in the absence of improved water).

Second, the positive effects of improved water found in rural children occurred only when optimal water was available and only when improved sanitation was available. The effects also increased as the level of sanitation improved. For example, the differ-

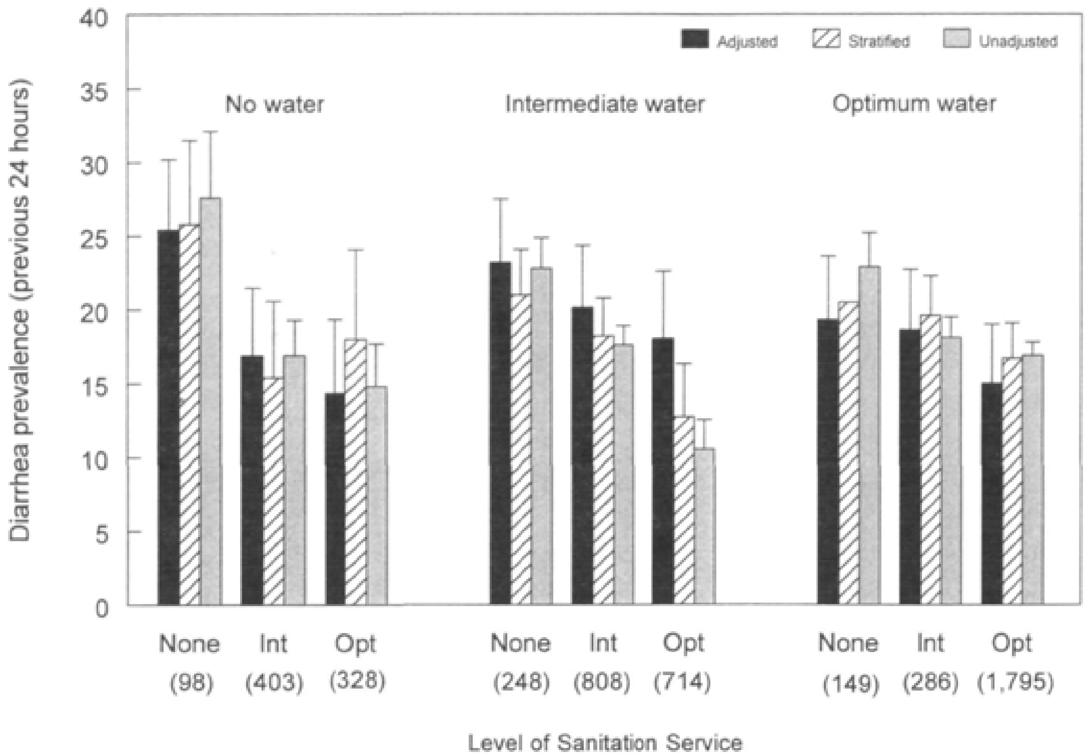

FIGURE 1. Adjusted, stratified, and unadjusted diarrhea prevalence according to water and sanitation services among 4,857 urban children aged 3–36 months from eight countries in Africa, Asia, and Latin America. None, no improved service; Int, intermediate service; Opt, optimal service. T-shaped bars, 95% confidence interval.

ence in rural children's height-for-age *Z* scores between persons with optimal water and persons with no improved water was 0.010 (95 percent CI −0.130 to 0.150) when no sanitation was present, 0.175 (95 percent CI 0.034 to 0.316) when intermediate sanitation was present, and 0.376 (95 percent CI 0.120 to 0.632) when optimal sanitation was present.

Third, urban children with intermediate water service always had lower height-for-age *Z* scores than children with unimproved water supplies, and this was true at each level of sanitation. The same was true for rural children, except those with intermediate sanitation. None of these differences, however, were statistically significant.

Synergy between water service and sanitation was also found. For instance, the difference between intermediate levels of both services and unimproved water and sanitation was 0.126 height-for-age *Z* scores (95 percent CI 0.037 to 0.215). Improvements in only water (−0.014, 95 percent CI −0.101 to 0.074) or only sanitation (0.059, 95 percent CI −0.031 to 0.148) were small and statistically insignificant. When intermediate levels of both water and sanitation were compared with optimal levels of water and sanitation, an additional 0.503 (95 percent CI 0.342 to 0.666) *Z* score change was found. If only optimal levels of water (0.108, 95 percent CI −0.032 to 0.248) or sanitation (0.098, 95 percent −0.035 to 0.231) were available, the differences were small and insignificant.

In summary, the effects due to water and sanitation were noticeably different from one another. The effects of sanitation were consistent and large in both urban and rural children, and the effects were enhanced as water service improved. For water supply, the effects found were small. They were positive only in rural children, only when improved sanitation was present, and only when optimal water service was available.

Weight-for-age

The results for weight-for-age (tables 4 and 5) were similar to but not identical to the results for height-for-age. The adjusted and stratified effects (models 1 and 2a–2f) were similar (figures 4 and 5), the effects of sanitation were always positive, and the effects of water were found only when optimal supplies were present and sanitation was improved.

The difference in weight-for-age *Z* scores from improvements in sanitation ranged from a small 0.095 (95 percent CI −0.042 to 0.232) to a large 0.344 (95

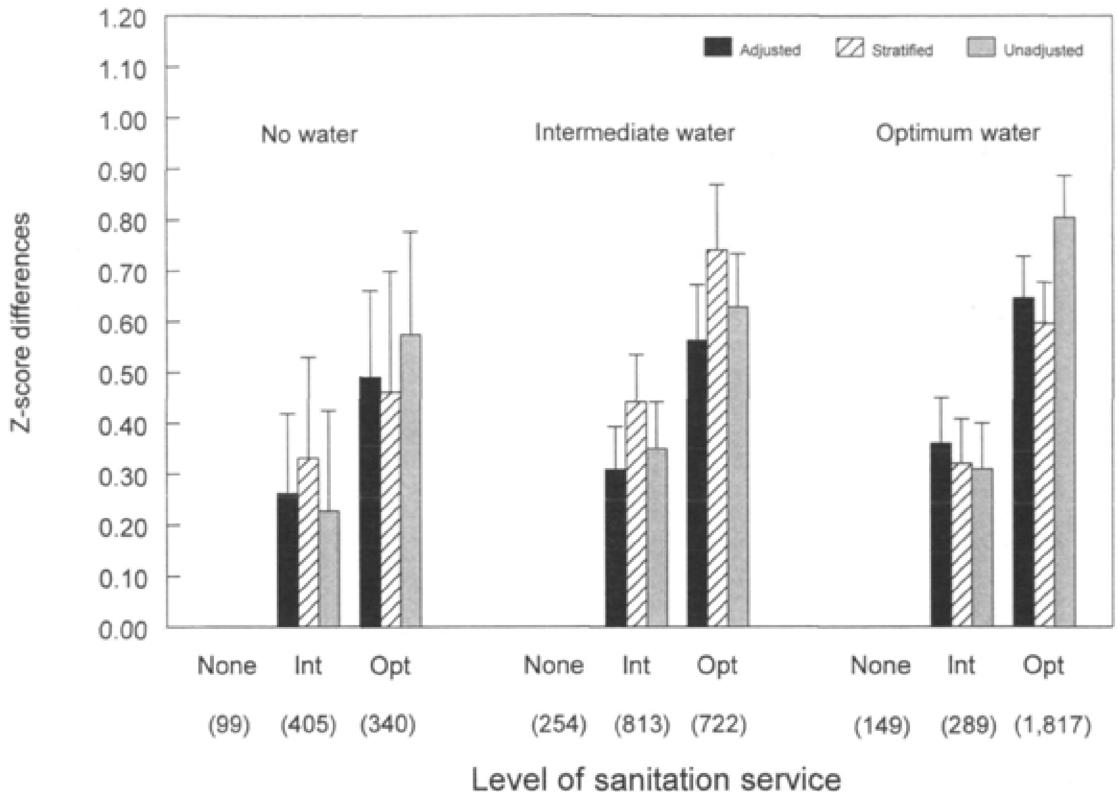

FIGURE 2. Adjusted, stratified, and unadjusted differences in height-for-age *Z* scores according to water and sanitation services among 4,888 urban children aged 3–36 months from eight countries in Africa, Asia, and Latin America. None, no improved service; Int, intermediate service; Opt, optimal service. T-shaped bars, 95% confidence interval.

percent CI 0.209 to 0.479) in urban children and from 0.072 (95 percent CI −0.002 to 0.146) to 0.460 (95 percent CI 0.301 to 0.619) in rural children. In addition, incremental improvements in sanitation always resulted in additional increases in weight among both urban and rural children. For example, in rural children, intermediate versus no sanitation in the absence of improved water was associated with a 0.072 (95 percent CI −0.002 to 0.146) change in *Z* score. Moving to optimal sanitation was associated with an additional 0.216 (95 percent CI 0.034 to 0.398) *Z* scores. The same trend occurred for each level of water in both urban and rural samples.

Improvements in water were associated with increases in weight in both urban and rural children, but only when sanitation was improved and optimal water was present. The effects were also weaker than those found for sanitation. The largest effect that improved water had on weight-for-age *Z* scores in urban children was 0.139 (95 percent CI 0.014 to 0.264) when optimal and unimproved water were compared and when optimal sanitation was present. The next largest effect was 0.067 (95 percent CI −0.180 to 0.314) when optimal water was compared with unimproved water in the absence of sanitation. The situation was similar in rural children: The largest effect of water was found when optimal water was compared with unimproved water, 0.256 *Z* scores (95 percent CI 0.042 to 0.470), in the presence of optimal sanitation. Optimal versus unimproved water in the presence of intermediate sanitation was associated with a 0.149 (95 percent CI 0.031 to 0.267) change in *Z* scores.

Finally, complementarity or synergy occurred as improvements in water and sanitation took place together. For example, the difference in weight-for-age *Z* scores between intermediate levels of both water and sanitation and no water or sanitation of any kind was 0.115 *Z* scores (95 percent CI 0.040 to 0.189). Improvements in only water (0.017, 95 percent CI −0.056 to 0.090) or only sanitation (0.072, 95 percent CI −0.003 to 0.147) were small and insignificant. An additional 0.429 (95 percent CI 0.293 to 0.564) change in *Z* scores was found if water and sanitation service were both improved to optimal levels. If only optimal levels of water (0.106, 95 percent CI −0.012 to 0.224) or sanitation (0.100, 95 percent CI −0.011 to 0.211) were available, the differences were small and insignificant.

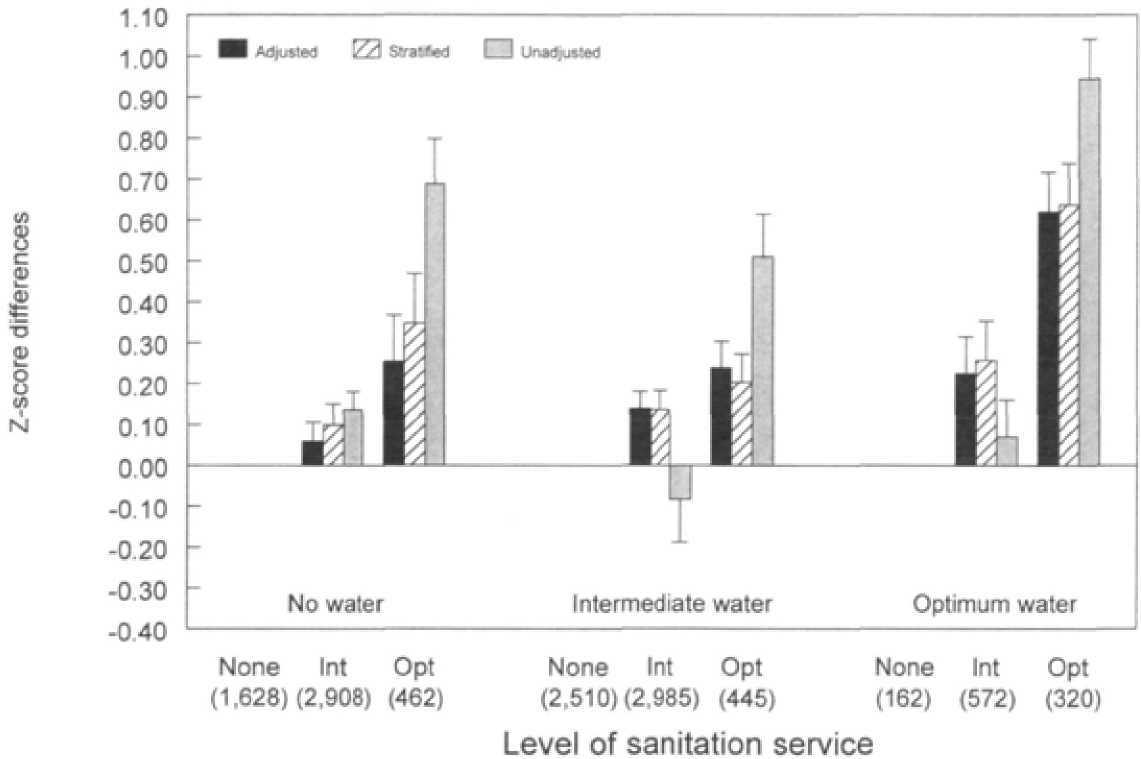

FIGURE 3. Adjusted, stratified, and unadjusted differences in height-for-age *Z* scores according to water and sanitation services among 11,992 rural children aged 3–36 months from eight countries in Africa, Asia, and Latin America. None, no improved service; Int, intermediate service; Opt, optimal service. T-shaped bars, 95% confidence interval.

Weight-for-height

No associations were found between incremental improvements in water or sanitation and the weight-for-height of children in urban areas (table 4). Improved water and sanitation and higher weight-for-height *Z* scores were found in rural areas, but incremental improvements in weight-for-height were not found (table 5). Improvements in sanitation were associated with larger weight-for-height *Z* scores, but only in the absence of improved water supplies. Optimal versus no sanitation was associated with 0.113 (95 percent CI 0.012 to 0.214) higher *Z* scores. Similarly, optimal water versus no water was associated with 0.170 (95 percent CI 0.010 to 0.330) higher weight-for-height *Z* scores, but only in the absence of improved sanitation.

DISCUSSION

Several general conclusions can be made about the health impact of improvements in water and sanitation in this study. First, improvements in sanitation had health impacts for diarrhea and anthropometric factors at all levels of water supply, even when the only water available was unimproved. Second, improvements in water did not result in health impacts if sanitation remained unimproved. Finally, improvements in water and sanitation together were synergistic in producing larger impacts than either alone, particularly in rural areas. More specifically, incremental improvements in sanitation facilities resulted in incremental improvements in health, but this was not true for water supplies. Incremental benefits from sanitation were larger in urban areas than in rural areas. The effect of improved water, when found, usually appeared only when optimal water service was available and only when improved sanitation was present, and the magnitude of the effect was less than that for improved sanitation. In fact, intermediate improvements in water were associated with no effect on diarrhea or on the heights or weights of children, and in some cases persons with intermediate water service were worse off than they would have been if no improved water were available. Finally, nutritional status was a more sensitive indicator of health benefits than was diarrhea.

The effect of improvements in sanitation and water on child nutritional status can also be expressed in terms of weight (kg) and height (cm) for an 18-month-old child, the average age in both the urban and rural samples. Intermediate improvements in sanitation

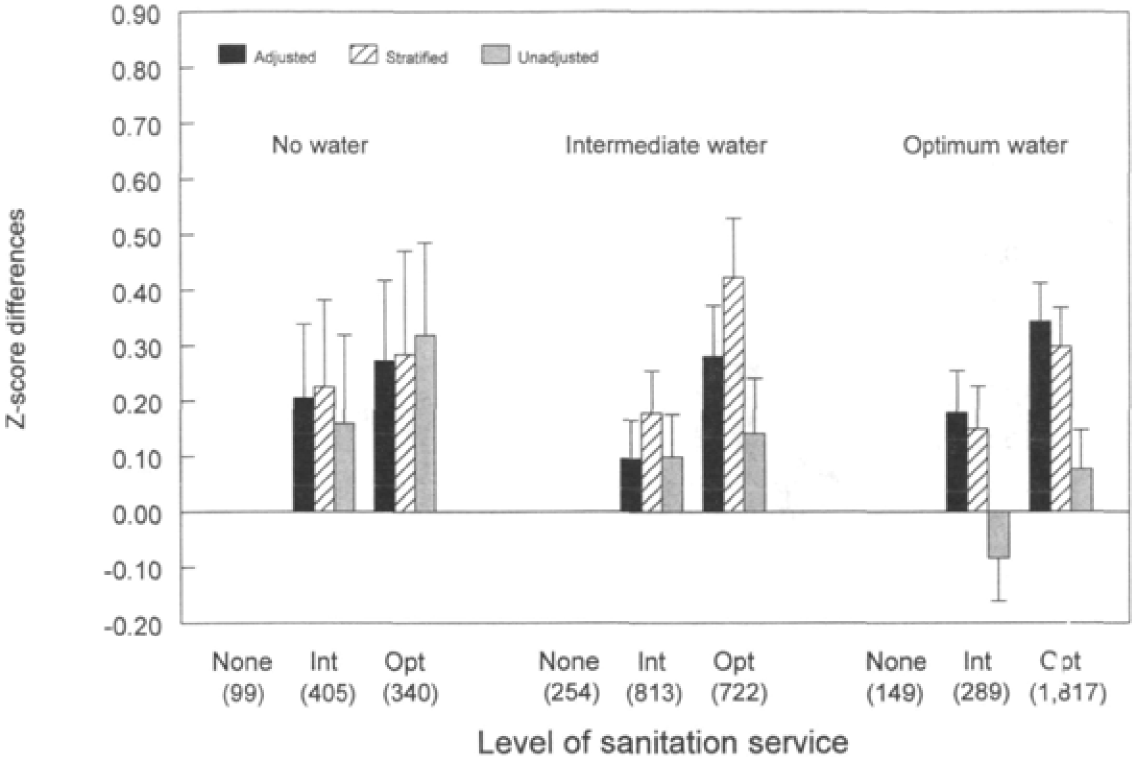

FIGURE 4. Adjusted, stratified, and unadjusted differences in weight-for-age *Z* scores according to water and sanitation services among 4,888 urban children aged 3–36 months from eight countries in Africa, Asia, and Latin America. None, no improved service; Int, intermediate service; Opt, optimal service. T-shaped bars, 95% confidence interval.

were associated with increases in height ranging from 0.8 cm to 1.1 cm, and optimal sanitation improvements increased heights 1.5–1.9 cm more in comparison with no improved sanitation. These sanitation improvements represent a reduction in height deficit, relative to the reference standard, ranging from 22 percent to 53 percent for urban children and from 4 percent to 37 percent for rural children. The corresponding reduction in weight deficit resulting from improved sanitation, relative to the reference standard, ranged from 11 percent to 41 percent for urban children and from 5 percent to 35 percent for rural children. Differences of such magnitude are not always found following nutritional interventions (18).

Improved water and sanitation were found to complement each other with regard to child nutritional status in rural areas. To this author's knowledge, only two other studies have reported on the complementarity between improvements in water and sanitation, one involving water quantity (19) and the other water quality (20). In Lesotho (19), preschool child growth was 2.0 cm and 1.0 kg greater among children with both improvements available in comparison with only one type of service or no improved service at all. The Lesotho study found significant differences in height and weight despite a small sample size, and the water and sanitation improvements were of an intermediate nature. In the Philippines (20), improved water quality was found to have an effect on infant diarrhea only for families living under good sanitary conditions; it had no effect under poor environmental conditions. Improved water and sanitation have also been reported to complement other factors (21), such as better education, higher income, and better hygiene, but current knowledge on the complementarity of these improvements with most amenable factors is limited.

This study had several advantages over other studies that have reported on improved water and sanitation and their health effects on young children (3, 4). First, because eight countries were included, the sample examined was large. For this reason, nonsignificant differences cannot be discounted because of there being few children in the sample. When statistically significant differences were found, the magnitudes of the differences were important biologically. For example, a difference in height of 0.8–1.9 cm, found among children with improved sanitation compared to those without it, is a large difference.

Second, many confounding variables related to community, household, maternal, and child factors were controlled for in the analysis. It is impossible to measure and control for all confounding factors or

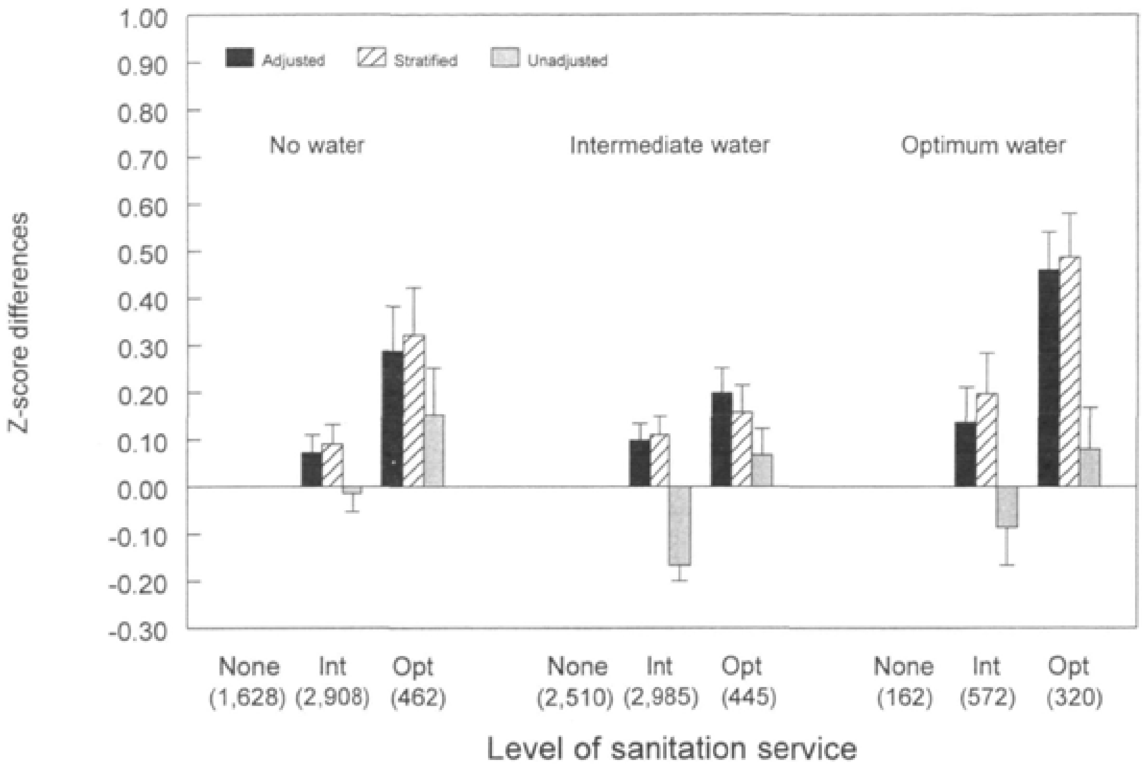

FIGURE 5. Adjusted, stratified, and unadjusted differences in weight-for-age *Z* scores according to water and sanitation services among 11,992 rural children aged 3–36 months from eight countries in Africa, Asia, and Latin America. None, no improved service; Int, intermediate service; Opt, optimal service. T-shaped bars, 95% confidence interval.

differences between comparison groups, or even to guarantee control in experimental studies. Nevertheless, the major confounding variables identified in other studies were controlled for in this study. It is unlikely that unknown confounding variables, or clustering, could account for the remaining differences found, particularly those with large effects. Because water supplies are usually improved within a broad geographic area (e.g., a village) and sanitation improvements are often made at the household level, it is difficult to control for clustering effects when analyzing both factors together. Nevertheless, when data on twin siblings were eliminated, identical results were obtained.

Third, it is generally assumed that health effects from improved water supplies are larger than those from improved sanitation, and that reported effects of improved sanitation occur because of confounding due to improved water. The results reported above dispel both notions. First, many people included in this study had improved sanitation without improved water, improved water without sanitation, both, or neither. Second, the effects of both types of improvements were examined in the presence and absence of the other type of service. Thus, the effects of sanitation reported above are not due to confounding from water supply.

Fourth, the results held up across nationally representative samples in eight different countries on three different continents, under very diverse climates, religions, altitudes, seasons, and other factors. The individual country analyses support this as well (22). The full regressions were repeated for every outcome, each time eliminating children from one country, to see whether any particular country contributed excessively to the results. In all cases, the interpretation of the relative effects and the conclusions remained the same. For diarrhea, the removal of Bolivia, Burundi, Guatemala, Sri Lanka, Togo, and Uganda resulted in virtually identical results, with estimated prevalences falling within 1–2 percentage points of those seen in the full analysis. The estimated effects were smaller, by 1.5–2.5 percentage points, when Ghana was eliminated and were larger by 0.5–3.5 percentage points when Morocco was eliminated, in comparison with the full analysis. Two countries, Bolivia and Guatemala, contributed to the most frequent and widest deviations in height-for-age *Z* scores. Bolivia, Ghana, and Guatemala contributed to the most frequent and widest deviations in weight-for-age among urban children, while Morocco contributed to the most in rural children. The deviations from any one country, however, were not consistently lower or higher than the estimate obtained from the full model, and in most cases the estimates were usually well within one tenth of a *Z* score from the full regression. The prevalence of diarrhea varied from less than 5 percent to nearly 50 percent in these settings, and rates of malnutrition varied more widely. Thus, the results suggest that improved sanitation could have important health benefits in diverse locations among populations with different levels of health status and different types of water supply. Similarly, benefits from optimal water should be realized in a variety of locations.

A cross-sectional survey is not as powerful as a longitudinal study. Longitudinal studies allow for the measurement of incidence, duration, and severity of diarrhea or other diseases, as well as the growth of children. Cross-sectional data may, therefore, miss important health and nutritional effects, not because they were not present but because the studies were not designed to measure the severity and incidence of health events. Nevertheless, important effects were found in this study for diarrhea and nutritional status.

Although health benefits from optimal water service were found, even though they were small, it was not known whether these benefits were due to improvement in the quality of water, usage of more copious quantities of water, both factors, or some other mechanism. The small differences due to improved water, whether optimal or intermediate, suggest that water quality is not of prime importance. Evidence from other studies suggests that usage of water for personal and domestic hygiene is more important than the quality of drinking water (1). However, the nearness and availability of an improved water source has been reported to also lead to more time for child feeding and food preparation (21, 23, 24). This could result in less diarrhea through better food preparation practices or more frequent feeding (25), rather than better personal hygiene. Possible mechanisms for an effect of time savings could be the fact that there is more time for child care, including breastfeeding and preparation of weaning foods; more time for income-generating activities that allow for the purchase of better health care, better food, or both; and more time for socialization and learning opportunities, such as visiting clinics to attend child care classes or participating in activities designed to improve child health (e.g., joining mothers' clubs). Savings in energy expenditure from water being brought closer to households has also been reported recently in Guatemala (23) and Nepal (26). In rural Guatemala, women's savings in energy expenditure resulted in a commensurate reduction in energy intake. This savings may be transferred to children to increase their intake of food at no extra cost.

The lack of a health benefit from intermediate improvements in water supply is surprising. A negative association between intermediate water and health has been reported elsewhere (27). There may be two reasons for this finding. First, it has been speculated that traditional water supplies may be beneficial, compared with improved water supplies, in preventing *Shigella sonnei* (28). The presence of *Plesiomonas shigelloides,* which has an antigen similar to that of *S. sonnei,* in traditional water may immunize people against *S. sonnei.* Other organisms in traditional water sources may provide protection against known pathogens. Second, it is commonly accepted that community water supplies are frequently recontaminated prior to consumption (29), negating the health benefits of improved water service.

One of the major benefits of, or justifications for, installing improved water and sanitation facilities in developing countries is to reduce the diarrheal disease burden, but problems exist when diarrhea data are relied upon to demonstrate health impacts. Recall data on diarrhea prevalence from cross-sectional studies may be too insensitive to measure changes in the incidence or severity of diarrhea (30). Because a reduction in diarrhea prevalence is only one of several reported health benefits resulting from improvements in water and sanitation (1), relying on diarrhea data alone could underestimate, or miss other, health benefits deriving from these improvements. Even if other effects are present, it is unlikely that several health parameters will be measured in any single study; thus, anthropometry may be the best overall indicator with which to capture cumulative insults to health and nutrition, with height-for-age measuring cumulative, long-term insults. Data on diarrhea are usually measures of a symptom, i.e., presence/absence or number of days with abnormal or loose stools, with the symptoms varying by pathogen. This does not measure the extent of the nutritional insult. An inverse correlation between persistent small bowel abnormalities and growth of infants was reported in a study conducted in the Gambia (31). Growth-depressing intestinal permeability occurred 76 percent of the time, but diarrhea was prevalent in only 14 percent of children for any given week. Misclassification and underreporting (32) would make it harder to find differences between comparison groups.

Access to and use of improved water and sanitation facilities are not synonymous. The incremental differences in health found with incremental improvements in sanitation and optimal water services may be due to usage patterns. People with intermediate sanitation may have used the facilities less frequently, or the facilities may have been used by only some family members, in comparison with optimal systems. Perhaps intermediate services could achieve greater benefits if all family members were encouraged to use the facilities at all times, including the appropriate disposal of feces of young children. Data on hygiene practices were not available. Better hygiene practices have been reported to be associated with less diarrhea (33, 34). Perhaps optimal services facilitate better hygiene practices.

These findings pose several policy-related questions. First, improved sanitation appears overwhelmingly to confer broader and larger benefits to health than improved water supplies. If a primary objective of improved services is health, should sanitation receive a higher priority than water, and should water projects insist on improved sanitation? Second, improved services in water and sanitation provide additional benefits beyond disease reduction. Should other, non-water- and sanitation-related programs that benefit from water and sanitation improvements demand, link with, and contribute financially to these improvements? Answering these questions will require better information on the cost of technologies, the sustainability and usage of different types and levels of services, and the need for compatible technologies for incremental improvements in services. Finally, better information is needed on institutional constraints to more successfully link water and sanitation.

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