The impact of a school-based water supply and treatment, hygiene, and sanitation programme on pupil diarrhoea: a cluster-randomized trial

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SUMMARY

The impact of improved water, sanitation, and hygiene (WASH) access on mitigating illness is well documented, although impact of school-based WASH on school-aged children has not been rigorously explored. We conducted a cluster-randomized trial in Nyanza Province, Kenya to assess the impact of a school-based WASH intervention on diarrhoeal disease in primary-school pupils. Two study populations were used: schools with a nearby dry season water source and those without. Pupils attending 'water-available' schools that received hygiene promotion and water treatment (HP&WT) and sanitation improvements showed no difference in period prevalence or duration of illness compared to pupils attending control schools. Those pupils in schools that received only the HP&WT showed similar results. Pupils in 'water-scarce' schools that received a water-supply improvement, HP&WT and sanitation showed a reduction in diarrhoea incidence and days of illness. Our study revealed mixed results on the impact of improvements to school WASH improvements on pupil diarrhoea.

Key words: Diarrhoea, water (safe), hand hygiene, water (quality), waterborne infections.

INTRODUCTION

It is estimated that between 666 000 and 801 000 children die each year from diarrhoeal diseases, 11% of the total child deaths and 89 million disability-adjusted life years [1–3]. While the majority of the deaths are in children aged <5 years, the burden of disease in school-aged children should not be ignored. There are an estimated 2·6 billion episodes of disease per year in children, adolescents and adults [4], and 734 000 deaths in people aged >5 years [1].

The impact of improved water, sanitation, and hygiene (WASH) conditions and behaviours in the domestic environment in reducing diarrhoeal disease for children aged <5 years have been documented [5–7]. Few studies have focused on improving school-level WASH conditions. There is some evidence that improved handwashing with soap at school can reduce illness and lead to reduced absence in school-aged children [8–10], especially for girls [11, 12]. In addition to limiting pathogen transmission in the public domain – such as at schools – school-level WASH

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interventions may also reduce the overall community disease burden [13].

Data on access to water and sanitation in schools in low-income countries is scarce. An evaluation by UNICEF found that in schools in 49 low-income countries, only 51% had access to adequate water and 45% had adequate sanitation facilities [14]. Understanding the impact of school WASH in reducing diarrhoeal illness may help governments and international donors allocate appropriate resources to school-based environmental health interventions. In this study, we assessed the impact of a school-based WASH programme on diarrhoeal diseases in primary-school pupils. We employed a cluster-randomized trial design to compare the difference in period prevalence and days of diarrhoeal illness in pupils who attended schools that received different WASH improvements and those that attended control schools. We hypothesized that improvements in school WASH conditions would result in lower diarrhoeal disease in pupils.

METHODS

Setting

The study was conducted between January 2007 and November 2008 within four districts of Nyanza Province in western Kenya. Districts were selected in collaboration with the Ministry of Education to reflect the diversity in climatic, health, and water availability conditions in the region. Contiguous districts were grouped into three geographical strata: Nyando/Kisumu, Rachuonyo, and Suba districts. This study was part of a 5-year applied research programme assessing the health impact, educational impact, knowledge diffusion, and sustainability of a school-based WASH intervention [11, 15–18].

School eligibility, school selection, and study design

We conducted a rapid assessment of primary schools, which provided school-specific information on water source available and pupil:latrine ratios. Schools were classified based on access to a water source during the dry season as either (1) 'water available' with a water source within 1 km, or (2) 'water scarce' with no source within 1 km. In addition, per criteria specified by the Ministry of Education, water-scarce schools have no 'improved' source within 2 km. Schools were eligible for either study group if they exceeded the Government of Kenya's recommended

pupil:latrine ratio of 30:1 for boys and 25:1 for girls [19]. The selection of eligible schools is detailed in Figure 1.

Based on these separate eligibility criteria, this study employed two separate sampling frames: a water-available study group and a water-scarce study group, and eligible schools were randomly allocated to intervention status independently in each study, and data analysed separately. In the water-available group, 135 schools were randomly allocated into one of three intervention arms: (1) hygiene promotion and water treatment (HP&WT), which included teacher training on hygiene behaviour change, containers for safe drinking water storage, buckets with taps to be used for handwashing, and a 1-year supply of WaterGuard (a liquid chlorine-based sodium hypochlorite solution used for point-of-use water treatment); (2) HP&WT with the addition of school latrines (HP&WT+Sanitation), which included up to seven ventilated improved pit latrines, depending on existing pupil:latrine ratios; or (3) control, to receive the intervention after data collection was complete.

In the water-scarce group, 50 schools were randomly allocated into either (1) an improved water supply at school, with the subsequent improvements for HP&WT+Sanitation described above, or (2) control. For characterization of 'improved' water supply, we used the definitions from the UNICEF/WHO Joint Monitoring Programme [20]. Due to poor groundwater potential and contamination, 13 schools designated to receive water supply improvements were provided rainwater-harvesting tanks equivalent to 60 m^3. We estimated that this size tank would be sufficient to maintain water supply through much of the dry season. For the remaining schools, boreholes were drilled or rehabilitated and fitted with hand pumps. These boreholes were sited based on groundwater potential and located either on school property or located off-site and reticulated to the school. New water points were managed jointly by the school and community members and provided access to an improved water source to both the school and households in the community.

For all intervention arms, one teacher and one school management committee member were trained on hygiene behaviour change approaches, how to treat stored water, and how to maintain school WASH infrastructure. School representatives were encouraged to engage local parents in procurement of funds to maintain facilities and purchase consumables, such as soap. Community members were
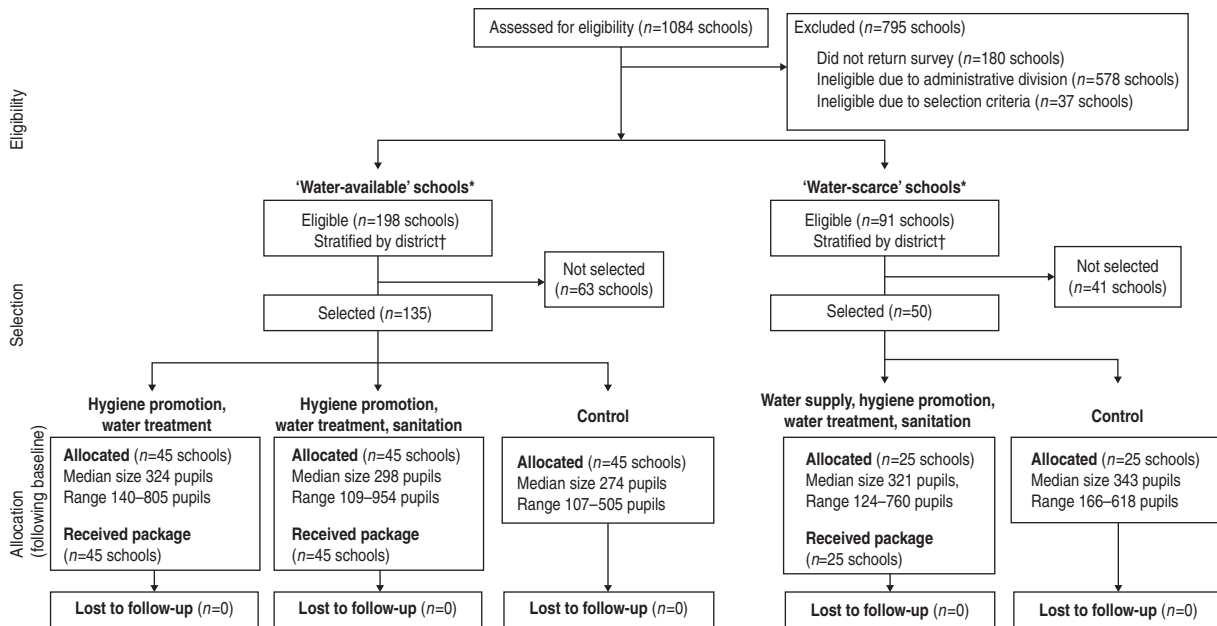
Fig. 1. Flow chart of school selection. * Schools having no water source within 1 km and no improved source within 2 km were classified as 'water scarce'. All other schools were designated 'water available'. † Selection was stratified across three geographical clusters spanning contiguous administrative divisions in four districts (Nyando/Kisumu districts, Rachuonyo District, Suba District).

engaged in the management of water facilities and provision of local material (such as sand) and construction of latrines. All children in all schools were dewormed yearly with 400 mg albendazole. Deworming took place after baseline data collection and 3 months prior to final data collection.

Sample size

Sample size for this study was constrained by the number of schools, pupil surveys, and follow-up time points in the larger trial, whose primary outcome was assessment of pupil absence [11]. As such, the study was not powered with changes in diarrhoea incidence in school-aged children as a primary outcome. As noted by Fischer Walker & Black [4], there is limited data on diarrhoeal incidence in children aged 5–14 years in sub-Saharan Africa. We assumed 15% for 1-week period prevalence and a design effect of 2. A sample size of 25 pupils per school and 45 schools per intervention arm in the water-available study group allowed us to detect a 32% reduction in diarrhoea at an $\alpha = 0.05$ with a power of 80%, in either intervention arm compared to the controls. For the same parameters in the water-scarce group, 25 pupils per school and 25 schools per intervention arm allowed us to detect a 43% reduction in diarrhoea. We found no previous studies that have reported

estimates on the impact of school WASH improvements on pupil diarrhoea risk; however, these reductions are commensurate with those reported for impacts of household WASH improvements on children aged <5 years [6].

Data collection

Data collected at baseline (February–March 2007) and following implementation (September–October 2008) included structured interviews with school head teachers and structured observations of school WASH conditions. Data included access to an improved water supply; consistency of water access; water treatment practices; number, type, and condition of school latrines; and access to water and soap for handwashing. Residual chlorine tests were carried out – when head teachers indicated that the stored water had been treated – using Hach Free and Total Chlorine kits (Hach Co., USA). These data were used to assess the balance of the randomization process and to assess treatment fidelity at follow-up.

Surveys with a selection of pupils were completed at baseline and follow-up; pupils were selected from grades 4–8 only (aged at least 8 years) due to ability to answer questions. Due to high turnover of pupils, we elected to randomly select 25 pupils at each time point. Pupils were selected through systematic random

sampling from school registers, ensuring balance of sex and grade proportional to population. Trained enumerators conducted pupil surveys in the local language (Dholuo). The survey captured demographic information such as age, sex, and grade; knowledge and attitudes regarding WASH practices at school and home; and pupil perceptions of school WASH conditions. One-week period prevalence of diarrhoea and duration of diarrhoea episodes for the week prior to data collection was assessed via self-report. The case definition of diarrhoea was ⩾ 3 loose or watery stools over a 24-h period [21].

We also report community-aggregated baseline data on community WASH conditions derived from structured interviews with female heads of households living in the school catchment area. Methodology for this survey and more complete results are found elsewhere [11]. Aggregate household data was used to assess imbalance in the study population and as covariates in multivariable analysis. All data were collected using Dell Axim x51 (Round Rock, USA) personal digital assistants.

Data analysis

Data were cleaned in SAS version 9.3 (SAS Institute Inc., USA) and analysed in Stata version 11 (StataCorp., USA). Baseline data on pupil diarrhoea were not available due to problems encountered with the outcome variable on the data collection devices; as such we relied on randomization to control for baseline imbalances [22, 23]. We report baseline prevalence for parent-reported diarrhoea as a reference. To compare imbalance at baseline in the absence of a baseline measure of effect, we assessed various school characteristics. Community-aggregated data are reported as mean of proportions or mean of means; these data were not derived from the specific pupils under study, but rather a random selection of households in the school catchment area.

As part of this analysis, principal component analysis was used to calculate a wealth index from various household assets [24, 25]. School WASH conditions – intermediate outcomes associated with the fidelity of the intervention – were assessed at baseline and follow-up by trained enumerators. For assessment of treatment fidelity, we conducted a difference-in-difference analysis on the logit scale, in which the interaction term between intervention and data collection round is used to assess changes in intervention against controls while accounting for baseline differences [11].

For multivariable regression models assessing the impact of the intervention on diarrhoea, we calculated the difference in 1-week period prevalence of diarrhoea between pupils in each intervention and its respective control arm. Risk ratios (RR) and P values were calculated using generalized linear models using a log link and binomial distribution. Crude estimates of days of illness were calculated as the total number of reported days of diarrhoea per 100 person-days for the 1 week prior to data collection. Our multivariable model of days of diarrhoea estimated the difference in days of diarrhoea between children in the intervention $vs.$ those in the control in students that reported any diarrhoeal illness. Population-level estimates of effect for both period prevalence of diarrhoea and days of illness were calculated using the 'svy' command in Stata, which adjusted our variance to account for clustering at the school level using robust standard errors, pupil selection weights, and our stratified sampling design.

To estimate the effect of the intervention on diarrhoea, we first tested for interaction with geographical strata. Since none was found, we present models controlling only for geographical strata (model 1) and models with a $priori$-determined covariates (model 2). These covariates included pupil sex and age, as well as school and aggregated community characteristics at baseline. Some covariates were missing in up to five schools and mean values calculated by geographical strata were imputed for these covariates. Effect estimates and standard errors were nearly identical to measures with and without imputed values. Since previous studies found differences in the impact of school-based intervention on school absence by sex [11], we ran sex-stratified models. All significance was assessed at $\alpha = 0.05$.

Ethics

Ethical clearance was obtained by Emory University's Institutional Review Board (Atlanta, GA, USA) and the ethics review board at Great Lakes University of Kisumu (Kisumu, Kenya); written authorization for the study was obtained from the Kenyan Ministries of Health, Education, and Water. Teachers provided permission to operate in schools under their authority from the Ministry of Education and pupils provided oral assent prior to participation in the study.

Table 1. *School conditions and household characteristics at baseline for both study groups and all intervention arms: hygiene promotion and water treatment (HP&WT); HP&WT+Sanitation; water supply (WS)+HP&WT +Sanitation; and their respective controls*

Variable	Water-available group			Water-scarce group	
	Control	HP&WT	HP&WT + Sanitation	Control	WS + HP&WT + Sanitation
School conditions	(n=45)	(n=45)	(n=45)	(n=25)	(n=24)
School enrolment in number of pupils	274 (83)	355 (143)	344 (182)	370 (125)	332 (142)
Pupils per teacher	28 (7)	33 (10)	33 (12)	36 (12)	32 (10)
Proportion of girls enrolled	48(4)	48 (3)	48(4)	48 (4)	48 (3)
Electricity at school	0 (0%)	2 (4%)	2 (4%)	0 (0%)	1 (4%)
Iron sheet roofing throughout school	43 (98%)	45 (100%)	43 (98%)	25 (100%)	24 (98%)
Cement floor throughout school	5 (11%)	13 (29%)	10 (22%)	8 (32%)	6 (25%)
Household demographics*	(n=45)	(n=45)	(n=45)	(n=25)	(n=25)
Female-headed households	29% (16)	30% (17)	33% (17)	29% (11)	33% (14)
Female head of household completed primary school	46% (16)	48% (18)	46% (18)	43% (13)	49% (16)
Distance to school from home in minutes	18 (6)	19 (9)	18 (6)	18 (6)	20 (6)
Household respondent used soap during handwashing demonstration	68% (20)	72% (15)	70% (19)	67% (12)	70% (19)
Household currently using improved drinking-water source†	66% (32)	64% (31)	64% (30)	69% (30)	60% (32)
Latrine coverage in community‡	38% (21)	38% (22)	39% (23)	41% (27)	43% (23)
Households in poorest wealth quintile	23% (14)	19% (13)	23% (15)	17% (11)	16% (12)
Households in least poor wealth quintile	15% (11)	22% (15)	17% (18)	20% (14)	27% (19)

Data are means or mean% [standard deviation (S.D.)] or number (%).

* Mean and (S.D.) calculated as cluster-level means or proportions; not from individual study children.

† Improved sources include boreholes, rainwater harvesting tanks, protected springs, and protected wells. Definitions found in WHO and UNICEF, 2010.

‡ Proportion of households with a latrine within compound or home.

RESULTS

Baseline characteristics

School and community characteristics at baseline are given in Table 1. Intervention and control schools in the water-available study group were similar for most assessed characteristics; although intervention schools had fewer pupils and fewer cement floors than controls. Control schools had higher pupil:latrine ratios. For the water-scarce study group, school and community characteristics were similar in control and intervention arms, although intervention schools were slightly larger than control schools.

As discussed above, we were unable to use pupil-reported diarrhoea measures at baseline to assess imbalance from our randomization. Parent-reported diarrhoea in school-aged children collected at households in the catchment area of study schools collected after pupil baseline but prior to randomization revealed similar mean values for diarrhoea in school-aged children in HP&WT schools [6·2%, 95% confidence interval (CI) 4·2–8·2], HP&WT+Sanitation schools (6·8%, 95% CI 4·9–0·87), and control schools (8·3%, 95% CI 4·7–11·8). Parents of children that received water supply reported 9·3% period prevalence of diarrhoea in school-aged children (95% CI 4·2–14·4) compared to 4·1% (95% CI 2·9–5·2) in controls (data not shown).

School conditions

Access to an improved water source – as defined by the Joint Monitoring Programme – was similar across intervention arms at follow-up for those in the water-available group (Table 2) [20]. In the water-scarce group, school access to an improved water source in the dry season increased by 43 percentage points to 60% in the intervention arm, but only increased from 8% to 12% in the control group (P=0·18). Observed presence of drinking water was 84% at follow-up (46% at baseline) in the intervention

Table 2. *School WASH conditions at baseline and follow-up for all intervention arms: hygiene promotion and water treatment (HP&WT); HP&WT+Sanitation; water supply (WS), HP&WT+Sanitation; and their respective controls*

| | Water-available group | | | | | | | | Water-scarce group | | | | |
| | Control (n=45) | | HP&WT (n=45) | | | HP&WT+Sanitation (n=45) | | | Control (n=25) | | WS, HP&WT+ Sanitation (n=25) | | |
Variable	Baseline	Follow-up	Baseline	Follow-up	P	Baseline	Follow-up	P	Baseline	Follow-up	Baseline	Follow-up	P
School current water source is improved*	18 (41%)	29 (66%)	20 (45%)	30 (67%)	0·80	13 (30%)	27 (60%)	0·69	13 (52%)	21 (84%)	11 (46%)	21 (84%)	0·80
School dry season water source is improved*	16 (36%)	15 (34%)	11 (24%)	16 (34%)	0·32	13 (30%)	17 (38%)	0·46	2 (8%)	3 (12%)	4 (17%)	15 (60%)	0·18
Drinking water available day of field visit	23 (52%)	8 (18%)	24 (53%)	33 (73%)	<0·001	17 (39%)	37 (82%)	<0·001	14 (56%)	6 (24%)	11 (46%)	21 (84%)	<0·001
Handwashing water available day of field visit	4 (9%)	2 (4%)	7 (16%)	32 (71%)	<0·01	1 (2%)	36 (80%)	<0·001	4 (16%)	0 (0%)	4 (16%)	20 (80%)	<0·01
Chlorine residual in stored drinking water	0 (0%)	0 (0%)	2 (5%)	28 (62%)	0·01	1 (2%)	30 (67%)	<0·01	0 (0%)	0 (0%)	0 (0%)	16 (64%)	0·04
Proportion of pupils reporting													
Drinking water always available	15% (20)	29% (32)	15% (24)	66% (27)	<0·001	18% (23)	74% (22)	<0·001	14% (18)	20% (21)	12% (18)	78% (22)	<0·001
Handwashing water always available	12% (17)	22% (26)	16% (24)	68% (28)	<0·001	16% (21)	76% (22)	<0·001	15% (19)	10% (13)	8% (15)	80% (25)	<0·001
Soap always available	2% (10)	2% (7)	1% (4)	36% (28)	<0·001	1% (3)	41 (27)	<0·001	2% (4)	1% (2)	3% (5)	40% (29)	<0·001
Pupils per latrine	61 (44)	51 (16)	61 (30)	55 (25)	0·66	77 (61)	41 (22)	0·03	70 (41)	61 (24)	66 (35)	36 (14)	0·09
Boys per latrine	57 (38)	54 (26)	67 (36)	57 (30)	0·47	82 (58)	44 (28)	<0·01	76 (61)	65 (29)	74 (42)	39 (15)	<0·001
Girls per latrine	57 (40)	50 (20)	60 (32)	56 (25)	0·77	78 (68)	40 (25)	<0·01	58 (35)	59 (27)	63 (36)	37 (17)	0·03

Values are *n* (%) or means and mean% (standard deviation).

P values compare schools in the intervention arm to those in the control arm, adjusting for baseline characteristics.

Exact tests used for binary outcomes with cell counts of zero.

* Improved sources based on definitions established by the UNICEF and WHO Joint Monitoring Programme.

Table 3. *Logistic and linear regression models of pupil-reported diarrhoea for schools that received WASH improvements compared to control school water-scarce groups (n = 1238)*

Variable	Reported diarrhoea (%)	Model 1			Model 2		
		RR	95% CI	P	RR	95% CI	P
One week period-prevalence							
Water supply, sanitation, HP&WT (n = 632)	22 (3·6)	0·39	0·22 to 0·69	<0·01	0·34	0·17 to 0·64	<0·01
Control (n = 606)	53 (8·9)	Ref.					
Days of diarrhoea	Days of diarrhoea (s.e.)	Coeff.	95% CI	P	Coeff.	95% CI	P
Water supply, sanitation, HP&WT (n = 23)	2·60 (0·23)	0·256	−0·310 to 0·822	0·36	0·158	−0·682 to 0·999	0·70
Control (n = 54)	2·33 (0·17)	Ref.					

CI, Confidence interval.

Period prevalence is *n* (%) of pupil-reported episodes of diarrhoea in a 2-week period. Days of diarrhoea is the mean and standard error (s.e.) of days reported within the same 2-week period. RR is risk ratio derived from generalized linear modelling of reported period prevalence of diarrhoea. Days of diarrhoea modelled using linear regression. Model 1 accounts for design variables such as geographical strata and pupil selection weights. Model 2 controls for sex and age, community and school-level characteristics at baseline, and geographical strata. Covariates include pupils per teacher; cement floor at school, proportion of female heads of household (FHH), FHH education level, FHH soap use at home, proportion of households with a protected water source and latrine, latrine condition score, wealth index, and proportion of orphan pupils at school.

schools, *vs.* 24% (56% at baseline) in the control group (*P* < 0·001). Pupils in all intervention schools reported significant increases in availability of drinking and handwashing water and soap, even in those intervention schools that did not receive a water supply improvement. These data are corroborated by observations at school of water availability and detection of residual chlorine, indicating water treatment. Schools that received new latrines reduced their pupil:latrine ratios by nearly 50% from 77:1 to 41:1 in HP&WT+Sanitation schools and from 66:1 to 36:1 in those schools in the water-scarce group, compared to controls (from 61:1 to 51:1 and from 70:1 to 61:1, respectively).

Impact of improved WASH on diarrhoeal disease

At follow-up, we interviewed 4655 pupils from 185 public primary schools from both the water-scarce and water-available study groups, resulting in 32585 pupil-days of potential diarrhoea recall. In total, 23 pupils (<1%) did not provide diarrhoeal data. Multivariable regression models were used to calculate 1-week period prevalence of diarrhoea and days of illness adjusting for geographical strata only (model 1) and adjusted for pupil, school, and

community-level characteristics as well as geographical strata (model 2). Adjusted models were not appreciably different than unadjusted models; as such, we focused on adjusted parameter estimates.

In the water-scarce study group, our sample size included 1238 pupils, 622 (49·5% girls) in the intervention and 606 (47·5% girls) in controls. In the water-scarce study group, 23 (3·6%) pupils in schools receiving water supply improvements (WS), HP&WT, and sanitation reported an episode of diarrhoea in the week prior to data collection compared to 54 pupils (8·9%) in the control schools (Table 3). The mean number of days of reported diarrhoea in children who reported any diarrhoea in the previous 7 days was 2·60 [standard error (s.e.) = 0·23] in the intervention schools compared to 2·33 (s.e. = 0·17) days of diarrhoea in control schools.

We found a 56% difference in the risk of diarrhoea for pupils attending intervention *vs.* control schools [adjusted risk ratio (aRR) 0·34, 95% CI 0·17–0·64]. Relative risk was similar when stratified by sex: (girls: aRR 0·43, 95% CI 0·17–1·05; boys aRR 0·26, 95% CI 0·13–0·54). Of those children reporting any diarrhoea in the past week, the models did not detect a difference in reported days of diarrhoea between intervention and control (coefficient 0·158, 95% CI

Table 4. *Logistic and linear regression models of pupil-reported diarrhoea for schools that received WASH improvements compared to control schools in water-available schools (n=3394)*

Variable	Reported diarrhoea (%)	Model 1			Model 2		
		RR	95% CI	P	RR	95% CI	P
One week period prevalence							
HP&WT (n=1156)	62 (5·4)	1·00	0·70 to 1·43	0·99	0·87	0·62 to 1·21	0·41
HP&WT+Sanitation (n=1134)	65 (5·7)	0·95	0·67 to 1·35	0·79	0·88	0·60 to 1·28	0·51
Control (n=1127)	68 (6·0)	Ref.					
Days of diarrhoea	Days of diarrhoea (S.E.)	Coeff.	95% CI	P	Coeff.	95% CI	P
HP&WT (n=62)	2·67 (0·24)	0·0734	−0·432 to 0·579	0·77	−0·023	−0·490 to 0·443	0·92
HP&WT+Sanitation (n=65)	2·55 (0·16)	−0·0074	−0·404 to 0·390	0·97	−0·051	−0·472 to 0·370	0·81
Control (n=68)	2·58 (0·11)	Ref.					

CI, Confidence interval.

Period prevalence is n (%) of pupil-reported episodes of diarrhoea in a 2-week period. Days of diarrhoea is the mean and standard error (S.E.) of days reported within the same 2-week period. RR is risk ratio derived from generalized linear modelling of reported period prevalence of diarrhoea. Days of diarrhoea modelled using linear regression. Model 1 accounts for design variables such as geographical strata and pupil selection weights. Model 2 controls for sex and age, community and school-level characteristics at baseline, and geographical strata. Covariates include pupils per teacher; cement floor at school, proportion of female heads of household (FHH), FHH education level, FHH soap use at home, proportion of households with a protected water source and latrine, latrine condition score, wealth index, and proportion of orphan pupils at school.

−0·682 to 0·999). We assessed the effect 'modification of water supply type' on the effect of the intervention; data did not reveal any difference between diarrhoea in pupils in schools that received the borehole *vs.* rainwater harvesting infrastructure (aRR 1·01, 95% CI 0·32–3·14, data not shown).

In the water-available study group, our sample included 1156 pupils in the HP&WT arm (47·1% girls), 1134 in the HP&WT+Sanitation arm (49·6% girls), and 1127 (47·6% girls) in the control group. Sixty-eight (6·0%) pupils in control schools reported diarrhoea in the week preceding data collection, compared to 62 (5·2%) in the HP&WT arm and 65 (5·7%) in the HP&WT+Sanitation arm (Table 4). Pupils in the control schools with any diarrhoea in the previous week reported 2·58 (S.E. = 0·11) days of diarrhoea, compared to 2·67 (S.E. = 0·24) days in the HP&WT schools and 2·58 (S.E. = 0·11) days in the HP&WT +Sanitation schools.

We found no difference in the risk of diarrhoea in pupils in the HP&WT group (aRR 0·87, 95% CI 0·62–1·21) nor in those that attended the HP&WT +Sanitation schools (aRR 0·88, 95% CI 0·60–1·28) compared to the controls arm. For girls, data revealed a non-statistically significant 37% reduction in risk of diarrhoea in the HP&WT intervention arm compared

to those in the control group (aRR 0·63, 95% CI 0·36–1·09). The days of reported illness in children was similar between pupils attending schools that received HP&WT (coefficient −0·023, 95% CI −0·490 to 0·443) or HP&WT+Sanitation (coefficient −0·051, 95% CI −0·472 to 0·370) compared to those attending control schools.

DISCUSSION

Our data revealed mixed evidence on the impact of school WASH improvements on pupil diarrhoea. We found evidence in schools without nearby access to water in the dry season that the provision of a comprehensive school-based WASH intervention that included water-supply improvements was effective in reducing the risk of diarrhoeal diseases. The 66% overall difference in period prevalence of diarrhoeal illness between pupils in the intervention and control schools was similar for both boys and girls. These finding were similar to those we found in our analysis of diarrhoea and clinic visits in children aged <5 years [26]. The intervention did not reduce days of illness in children who had diarrhoea in the previous week.

We found no evidence that school-level interventions limited to hygiene and water treatment promotion and sanitation reduced diarrhoea period

prevalence or days of diarrhoea. Schools in this study group had access to a dry season water source within 1 km of the school. However, this level of access may have been insufficient to improve handwashing conditions and availability of water to reduce diarrhoea.

Consistent with other findings from this trial, our results suggest that latrine construction was not effective at reducing diarrhoeal disease or pupil absence [11]. One possible explanation is that in the absence of a concerted effort to maintain the latrines or an effective handwashing intervention, construction of latrines alone may increase exposure to faecal pathogens [16]. Anecdotal evidence suggests that girls benefit more from latrine construction at schools. However, there was no meaningful difference in sex-stratified results.

Results suggesting that comprehensive school WASH improvements may be protective against diarrhoea are consistent with other published studies of school-based interventions, although our specific findings contradict the effect of individual intervention types. Migele et al. [27] found reductions in diarrhoea risk associated with a simple water treatment and handwashing intervention commensurate with the 61% we observed in our water-scarce study group. However, Migele et al.'s study was conducted in one boarding school, relied on teacher records, and used before-and-after measures of effect with no control. Diarrhoea levels were too low in both intervention and control groups to allow Bowen and colleagues to isolate any attributable differences prevalence associated with a comprehensive handwashing intervention [8]. Talaat and colleagues found a 30% reduction in absence from illness as a result of an intensive handwashing campaign in Egypt [10].

We cannot rule out the possibility that the lack of detectable differences in diarrhoea in intervention schools in the water-available group was due to the fact that water – a prerequisite for handwashing and water treatment – was, in fact, not present in sufficient quantities throughout the year. School-level data revealed that access to water in many schools in the water-available group was intermittent, poor, and more distant than reported. Distance to the water source is potentially as important as source quality, as transporting water may increase water contamination and reduce quantity [28–30]. Even nearby sources outside of the school may become contaminated, increasing the risk of diarrhoea.

While some reductions in period prevalence of diarrhoea were observed, number of reported days of diarrhoea in children reporting illness was not changed. Some caution should be used in interpreting these findings, as the sample size was small. Additional investigation of the impact of school WASH conditions on incidence and illness duration is warranted.

There is evidence that integrated WASH interventions are no more effective in preventing diarrhoea than individual water, hygiene and sanitation interventions [6]. We found limited protection against diarrhoea associated with hygiene promotion and water treatment alone, and the inclusion of sanitation improvements resulted in no additional improvement in health outcomes in our study population. On the other hand, we found that an integrated WASH intervention was protective against diarrhoea when interventions included improvements in access to an improved water supply. This is inconsistent with previous evidence that found water-quality interventions to be effective in preventing diarrhoea even in the absence of improved water supplies [31]. Because study groups comprised two distant school populations, we were unable to directly compare the impact of an integrated WASH intervention that includes water supply to interventions that did not. The effectiveness of an intervention on reducing diarrhoeal disease may be based on background rates of disease and baseline WASH conditions as well as the change conferred by an improvement in access.

Since many studies of the relationship between WASH access and diarrhoea have been conducted at the household level, our school-specific data may represent a fundamentally different context. Our study is of the impact of exposure reduction at a public domain, as opposed to at households [13]. The role of WASH on mitigating disease burden is likely to be affected by the context and pathogen-specific pathways present in all environments [32, 33].

Limitations

There are a number of limitations that may impact the internal and external validity of our findings. For internal validity, the water supply intervention was not consistent across all intervention schools and communities. Since 12 of the intervention schools received a community water supply, we cannot completely attribute the reduction in diarrhoea solely to a school-based intervention. We found no difference between diarrhoeal outcomes in pupils in schools that received a community borehole or a large rainwater catchment

system at school, and available evidence suggests that rainwater is a better solution than unimproved sources and no different than other improved sources [34].

The suboptimal fidelity of the intervention limited our ability to detect a difference between intervention and control arms. For example, although we report considerable improvement in pupil:latrine ratios, only 29% of schools that received improvements achieved the Government of Kenya's approved ratios. Of the schools that received hygiene promotion, only 44% had handwashing water and soap available at follow-up. Researchers had little control over the specific intervention, which was developed by implementing partners to be consistent with standard best practices. As such, these data should be considered as part of an effectiveness trial of the impact of an intervention in a real-world setting, not as evidence of the impact of an ideal improved school WASH environment on health outcomes. Finally, baseline and follow-up occurred at different times of the year. The seasonal difference in disease burden was adjusted by the use of controls; however, the potential impact of WASH improvements is likely to vary throughout the year.

Recall bias may influence the precision of our estimates and external validity of our findings [23, 35]. Various studies of caregiver recall bias for reported diarrhoea in young children have revealed an underestimate of diarrhoea incidence as recall period increases [36–39]. While objective measures of enteric infections or alternative health measures, such as tropical enteropathy and stunting are being explored, they are costly and not widely used currently [40, 41]. Because diarrhoea in school-aged children was a secondary outcome measure for the overall research project, we concluded that the improvement in power obtained by using a longer recall period was justified even with an underestimation of less severe diarrhoea cases.

Data collection at a single time point and the lack of a viable baseline is a limitation of this study. Given the temporal and periodic nature of diarrhoea as an outcome, a single baseline measure of diarrhoea may not be well correlated with follow-up [23]. Even so, the baseline measure of parental-reported diarrhoea, although not significantly different between treatment arms, supports the conclusions for each study group. The higher rates of baseline, parent-reported diarrhoea in the intervention group for the water-scarce group means that our actual impact may be greater than reported. Conversely, the minimal differences in the water-available arm underscores the lack of an observed effect of the intervention in reducing diarrhoea.

CONCLUSION

WASH conditions at the world's schools are dire [42, 43]. Our findings suggest that in the absence of adequate water supplies, a comprehensive WASH intervention at the school level can be effective in preventing diarrhoea. However, a basic intervention of hygiene promotion, water treatment, and behaviour change found no evidence of reducing illness, similar to another recent finding from the same region [44]. Combined with evidence that improving school WASH can reduce absence and soil-transmitted helminth re-infection [11], these results provide additional support for the comprehensive WASH interventions at the school. Randomized trials of this scale in low-income settings are challenging, and few opportunities for rigorous evaluation exist. Results from this study do not specifically suggest the need for additional epidemiological studies on pupil diarrhoea. However, there is a need to understand the health and educational impacts of integrated school health programmes. Since trials such as these are challenging and expensive, large-scale programmes should consider allocating resources and planning for rigorous process evaluations to ensure programme effectiveness, if not health or educational impact. A recent trend away from reliance on self-reported methods towards more objective methods to measure gut health will add expense, but improve the rigour of morbidity assessments. Additional research to explore what improvements to water supply, water quantity, sanitation, and hygiene at school are most effective and cost-effective in reducing disease burden is warranted.

DECLARATION OF INTEREST

None.

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